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LTE-U Interference in Unlicensed Spectrum: the Impact on Local Communities and Recommended Solutions

Prepared for WifiForward
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1 Executive Summary

Local governments are increasingly concerned that interference from certain carrier wireless technologies operating in unlicensed spectrum—particularly the technology known as Long Term Evolution–Unlicensed (LTE-U)—could undermine key governmental, educational, and public safety functions that rely on Wi-Fi.

Communities use Wi-Fi for these functions because it delivers reliable, cost-effective connectivity. The potential for LTE-U to undermine Wi-Fi has serious implications for local governments, because LTE-U interference with Wi-Fi would:

1. Reduce the ability of local governments, libraries, and school systems to use cost-effective wireless technologies to serve their populations,

2. Hinder digital inclusion efforts aimed at allowing low-income groups to benefit from online services and resources,

3. Force local governments into high-cost contracts with the very carriers that are introducing LTE-U,

4. Impose unexpected budget gaps as local governments and school systems are forced to replace or augment already-purchased Wi-Fi-compatible equipment, and

5. Stifle the potential innovations of Smart City and Internet of Things (IoT) developments—or potentially put wireless carriers in an unfairly advantageous position to charge cities for connecting innovative new devices.

CTC Technology & Energy—an independent engineering consulting firm with more than 30 years of experience supporting local government clients nationwide—prepared this report as a technical analysis of whether, barring further testing, refinement, and standardization, unlicensed LTE interference is likely to impact local government and public interests.

It is not the intent of this paper to repeat the established research on LTE-U interference. Rather, taking the current environment and technological ecosystem as a given—and recognizing the critical need for unlicensed spectrum to continue to enable innovation—we seek to:

1. Call attention to critical considerations for local governments in their operational and consumer-protection roles,

2. Consider how the current Wi-Fi environment will be impeded if LTE-U interference prevents reliable Wi-Fi communications, and

3. Learn from the successful coexistence efforts taken by technologies currently using unlicensed spectrum (e.g., Wi-Fi, Bluetooth, ZigBee) that show how to preserve the value of the technologies local governments have invested in while still enabling innovation.

We conclude that the current version of LTE-U might cause damaging interference to local governments. We therefore recommend potential technical improvements to LTE-U that might allow the technology to smoothly coexist with Wi-Fi.

1.1 Wi-Fi Is Essential to Local Governments for Education, Public Safety, Economic Development, and Smart City Innovation

Wi-Fi is an operational tool for localities that use it for governmental and public safety communications, Smart City innovations, and connectivity in schools and libraries. Wi-Fi has also become a crucial technology in communities nationwide for a huge range of business and personal uses.

Wi-Fi is enabling cities to reinvent infrastructure, deliver services more efficiently, and reduce the digital divide. In addition, Wi-Fi is a crucial tool for local communities more generally, as is evidenced by the fact that almost every community in America has some level of Wi-Fi coverage in public places[1]—whether it is blanket coverage in core business districts, service in school and library buildings, or a more limited service in public parks, community centers, or government facilities.

From a functional standpoint, too, unlicensed wireless has become central to Internet connectivity for local governments, citizens, and businesses. Laptop computers commonly do not even have Ethernet interfaces—they connect to the Internet over Wi-Fi, not a cabled connection. And wireless devices that have the capability to communicate directly with carrier networks generally connect to local Wi-Fi networks by default when Wi-Fi is available, in order to reduce users' costs.

[1] 98 percent of libraries offer free Wi-Fi and 80 percent of schools have some form of Wi-Fi in 90 percent of their classrooms. See "ALA Library Fact Sheet 6," American Library Association, http://www.ala.org/tools/libfactsheets/alalibraryfactsheet06 (accessed December 22, 2015), and "Analysis of Costs to Upgrade and Maintain Robust Local Area Networks for all K=12 Public Schools," Education Superhighway, May 2014, http://www.educationsuperhighway.org/wp-content/uploads/2014/11/Connecting-Every-Classroom-LAN-WiFi-Analysis-May-2014.pdf (accessed December 22, 2015).

As wireless carriers increasingly rely on handoff to Wi-Fi for both data and voice,[2] the public now relies on Wi-Fi, including the Wi-Fi access points deployed by local governments,[3] to access data, make calls, and view video, especially in congested areas and indoor areas where traditional carrier macrocells are in heavy use or unavailable. As discussed in Section 4.1, these are the same conditions where LTE-U interference is most likely. In this scenario, LTE-U interference, if not properly managed, could result in the inability of citizens to reach 9-1-1 on their cell phones.

Local governments also have a key interest in Wi-Fi for economic development purposes. Nationwide, there are hundreds of examples of local governments using Wi-Fi to encourage foot traffic in historic downtowns or revitalization areas, or using it as a significant attractor in convention centers, sports stadiums, airports, or other places where the locality seeks to stimulate economic activity.

All of these uses of Wi-Fi have been made possible through cost-effective and thoughtful local implementations—and most critically by low-cost and reliable access to unlicensed spectrum. These uses would not be possible if the communities had to pay cellular carriers for expensive wireless service contracts, or if the Wi-Fi connections were unreliable. The cities' benefits continue to expand, too, as Wi-Fi deployment has skyrocketed in recent years. By one account, there are more than 32 million Wi-Fi hotspots in the U.S.[4]

As a technical adviser to hundreds of local governments nationwide, CTC would be concerned about the deployment of a version of LTE-U that disrupts Wi-Fi—because such LTE-U interference has the potential to block these successful deployments and key public interests, to create operational problems and new costs for local governments, public safety agencies, and schools, and to cause similar difficulties for Americans in their homes and in their businesses.

1.2 Carriers Plan to Use Long Term Evolution–Unlicensed (LTE-U) to Handle Growing Demand for Mobile Data

Increasingly, consumer electronic devices and IoT sensors rely on wireless technologies to connect to the Internet. As a whole, global IP traffic continues to grow at a rapid pace, and

[2] Wi-Fi calling descriptions from T-Mobile and AT&T, http://www.t-mobile.com/offer/wifi-calling-wifi-extenders.html?cmpid=ADV_PB_p7899515833&gclid=CPGgkcGuhsoCFc6RHwodXvoEhw&gclsrc=aw.ds, accessed December 31, 2015, https://www.att.com/shop/wireless/features/wifi-calling.html, accessed December 31, 2015.
[3] The government of the District of Columbia deployed more than 600 access points. One of the key considerations was to make it possible for the public to call 9-1-1 from locations where cell service was poor or prone to congestion—including in building stairwells, basements, and garages, and during large public events.
[4] "Wi-Fi Growth Map," iPass, http://www.ipass.com/wifi-growth-map/index.html (accessed November 18, 2015).

wireless traffic accounts for a greater percentage of that traffic each year, growing at a much faster rate than traffic from wired devices.[5]

There are a number of different wireless technologies that can be used to transmit data to and from a connected device. Some, like Wi-Fi and Bluetooth, send and receive signals over unlicensed spectrum. These tend to be low power, carrying signals over relatively short distances. Others, like High-Speed Downlink Packet Access (HSDPA) and LTE (also known as 4G), use licensed spectrum and can carry signals over longer ranges. Wi-Fi and unlicensed technologies can also operate over longer ranges, as long as they are operating in a point-to-point mode, as opposed to a “hotspot” point-to-multipoint mode.

In recent years, mobile carriers have seen exploding demand for mobile data. Although the Federal Communications Commission (FCC) has taken steps to make more spectrum available for carriers through auctions of licensed spectrum, carriers report that consumers’ demand for mobile data has outpaced what carriers could provide over proprietary spectrum using their existing technology. In addition, as the public sought to avoid monthly limits on bandwidth, users of carrier mobile devices increasingly make use of unlicensed bands. In response, the carriers have set up their own Wi-Fi networks to offload data from congested cellular networks, especially in places like airports and stadiums where Wi-Fi is the most cost-effective way to provide coverage, or where carriers have not yet or cannot place small cells.

LTE-U is a new way for wireless carriers to use unlicensed spectrum to increase the capacity of their networks. And, as discussed in Section 3, the technology provides the carriers with more control over the spectrum than simply using Wi-Fi, because devices using LTE-U can more aggressively capture the unlicensed spectrum, and because LTE-U devices need to be controlled by the carrier’s LTE network in order to have access to a carrier’s LTE-U hotspot.[6] Unlike Wi-Fi offload, LTE-U uses the same technology that the carriers use in their proprietary bands, allowing LTE-U to fully integrate with the carriers’ existing networks.

LTE-U is being developed to operate in the unlicensed 5 GHz spectrum band, though it eventually could expand into the 2.4 GHz and 3.5 GHz bands. Both of these bands are available for unlicensed use globally (subject to band boundaries and regulations that vary from country to country). Although Wi-Fi-enabled devices currently dominate these bands, other wireless technologies also use them.

[5] “The Zettabyte Era—Trends and Analysis,” Cisco, May 2015. http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/VNI_Hyperconnectivity_WP.html.

[6] In LTE-U the device analogous to a Wi-Fi access point or hotspot is a small LTE eNodeB access point, typically a small cell mounted on a utility pole or light post, or indoors.

In order to ensure coexistence, unlicensed spectrum technologies such as Wi-Fi and ZigBee employ a listen-before-talk (LBT) mechanism to confirm that a channel is free before a device begins transmitting. In Europe and Japan, devices operating in the 5 GHz unlicensed bands are required by regulation to follow an LBT protocol, but there is no such obligation in the U.S., China, India, or South Korea. As a result, two versions of LTE are being developed for the unlicensed bands. LTE-U is being developed without an LBT protocol for use in countries like the U.S., while Licensed Assisted Access (LAA) LTE is being developed with an LBT protocol for use in Europe and Japan.

1.3 Research Indicates that LTE-U Systems Can Dominate the Unlicensed Spectrum at the Expense of Wi-Fi

Our analysis began with a review of research already published on the topic. We researched the design of Wi-Fi and similar technologies, including their mechanisms for coexistence in unlicensed bands—which mitigate, but do not eliminate, performance problems. We drew on our past experience in Wi-Fi planning and deployment, and our experience with a wide range of wireless communications networks and technologies. We also considered our ongoing engagements with clients that rely on Wi-Fi and other wireless technologies to provide critical services to the public, first responders, students, and government employees—including the District of Columbia, the cities of San Francisco, Boulder, Palo Alto, San Antonio, and Port Angeles, Washington, and the Delaware Department of Transportation.[7]

As discussed in this report, there is evidence that LTE-U systems can impair or shut down Wi-Fi in a wide range of common scenarios in local government operations, because LTE-U often does not sense Wi-Fi devices. When an LTE-U system does sense Wi-Fi devices, it is designed to transmit with an on-off duty cycle rather than wait for silence—so it essentially talks over the Wi-Fi devices.[8] (See Section 3.1.3 for more detail.)

Even when an LTE-U system is programmed to wait (e.g., the LAA variant, which is planned for environments where LBT is required by regulation), it waits for a much shorter amount of time than a Wi-Fi system. Collectively, these attributes mean that both LTE-U in its current form and LAA can dominate the unlicensed spectrum rather than share it with Wi-Fi.

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[7] See, for example, representative samples of CTC's wireless projects, including: "Mobile Broadband Networks Can Manage Congestion While Abiding By Open Internet Principles" (http://www.ctcnet.us/publications/mobile-broadband-networks-can-manage-congestion-while-abiding-by-open-internet-principles/) and "City of Palo Alto Wireless Master Plan" (http://www.ctcnet.us/publications/city-of-palo-alto-wireless-master-plan/).

[8] LTE-U Forum, p. 18.

We note that the LTE-U Forum, representing equipment manufacturers and the industry,[9] and individual manufacturers have conducted tests that purport to show that coexistence is not a problem.[10] However, these tests do not explicitly take into account the use cases described in Section 4 below—outdoor devices interfering with indoor devices, interference with latency-sensitive applications, and interference with in-vehicle Wi-Fi. It is also not clear what types of Wi-Fi devices were tested[11] and whether coexistence was accomplished in each particular case with LTE-U and Wi-Fi attempting to share the same channel (as opposed to avoiding a used channel or turning LTE-U cells on and off, all of which are accomplished in a proprietary manner and not required by proposed standards). Same-channel coexistence is critical in increasingly congested environments where channel sharing may always be a necessity.

We believe that a wider range of testing, discussed in more detail in Section 5, will better clarify the ability of the technologies to coexist within the full range of actual use cases, with a wide repertoire of LTE-U and Wi-Fi equipment.

We are therefore concerned about the impact of introducing LTE-U on a utility pole, light pole, or indoor antenna system—and how LTE-U would affect existing Wi-Fi in residences, offices, schools, outdoor public spaces, vehicles, and Smart City applications. To our knowledge, these use cases have not been tested in a neutral test environment with actual prototype LTE-U equipment.

If LTE-U is deployed in a way that will have a high impact on Wi-Fi, we believe Wi-Fi may be limited to lower speeds and uneven performance due to its being "shouted down" by neighboring LTE-U devices. (See Section 3 for more detail.) It may also force Wi-Fi applications that, in an environment without LTE-U, could have run in a four-channel 80 MHz environment, to run at much lower speeds using only a fraction of that spectrum. This will jeopardize the use of Wi-Fi for a wide range of governmental, educational, business, and residential applications, especially higher-bandwidth uses, such as video, and latency-sensitive applications such as voice and audio.

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[9] "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." LTE-U Forum, http://www.lteuforum.org/ (accessed November 13, 2015).

[10] LTE-U Forum, also "Qualcomm Research LTE in Unlicensed Spectrum: Harmonious Coexistence with Wi-Fi," Qualcomm Technologies, June 2014, https://www.qualcomm.com/documents/lte-unlicensed-coexistence-whitepaper.

[11] Wi-Fi throughput in the presence of LTE-U depends on the type of Wi-Fi access point (AP). This is because different models of Wi-Fi AP have different ways of managing rate control and access to the spectrum in the presence of other signals. LTE-U Forum Technical Report, http://www.slideshare.net/zahidtg/15-105-06112015-google-inc-60001078145, accessed November 17, 2015, Jindal p. 9-11. (Jindal)

If LTE-U is deployed in the form advocated by the LTE-U Forum, it will put at risk the use of Wi-Fi in the 5 GHz band—which is the spectrum that enables reliable Wi-Fi service for the full range of uses described here, and that is making it possible for Wi-Fi to expand to speeds of hundreds of Megabits per second (Mbps) and, potentially, Gigabit (Gbps) speeds.

1.4 LTE-U Interference Could Disrupt Local Governments' Current Uses of Wi-Fi, Increase Communications Costs, and Threaten Future "Smart City" Innovation

If LTE-U interference prevents the reliable operation of local governments' Wi-Fi communications, local governments and the citizens they serve will face a new and costly hurdle preventing operational efficiencies and innovation. Furthermore, new deployments of Smart City and public safety communications may be put into uncertainty, with projects relying on Wi-Fi being delayed or requiring more costly (and limited) licensed wireless communications technologies.

This report discusses ways that LTE-U interference might affect Wi-Fi uses, including for critical local government operations, across a wide range of applications. For example:

- **LTE-U interference could disrupt Wi-Fi in schools and libraries.** The nation's public, private, and charter schools and public libraries increasingly use Wi-Fi as a means of offering Internet access to students, staff, faculty, and residents. The U.S. Department of Education's guidance to school districts is that wireless networks are the best way to connect within a school building: "While the fastest way to get an Internet connection to schools is typically with a wired connection, wireless access within school buildings is the best way to connect students and staff. Wireless access throughout all learning spaces enables students and staff to have mobility and flexibility when engaging with learning devices, such as tablets, laptops, and smartphones."[12] Similarly, public library Wi-Fi is now virtually ubiquitous, and daily use rivals wired connections.

  The only affordable wireless connection for the hundreds or thousands of students in a school is Wi-Fi, which functionally takes the place of wiring to the desktop and provides mobility and flexibility. Indeed, over the past few years, Wi-Fi has become an essential means of cost-effectively distributing bandwidth within schools because the costs to both purchase and operate Wi-Fi equipment are low. Interference from LTE-U could eliminate these favorable economics (and reduce the growth of Wi-Fi in schools and

[12] "Future Ready Schools: Building Technology Infrastructure for Learning," U.S. Department of Education, November 2014, http://tech.ed.gov/wp-content/uploads/2014/11/Future-Ready-Schools-Building-Technology-Infrastructure-for-Learning-.pdf.

libraries) by making Wi-Fi less technically effective, increasing costs for hardware and operations to offset poor performance, and requiring use of costlier technologies as an alternative.

- **LTE-U interference could disrupt Wi-Fi in police vehicles and ambulances.** Wi-Fi provides a local bridge between in-vehicle wireless access points and an increasing variety of public safety devices.

  A police vehicle may have a mobile data computer, a video camera, a GPS tracker, an intrusion detection system, and other sensors. The officer may also have a body camera or tracking device and may connect a smartphone. These devices are typically bridged through secure Wi-Fi, with the access point connected to an in-vehicle mobile data router that then connects over a mobile broadband network on licensed frequencies.[13]

  The environment in a fire vehicle, ambulance, or mobile command vehicle is similar, but those vehicles may also have medical devices, multiple mobile data computers, triaging devices, and vital signs detection equipment. (See Section 2.2 for more details on the importance of Wi-Fi in public safety vehicles.)

- **LTE-U interference could disrupt Wi-Fi in Smart City and IoT deployments.** While Wi-Fi has already enabled myriad public services, the potential for extraordinary growth remains. The City of Kansas City announced in 2015, for example, that it would use a citywide Wi-Fi network to enable a number of Smart City initiatives, including smart parking, lighting, retail analytics, and public safety and security applications.[14] Similarly, Newark Liberty International Airport has Wi-Fi-connected cameras and sensors that can identify long lines or specific license plates, and report suspicious activity to appropriate personnel.[15] The District of Columbia is using Wi-Fi for IoT applications including connections to smart parking meters. And a pilot data collection project in the City of Chicago, which uses a mixture of Wi-Fi and cellular technologies, will address one of the key issues facing local governments:

[13] Discussion with Seble Mengesha and Shawn Thompson, District of Columbia Office of the Chief Technology Officer, December 28, 2015.
[14] "Cisco, Sprint and Kansas City, MO., Announce Agreement to Deploy Smart+Connected City Framework," Sensity, June 8, 2015, http://www.sensity.com/pressrelease/cisco-sprint-and-kansas-city-mo-announce-agreement-to-deploy-smartconnected-city-framework.
[15] Diane Cardwell, "At Newark Airport, the Lights are On, and They're Watching You," *New York Times*, February 17, 2014, http://www.nytimes.com/2014/02/18/business/at-newark-airport-the-lights-are-on-and-theyre-watching-you.html?_r=0.

> "As urban populations increase, so too does the complexity involved in maintaining basic services like clean water and emergency services. But one of the biggest barriers to making cities 'smarter'—for example, comprehensively monitoring sources of waterway pollutants in real time—is quick and easy access to data… Future 'smart' cities would have to feature hundreds, maybe thousands, of strategically placed sensors. These devices would record everything from air pressure and temperature to microbial content, and the data would be relayed instantly to the laptops of people who can make decisions based on what they are seeing."[16]

A market-research company projects that the global outdoor Wi-Fi market will grow at a compound annual rate of close to 11 percent over the next four years.[17] This growth is needed to support the IoT, connecting millions of devices to one another in emerging Smart Cities. Estimates of the size of the IoT vary dramatically, ranging from projections of 10 billion connected devices by 2020[18] to 26.5 billion[19] and even 50 billion devices during that same timeframe.[20]

These connections will bring substantial economic benefits. A 2015 report from the McKinsey Global Institute estimated a potential annual economic impact ranging from $930 billion to $1.66 trillion by 2025.[21]

- **LTE-U interference could disrupt Wi-Fi in small businesses and homes.** Small businesses and citizens rely heavily on Internet access—and Wi-Fi is by far the predominant manner in which Americans access the Internet. In their consumer protection and public safety

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[16] Justin H. S. Breaux, "New Sensor Array Changes the Data-Collection Game," *Government Technology*, March 6, 2015, http://www.govtech.com/fs/New-Sensor-Array-Changes-the-Data-Collection-Game.html and http://wa8.gl/?page_id=154.
[17] Technavio, 2015, "Global Outdoor Wi-Fi Market: Research Analysis 2015-2019," http://www.technavio.com/report/global-outdoor-wi-fi-market-research-analysis-2015-2019?utm_source=T1&utm_medium=BW&utm_campaign=Media.
[18] Vala Afshar, "Smart Cities Start with Smart IT," *Huffington Post*, October 19, 2015, http://www.huffingtonpost.com/vala-afshar/smart-cities-start-with-s_b_8332816.html.
[19] PurpleWi-Fi.com, http://www.purpleWi-Fi.net/solutions/smart-cities/.
[20] Dave Evans, "White Paper: The Internet of Things: How the Next Evolution of the Internet is Changing Everything," Cisco Internet Business Solutions Group, April 2011, http://www.iotsworldcongress.com/documents/4643185/0/IoT_IBSG_0411FINAL+Cisco.pdf.
[21] James Manyika, *et al.,* "Unlocking the potential of the Internet of Things," McKinsey Global Institute, June 2015, http://www.mckinsey.com/insights/business_technology/the_internet_of_things_the_value_of_digitizing_the_physical_world.

roles, then, local governments have a significant stake in ensuring that their citizens and businesses have reliable, effective Wi-Fi service.

Increasingly, and to an extent that was not foreseen even five years ago, Wi-Fi is the last piece of the connection most Americans use to access the Internet. Whatever the transmission mechanism to the home or business, Wi-Fi is usually the final connection to consumers' devices.

The migration of 9-1-1 services to next-generation 9-1-1 systems managed and used by local governments adds a public safety component to this concern, too: Individuals in residences and businesses will be able to use text and Internet-based communications to reach and share information with emergency dispatchers and first responders. They will frequently be using Wi-Fi as the connection technology—making Wi-Fi central to next generation 9-1-1 and making LTE-U interference a potential hindrance to next generation 9-1-1 response.

Furthermore, Americans increasingly rely on Wi-Fi-enabled Internet connectivity not only for communication but for myriad other endeavors. By 2020, the average American will operate 50 Internet-connected devices in their homes, from thermostats, security systems, and washing machines to toothbrushes that monitor oral hygiene and pill bottles that track medication usage.[22]

Interference from LTE-U could substantially undermine Wi-Fi as an extension of faster Internet connections, undermining the most recent advancements in Wi-Fi that have enabled real-world support of nearly gigabit speeds for support of large file transfers, video streaming, and a range of telework, educational, and entertainment services.

From an operational standpoint, then, LTE-U interference will create numerous problems for residential and business Wi-Fi users. In a small business office environment, for example, most employees likely have multiple devices on their desks, including a mobile phone and a laptop. The newest small laptops do not even have interfaces to allow for a wired Ethernet connection. In other words, Wi-Fi is the only means by which an employee can connect to the Internet or intranet at work (or at home, for after-hours work or telecommuting). If there is interference with a business'

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[22] Reuters, "The Internet Of Things: By 2020, You'll Own 50 Internet-Connected Devices," *Huffington Post*, April 22, 2013, http://www.huffingtonpost.com/2013/04/22/internet-of-things_n_3130340.html. See also: Ely Portillo, "Developers: Ultrahigh-speed Internet isn't just a luxury anymore, it's a necessity," *The Charlotte Observer*, May 22, 2015, http://www.charlotteobserver.com/news/business/article21567612.html.

Wi-Fi, employees' laptops are not a reliable mechanism for accessing the Internet or intranet.

From a consumer standpoint, Wi-Fi interference presents the same kind of concern. The newest generation of devices that consumers use in their homes, including smart televisions and tablets, rely on Wi-Fi. Interference thus becomes an enormous consumer protection concern for local governments because the interference puts at risk the functionality of an entire generation of devices on which Americans rely.

- **LTE-U interference could increase costs for local governments.** Because of the business decisions of the mobile phone industry, which has generally placed monthly caps on subscribers' data use, Americans increasingly choose to migrate to Wi-Fi not just in their homes and offices, but anywhere that free Wi-Fi is readily available—including coffee shops, libraries, airports, and sports stadiums—to try to avoid the high cost of exceeding the monthly bandwidth caps imposed under most wireless contracts.

  Aided by smartphones that automatically seek out known connections (like the user's office or home Wi-Fi networks), consumers can seamlessly switch from cellular service to Wi-Fi to limit their cellular data usage.

  This is true for individuals and small business users, but also for local governments—which are often among the largest consumers of commercial communications services in a given region, and which must make budget-conscious decisions about service fees just like a typical household.

  Local governments such as the District of Columbia offload their wireless communications to Wi-Fi (potentially secure Wi-Fi on a separate SSID from the public access) whenever possible, such as when users are in proximity to a government building or public area hotspot. The District government moves users from commercial carrier networks to the District-operated Wi-Fi network to reduce data usage. This is done both for cost and capacity purposes.

  For example, photos and video from a Department of Public Works field inspector's tablet computer or a police officer's body camera video are uploaded on Wi-Fi rather than on the carrier network. Software updates to mobile data computers would be completed while a police vehicle was in a parking lot at the station (in proximity to the station's Wi-Fi network), rather than over the carrier network.

  If LTE-U creates interference with Wi-Fi, then Wi-Fi may be a less effective option for local governments and citizens to manage their data usage and spending on cellular networks. The choice and flexibility that consumers have to migrate to Wi-Fi would be seriously reduced if LTE-U creates interference.

Furthermore, until the issue of potential LTE-U interference is resolved, uncertainty about the reliability of Wi-Fi may delay or increase the cost of future Smart City and public safety communications applications—because localities will be reluctant to invest in potentially unreliable technology, and because devices that use Wi-Fi or other 5 GHz spectrum technologies may need to be redesigned or deployed in a more costly way.

1.5 LTE-U Must Be Tested, Refined, and Standardized to Enable LTE-U and Wi-Fi to Reliably Coexist

A reasonable wireless environment without unfair interference is necessary for local government operations and innovation. If LTE-U creates interference with Wi-Fi—if Wi-Fi is less reliable and less usable, and cannot expand into better unlicensed bands—then the potential innovation around Smart Cities and IoT that Americans are poised to be able to realize will be more costly, and there will be fewer technological solutions.

To avoid LTE-U being deployed in a destructive way and to stay with the precedent set by other users in unlicensed bands (e.g., Bluetooth, ZigBee), the LTE-U Forum and standards development entities must continue to refine the standards for the technologies to ameliorate the issues described above and make it possible for LTE-U and Wi-Fi and other technologies to coexist.

Localities can and should be involved in the standards-writing process, as well, in order to protect the very real local government interests (described above) that are implicated in this context.

Why does this matter for local government? Imagine the pace of innovation and change that is enabled by unlicensed spectrum—and how that will be stifled if Wi-Fi sometimes works and sometimes does not. Wi-Fi-enabled "smart" street lights, for example, are a local government innovation that create higher efficiency and better community service in a basic local government operation, and are enabled by reasonable access to unlicensed spectrum.

Imagine how much slower the pace of innovation will be for local governments—and how much more cost local governments will incur to meet its myriad communications needs—if Wi-Fi cannot be relied upon, if local government has to license technology rather than using an open platform, or if local government has to buy commercial services rather than using Wi-Fi. So the issue of LTE-U interference is not just an academic argument about spectrum use—it will have real impact on the services that we expect local government to provide, and that local government performs exceedingly well.

In the worst-case scenario, the local governments and citizens using Wi-Fi will lose substantial Wi-Fi functionality and will also lose the potential benefit of Wi-Fi innovation. Rather, they will be relegated to the following problematic choices:

1. Use only the existing congested 2.4 GHz spectrum[23] and unreliable 5 GHz spectrum, limiting users to tens of Mbps (rather than 100 Mbps and above), and making latency-sensitive applications such as streaming video and voice communications unreliable,

2. Deploy many more Wi-Fi access points to attempt to attain the needed coverage and reliability—driving up costs and creating siting, historic preservation, and environmental impact concerns,

3. Settle for dramatic limitations in range and reliability,

4. Pay cellular carriers to use licensed spectrum or LTE-U (incurring monthly fees for each device), or

5. Pay for direct wireline connections (e.g., via cable or fiber) at high cost.

Fortunately, there is a path forward to address the risk to government systems created by LTE-U: the standards-setting process. To alleviate the risk of degrading Wi-Fi systems, and to preserve the benefits of Wi-Fi for local governments and local populations, policymakers should ensure that the industry introduces LTE-U as it has introduced the major new unlicensed technologies of the past. That means bringing the technology to a technology standards body, designing tests through an open process, and then making adjustments to ensure that both LTE-U and other unlicensed technologies can thrive without displacing existing users.

We believe that this process should include adding basic co-existence features to LTE-U such as LBT, combined with greater sensitivity and increases in back-off time, all with the goal of making LTE-U coexist effectively with Wi-Fi and other technologies. This approach has been proposed and endorsed by a wide range of wireless users and stakeholders—including service providers, equipment manufacturers, wireless industry standards bodies, and application and technology developers—and would produce sharing that would protect government systems without the need for new regulation.[24]

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[23] This strategy would not work in the event that LTE-U began to operate in the 2.4 GHz spectrum as well.

[24] 3GPP TR 36.889 V13.0.0 (2015-06) 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Licensed-Assisted Access to Unlicensed Spectrum; (Release 13), http://www.3gpp.org/ftp/Specs/archive/36_series/36.889/36889-101.zip, accessed November 17, 2015 (3GPP TR 36.889), (3GPP TR 36.889); "IEEE 802 submission to 3GPP LAA Workshop on 29 August 2015 in Beijing, China, IEEE 802.19-15/00069r7, August 2015, ftp://ftp.3gpp.org/workshop/2015-08-29_RAN_LAA/Docs/LAA-150003.zip,

We are just at the beginning of determining how to make the technologies coexist; a wide range of critical use cases have not yet been tested. The proposed testbed needs to evaluate both Wi-Fi 802.11ac only, and Wi-Fi in conjunction with LTE-U and LAA. The tests must include:

1. Operation of latency-sensitive applications on Wi-Fi (streaming video) in a real use case environment,
2. Operation of office and school WLANs, including the full range of current and future applications,
3. Operation of Wi-Fi-enabled body cameras and other Smart City devices in both indoor and outdoor environments and in crowded public spaces, and
4. Operation of in-building Wi-Fi using Smart City and public safety applications and devices, including in a large office building, a subway system, and a parking garage.

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accessed November 17, 2015, (IEEE Beijing); "Wi-Fi and LAA Presentation by Wi-Fi Alliance to 3GPP LAA Workshop," ftp://ftp.3gpp.org/workshop/2015-08-29_RAN_LAA/Docs/LAA-150004.zip, accessed November 17, 2015 (Wi-Fi Alliance Beijing); "Contribution to 3GPP LAA Workshop, Cablevision, Suddenlink Communications, Tele Columbus, Charter Communications, Cox Communications, Comcast, Liberty Global, Cogeco Cable, Atlantic Broadband," ftp://ftp.3gpp.org/workshop/2015-08-29_RAN_LAA/Docs/LAA-150006.zip, accessed November 17, 2015 (Cable Beijing); "Automotive Perspective on Licensed Assisted Access, General Motors Research & Development Advanced Technical Center Israel (ATCI) Vehicle Connectivity Group," ftp://ftp.3gpp.org/workshop/2015-08-29_RAN_LAA/Docs/LAA-150007.zip, accessed November 17, 2015 (GM Beijing), "Licensed-Assisted Access to Unlicensed Spectrum—An Overview, Havish Koorapaty, Study and Work Item Rapporteur (Ericsson Inc.)," ftp://ftp.3gpp.org/workshop/2015-08-29_RAN_LAA/Docs/LAA-150002.zip, accessed November 17, 2015 (Ericsson Beijing).

2 Wi-Fi Enables Efficiency and Innovation in Virtually Every Aspect of Local Government Operations

Wi-Fi is a key tool in local governments' continuous search for efficiency, improvement, and innovation in the myriad services they deliver every day to citizens and businesses. From critical services such as public safety and education to the more mundane (but essential) range of daily operations, local governments depend on reliable, cost-effective Wi-Fi networks to support communications among people and equipment.

In the Smart City of the future, Wi-Fi will play an even greater role. Wi-Fi provides a highly affordable and scalable way to connect large numbers of IoT devices. Sensors will automatically coordinate traffic lights to shift traffic away from areas of congestion and reduce carbon emissions. Small devices will sense water leaks in the municipal water system and alert workers to make repairs, reducing water waste. "Smart" trash cans will alert the Department of Public Works when they are full, saving staff time. And ambulances will be equipped with medical equipment that automatically shares data with emergency room doctors—even as other devices in the ambulance communicate with traffic lights to clear the route to the hospital.

In the sections that follow, we describe some of the dozens of ways that local governments depend on Wi-Fi today—and will in the future.

2.1 Education

Wi-Fi-enabled devices are becoming an increasingly important feature in America's schools: 80 percent of schools report having Wi-Fi in at least 90 percent of their classrooms.[25] A 2013 Pew Research Center survey of nearly 2,500 teachers in the Advanced Placement and National Writing Project programs documented positive effects of wireless technologies in the classroom. Nearly all (92 percent) of respondents reported that the Internet has had a "'major impact' on their ability to access content, resources, and materials for their teaching." In particular, respondents indicated that mobile technology has become a valuable learning tool:

- Nearly three-quarters (73 percent) of AP and National Writing Project teachers indicate that they and/or their students use their mobile phones in the classroom or to complete assignments.

[25] "Analysis of Costs to Upgrade and Maintain Robust Local Area Networks for all K=12 Public Schools," Education Superhighway, May 2014, http://www.educationsuperhighway.org/wp-content/uploads/2014/11/Connecting-Every-Classroom-LAN-WiFi-Analysis-May-2014.pdf.

- Nearly half (45 percent) of respondents report that they or their students use e-readers and 43 percent use tablet computers in the classroom or to complete assignments.[26]

Indeed, schools are increasingly embracing one-to-one computer programs (also known as "ubiquitous computing"), whereby each student and teacher has one Internet-connected wireless computing device for use in the classroom. Research by the International Society for Technology in Education (ISTE) and the Consortium for School Networking confirms that these applications have meaningful results. In particular, Wi-Fi-enabled technology has:

- Led to measurable improvements in school performance (as measured on the Adequate Yearly Progress Tests under the No Child Left Behind Act of 2001),
- Improved attendance, decreased dropout rates, increased graduation rates, and allowed increased parental involvement,
- Improved school efficiency and productivity,
- Helped teachers satisfy professional requirements by helping develop lesson plans and providing continuing education opportunities,
- Enhanced students' problem-solving and independent-thinking skills,
- Enabled schools to meet needs of special education children,
- Increased equity and access in education by creating learning opportunities for geographically isolated students, and
- Improved workforce skills.[27]

Wi-Fi offers advantages over wired connections because of the mobility it provides (and its lower cost to implement, relative to wiring school buildings). While personal computers restrict access to specific locations, like computer labs, mobile devices make it easier for students and teachers to collaborate.[28] And unlike cellular connections, which typically operate under monthly data caps, Wi-Fi takes the wired connection a school already pays for and makes it accessible to any Wi-Fi-enabled device.

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[26] Kristen Purcell, *et al,* Pew Research Center, February 28, 2013, "How Teachers Are Using Technology at Home and in Their Classrooms," http://www.pewinternet.org/files/old-media//Files/Reports/2013/PIP_TeachersandTechnologywithmethodology_PDF.pdf.
[27] Holly Jobe, "Why Technology in Schools?", *EdTech Action Network*, February 26, 2013, https://web.archive.org/web/20130905081059/http://www.edtechactionnetwork.org/why-technology-in-schools.
[28] Eric Tabor, "Wi-Fi delivers multiple benefits to schools," ISG Technology, August 14, 2014, http://www.isgtech.com/news/82/wi-fi-delivers-multiple-benefits-to-schools.

Recognizing the benefits of connected devices, the Obama Administration announced a goal in 2013 to expand broadband and wireless Internet access to each of the nation's schools and libraries. Upon announcing the ambitious initiative, Obama declared, "In a country where we expect free Wi-Fi with our coffee, why shouldn't we have it in our schools? … We can't be stuck in the 19th century when we're living in a 21st-century economy."[29] This announcement was followed by an announcement in November 2014, in which President Obama reaffirmed the Administration's commitment to Wi-Fi in the nation's schools by inviting school superintendents to take the "Future Ready District Pledge," a commitment to provide students with high-speed Wi-Fi and broadband by 2018.[30]

2.2 Public Safety

Wi-Fi, in conjunction with fiber optic and cellular wireless networks, enable local governments to provide real-time data transfer to facilitate faster response times during emergencies. Using this technology, police officers, for example, can access maps and criminal records in the field. First responders can view GIS mapping and 3-D aerial imagery before arriving on scene to increase their "situational awareness" and develop a more tailored response.[31]

The District of Columbia operates an extensive Wi-Fi network serving the areas in and around government buildings and public spaces such as the National Mall. The network provides seamless connectivity for authorized staff members' devices (e.g., laptops, tablets, cameras) and building automation systems.

Metropolitan Police Department (MPD) officers' body cameras store video on the devices, then automatically upload it to the cloud via the District Wi-Fi network when the officer is within range of a hotspot. During large events requiring the mobilization of the entire department, MPD issues tablets and commercial LTE Wi-Fi hotspots to managers. The tablets contain pre-loaded instructions and templates to aid in handling specific assignments in the field. Updates are transmitted over the carrier network or the Wi-Fi network.

Firefighters also transmit data from the field over the District's Wi-Fi network—and firefighters and other Fire and EMS (DCFEMS) department employees depend on the District's Wi-Fi network for connectivity at all department facilities.

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[29] Philip Rucker, "Obama pitches plan to bring broadband and Wi-Fi to all schools," *Washington Post*, June 6, 2013, https://www.washingtonpost.com/politics/obama-pitches-plan-to-bring-broadband-and-Wi-Fi-to-all-schools/2013/06/06/d0c8779e-cebb-11e2-8845-d970ccb04497_story.html.

[30] Department of Education, Office of Educational Technology, "Future Ready District Pledge," http://tech.ed.gov/futureready/.

[31] Jennifer Grzeskowiak, "Wireless at work: The latest technology moves public services from the office to the field," American City and County, April 1, 2009, http://americancityandcounty.com/technology/wireless/public-services-200904.

In the District, too, large events such as the Presidential Inauguration place make reliable Wi-Fi communications even more critical. During a planned event or a public health incident, the District's Department of Health may deploy an emergency wireless router that can connect up to 150 Wi-Fi devices to satellite or commercial mobile broadband services. And "mutual aid" protocols can bring in several thousand additional first responders from other jurisdictions; these first responders often use Wi-Fi devices related to their particular missions or to communicate with their own teams outside the official communications plan.

The District's Wi-Fi network also enables field inspectors, Department of Youth Rehabilitation Services case workers, and other District government staff to synchronize their mobile devices without needing cellular connections.

In addition, the District's first responder vehicles have secure 802.11ac Wi-Fi access points to interconnect devices in and near the vehicle to a mobile data router, which connects to cellular networks or external secure District Wi-Fi, where available. (In the future, these mobile routers will connect to the FirstNet public safety mobile broadband network.[32]) This configuration enables the District to save money by having fewer cellular accounts; better manage and ensure the security of communications by having all communications travel through the router; and provide a flexible means of inexpensively adding in-vehicle or near-vehicle devices (which only need a Wi-Fi interface) and enabling all of the devices to find the best available cellular signal. Moreover, because of congestion in the 2.4 GHz frequency, the 5 GHz frequency proposed for LTE-U is highly critical for the District's public safety communications.

The District government uses this configuration in police vehicles, fire/rescue vehicles, and emergency command vehicles, essentially creating a local tactical Wi-Fi environment in and around the vehicles. In the first responder environment, the mobile Wi-Fi access points interconnect vehicle cameras, body cameras, tablet computers, mobile data computers, the vehicle's DVR system, the automatic vehicle location system, vehicle alarms, detectors on the gun rack, and the on-board diagnostic system.[33]

In the District and elsewhere, even if a locality's public safety system does not use Wi-Fi as a default or main source of connectivity, it currently needs the ability to use Wi-Fi systems in an emergency or during an investigation. Unexpected events may place first responders in

[32] The deployment of FirstNet will not eliminate the need for reliable Wi-Fi connectivity for public safety users in the District or any other locality. While FirstNet is expected to have full coverage in urban areas, there will remain rural areas in the country that may not be part of the initial network, if at all. Public safety users in these communities—and, indeed, in major American cities that have FirstNet coverage—will continue to need Wi-Fi for primary or back-up communications.

[33] Discussion with Seble Mengesha and Shawn Thompson, District of Columbia Office of the Chief Technology Officer, December 28, 2015.

situations where they need to access a local Wi-Fi spot. The same is true for non-law enforcement or emergency services personnel, especially during disaster aid and recovery. For example, Wi-Fi availability at reunification centers such as schools and recreation centers is crucial.

Wi-Fi's public safety benefits are not limited to the nation's largest cities. Port Angeles, Washington, a community with 19,000 residents on the Canadian border, deployed a Wi-Fi network that serves both public safety users and the public. The network improves the efficiency of the community's police force. Philip Lusk, Deputy Director of Power and Telecommunication Systems in Port Angeles, has dubbed the system a "force multiplier" for a strained police department. "[T]he timely information that first responders can receive [through the network] can help them do their jobs more effectively and better preserve public safety," Lusk explains.[34]

The Port Angeles Wi-Fi network addresses critical public safety needs, allowing police to access live or stored video from virtually any location, remotely patrol problem or high-risk areas, provide real-time officer safety updates, and quickly identify and appropriately respond to incidents. The network also supports communications between different types of first responders. For instance, it allows "on-scene sharing of documents, videos and other images between law enforcement, emergency medical personnel and medical providers." On-site paramedics can share videos of patients with a hospital that can provide timely medical information about the person and offer guidance back to the on-scene paramedics.[35] This capacity has enabled faster response times; an improved quality of care; a higher level of interdiction on "quality-of-life" crimes; and supported research needed to detect, investigate, and apprehend criminal offenders.

2.3 Economic Development

Wi-Fi is a tool that can help attract business and tourism. Washington, D.C., for example, extended free Wi-Fi coverage to the National Mall in 2010, along with more than 200 other hot spots around the city, including police stations, public libraries and schools. Upon announcing the initiative, Washington, D.C., Chief Technology Officer Bryan Sivak explained, "This is one

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[34] Freedman Consulting, LLC, "Toward an Understanding of Best Practices in Community Wireless Network: A Survey of Select Networks," May 2015, at 51-55, http://tfreedmanconsulting.com/documents/BestPracticesinCommunityWireless.pdf.

[35] Paul Gottlieb, "Port Angeles to become first all-Wi-Fi city in state," *Peninsula Daily News*, September 5, 2012, http://www.peninsuladailynews.com/article/20120906/news/309069991/port-angeles-to-become-first-all-Wi-Ficity-in-state.

more example of how we're deploying technology to make life and work for residents, businesses and visitors more convenient, efficient, and fun."[36]

Providing free coverage in tourist destinations is a global phenomenon. In Osaka, Japan, free Wi-Fi is available at 2,000 locations throughout the city. The Wi-Fi homepage serves as a guidebook and provide coupons to area attractions.[37]

Wi-Fi connectivity is not only relevant in urban tourist destinations. "According to the Woodall's Campground Management publication, 41 percent of the decisions on where to go camping are based on the availability of Wi-Fi and technology."[38] This statistic is driving Sam England, chief of the West Virginia Division of Natural Resources' Parks Section, to seek Wi-Fi connectivity for the state's park system. England explains, "Technology and Internet connectivity will help us remain relevant, especially with young visitors…. Most of them can disconnect for a short time, but then they might want to take selfies of themselves roasting marshmallows at a campfire and post the pictures to Facebook. They want to be connected and interactive." Connectivity is also seen as an important feature to attract business travelers to the parks' conference facilities.[39]

Wi-Fi is also used to enhance business districts in cities nationwide. Santa Monica, California boasts a Wi-Fi network that includes 32 hot spots along nine major commercial corridors. The network enhances traffic management and safety, by synchronizing 80 percent of the city's traffic lights, providing real-time parking information, and supporting 550 video surveillance cameras. Wi-Fi is also available in public spaces—including a number of parks, the libraries, the Civic Auditorium, City Hall, and other areas with heavy pedestrian traffic—helping lower the digital divide. The network has witnessed steady growth, beginning with 750 daily visitors in 2006 and rising to 3,800 in 2013.[40]

[36] Matt Williams, "Washington, D.C., Extends Free Wi-Fi Coverage to the National Mall," *Digital Communities,* September 8, 2010, http://www.digitalcommunities.com/articles/Washington-DC-Extends-Free-Wi-Fi-Coverage-to-the-National-Mall.html.
[37] "Osaka Free Wi-Fi," http://www.osaka-info.jp/en/Wi-Fi/.
[38] John McCoy, "West Virginia Officials on Quest to Connect State Parks to Cyberspace," *The Charleston Gazette (*via *Government Technology)*, June 5, 2015, http://www.govtech.com/state/West-Virginia-Officials-on-Quest-to-Connect-State-Parks-to-Cyberspace.html.
[39] *Id.*
[40] Institute for Local Self Reliance, "Santa Monica City Net: An Incremental Approach to Building a Fiber Optic Network," March 2014, http://ilsr.org/wp-content/uploads/2014/03/santa-monica-city-net-fiber-2014-2.pdf.

2.4 Libraries

Libraries in the U.S. have long been community gathering spaces—hosting more than 1.5 billion visitors annually, and serving virtually every community in the country.[41] Many are adopting technology to "modernize, strategize and recast themselves as digital platforms."[42] Libraries host civic hacker hubs, distribute e-books, provide digital clinics, connect remote residents via videoconferencing, and serve as business incubators.

Libraries nationwide offer computer training and assistance completing online job applications.[43] A 2013 Digital Inclusion Survey from the American Library Association found that 97.5 percent of libraries help visitors complete online government forms, 74.1 percent support e-government and civic engagement programs, and 98 percent offer technology training.[44] These services are often made available through Wi-Fi.

Libraries that are incorporating digital features are thriving. In Minnesota, libraries in the Twin Cities are providing free digital access, courses, homework help, and assistance completing online job applications. By filling these community needs, the libraries increased annual visitation from 1.9 million patrons to 2.3 million over the past decade.[45]

Libraries around the country are incorporating Wi-Fi into their services to meet the information and learning needs of their communities in innovative ways:

- A library in San Antonio Texas, has gone all-digital. The Bexar County Digital Library, also known as BiblioTech, provides e-books, e-readers, computers, iPads, and laptops—but no books—to its patrons.[46]

- In Ohio, branches of the Cuyahoga County Public Library feature "IPad labs that are designed to support emergent literacy… to [support] skill building necessary for

[41] "Public Libraries in the United States Survey, FY 2012," Institute of Museum and Library Services, December 2014, https://www.imls.gov/sites/default/files/legacy/assets/1/AssetManager/PLS_FY2012.pdf.
[42] Jason Shueh, "Data Reinvents Libraries for the 21st Century" *Government Technology*, June 5, 2015, http://www.govtech.com/Data-Reinvents-Libraries-for-the-21st-Century.html.
[43] "Public Libraries & Digital Inclusion," Information Policy & Access Center, 2015, http://digitalinclusion.umd.edu/sites/default/files/DigitalInclusionBrief2015.pdf.
[44] Jason Shueh, *Government Technology.*
[45] Judy Keen, *MinnPost*, "Twin cities libraries innovate to stay relevant in digital age," October 15, 2013, http://www.minnpost.com/cityscape/2013/10/twin-cities-libraries-innovate-remain-relevant-digital-age.
[46] Keen, *MinnPost.*

kindergarten readiness. These labs can even be scheduled by staff to use in sensory programming for children on the autism spectrum."[47]

- The St. Paul, Minnesota library system operates a mobile computer lab that provides multi-lingual computer and job search training in neighborhoods throughout the city. During story hours at Pierre Bottineau Library in Minnesota's Hennepin County, children use iPads to tap into interactive apps.[48]

- Instructors at the fire station across the street from the Davenport Public Library in Washington have used the library's Wi-Fi to access online materials when training volunteer firefighters in CPR.[49]

Free Internet access helps create a community gathering space, leading one library director in Pennsylvania to coin the phrase "coffee shop clientele" for the patrons who come into the Ligonier Valley Library where she works, log on to the library's free Wi-Fi network, and stay for the day conducting business or research for a school project. "This is a whole new clientele. The Wi-Fi has made a big difference (in usage)," Hudson explains, "It's like a coffee shop, but people don't need to buy a cup of coffee every hour."[50] And while there, citizens interact and learn from one another. Indeed, as Kristen Mastel, past president of the Minnesota Library Association, recognizes, "Libraries are labs for collaboration and innovation."[51]

These services are particularly important in a challenging economy. Free access to Wi-Fi becomes an increasingly valuable service when citizens may not be able to afford access at home. In a 2012 study by the Pew Research Center, 77 percent of respondents reported that free access to computers and the Internet was "very important."[52] Libraries provide a space to complete online job applications and receive online training.

Libraries play a critical role in reducing the digital divide—serving as a vehicle to connect those who might not otherwise be able to get online, particularly important in low-income areas. A

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[47] Rebecca Ranallo, "Cuyahoga's 'Digital Environments,'" Urban Libraries Council, http://www.urbanlibraries.org/cuyahoga-s-literacy---learning-division-pages-331.php.
[48] Keen, *MinnPost.*
[49] "Davenport Public Library – Providing Broadband Access to their community," Between the Lines: Washington State Library Blog, December 1, 2014, http://blogs.sos.wa.gov/library/index.php/2014/12/davenport-public-library-providing-broadband-access-to-their-community/.
[50] Joe Napsha, "Wi-Fi drives use of libraries in Westmoreland," *TribLive*, March 15, 2015, http://triblive.com/news/westmoreland/7701168-74/library-system-libraries#axzz3puxu8LXf.
[51] Keen, *MinnPost*.
[52] Kathryn Zickuhr, Lee Rainie and Kristen Purcell, "Library Services in the Digital Age," Pew Research Center, January 22, 2013, http://libraries.pewinternet.org/2013/01/22/library-services/.

report on Digital Inclusion in Tribal Libraries reveals the importance of free Wi-Fi in these communities through powerful testimonials about its benefit:[53]

- "We have five individuals who are now working who weren't before because they were able to access practice tests for their professions or were able to use our resources to apply for jobs."
- "Each day our After School Program uses the computer access to do multiple things from networking to gaming. We have many youth under high school age who have a significant interest in programming and game design due to the free, virtually unlimited access they have here in our library. We will soon be starting beginner courses in the use of word and spreadsheet processing software and application development with our youth."
- "The Internet has helped to remove the digital divide among communities and there is sharing of information unlike before."[54]

2.5 Public Health

Instant communication is a critical need for emergency responders. Wi-Fi enables hospitals to begin to determine treatment before patients even arrive. For instance, first responders and emergency room doctors can access HIPAA releases and begin medical treatment beyond basic triage in the field.[55] This is particularly important in the case of heart attack victims, who may require a rapid response. In St. Louis, Missouri, ambulances are equipped with defibrillator units that allow paramedics to share images with doctors during transit via Wi-Fi. This permits hospital staff to assess the data and determine appropriate treatment before the patient arrives. As a consequence, the hospital can begin to set up the room or take steps to prepare a procedure.[56] In other instances, emergency room doctors can provide guidance over video to allow treatment to begin at the accident site. In these ways, Wi-Fi expedites treatment and improves prospects for recovery.

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[53] Miriam Jorgensen, Traci Morris, and Susan Feller, "Digital Inclusion in Native Communities: The Role of Tribal Libraries, Oklahoma City, OK," *Association of Tribal Archives, Libraries, and Museums* (2014), p. 44–45, http://www.atalm.org/sites/default/files/Report.pdf.

[54] Miriam Jorgensen, Traci Morris, and Susan Feller.

[55] "Corpus Christi Pioneers Metro-Wide Wi-Fi Mesh Network for AMR (July 2007), " Tropos Networks, http://smartcitiescouncil.com/system/tdf/public_resources/Corpus%20Christi%20WiFi%20network.pdf?file=1&type=node&id=320.

[56] Brian Heaton, "Heart Attack Treatment in St. Louis Speeds Up Speeds Up With Wi-Fi," *Emergency Management*, March 30, 2012, http://www.emergencymgmt.com/health/Heart-Attack-Treatment-St-Louis-Wi-Fi-EM.html.

Wi-Fi-enabled monitoring devices can also ease burdens on crowded hospitals. U.S. hospitals admit more than 35 million patients each year and handle more than three times that many emergency room visits. This places a significant burden on the facilities and their staff. Wi-Fi-enabled blood pressure monitors and glucose monitors, however, can replace in-person visits, reducing pressure on limited beds and staff and affording higher quality of care to admitted patients. The U.S. market for such devices was $3.9 billion in 2007; it is expected to grow to $20 billion in 2016.[57] This market is enabled by home Wi-Fi networks.

2.6 Transportation Management

Wi-Fi has the potential to transform roadways, easing traffic, improving safety, making road maintenance more efficient, encouraging the use of public transit, and expediting parking.

2.6.1 Managing Traffic

The average U.S. commuter spends 42 hours each year in traffic, with significant costs in lost productivity, fuel economy, emissions, and wear-and-tear on vehicles.[58] Congestion has been rising steadily; nationwide, the average daily time in traffic has more than doubled since 1982. And in some urban areas, the problems are even worse; the average commuter in Washington, D.C. experiences 82 hours in traffic each year—nearly twice the national average.[59]

Wi-Fi provides a critical tool to help alleviate traffic. In 2015, Seattle piloted a new traffic management program that uses Wi-Fi sensors to track cars through the city, providing the Seattle Department of Transportation (SDOT) with useful information about travel times and points of congestion. SDOT then uses this information to adjust signals and update signs, allowing vehicles to move through the city more smoothly. The city intends to expand the program.[60]

2.6.2 Maintaining Roads

Road-weather information systems ("RWIS") enable city officials to anticipate and adapt to changing weather conditions. The monitors rely on a mix of Wi-Fi and cellular networks to provide data on friction and basic weather details, such as temperature and humidity. Using a range of technologies, the monitors communicate with plow trucks to help cities make more informed decisions about when to plow or salt the roadways. Daryl St. Clair, Chief of

[57] Nicole Lewis, "Remote Patient Monitoring Market To Double By 2016," *InformationWeek*, July 24, 2012, http://www.informationweek.com/mobile/remote-patient-monitoring-market-to-double-by-2016/d/d-id/1105484.
[58] Reuters, "U.S. Commuters Spend About 42 Hours a Year Stuck in Traffic Jams," August 26, 2015, http://www.newsweek.com/us-commuters-spend-about-42-hours-year-stuck-traffic-jams-365970 (reporting that these factors cost $160 billion annually).
[59] Reuters.
[60] David Kroman, "Seattle installs new system to track individual drivers," *Crosscut*, September 8, 2015, http://crosscut.com/2015/09/seattles-new-technology-tracks-how-we-drive/.

Maintenance for the Pennsylvania Department of Transportation, reports that RWIS allows cities to adjust their application rates in real time, conserving resources and reducing accidents.[61] A similar network in Idaho led to an estimated 10 percent reduction in accidents, notwithstanding a 33 percent increase in snowfall.

2.6.3 Encouraging Transit

In Chicago, the Metra system is rolling out a pilot network of 10 rail cars with Internet hot spots, as well as free Wi-Fi in station waiting areas.[62] Kansas City is incorporating a Wi-Fi network along a two-mile segment of its streetcar line. The amenity will make the transit system more appealing to commuters; however, it will also enable an array of other city services. The updated route will include smart lighting and cameras, as well as 25 interactive digital kiosks that will provide commuters information about local events and city services. Wi-Fi will also enable the city to collect information from lights, traffic signals, pavement, and water pipes along the route, allowing it to moderate traffic flow and make city services more efficient.[63]

Other transit systems are likewise collecting data via Wi-Fi to improve services. In London, the Underground is using its Wi-Fi network to gather information about how passengers move within the stations, which will ultimately allow the city to improve station design and safety to accommodate passenger needs.[64]

Transit communication can flow in two directions, empowering citizens to improve the system. For instance, New Jersey Transit is developing a mobile app that allows riders to use their smartphones as reporting tools to document incidents as they happen and allow officials to respond more rapidly. Wi-Fi would eliminate a barrier to entry and encourage greater citizen participation. In New York, an app allows riders to "crowdsource" data about subway conditions—noting if a train is "Not Running, Normal, Packed, [or to be] Avoid[ed]—and color

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[61] Ben Miller, "Smarter Road Weather Sensor Networks Offer Better Safety, Forecasting," *Government Technology*, October 16, 2015, http://www.govtech.com/Smarter-Road-Weather-Sensor-Networks-Offer-Better-Safety-Forecasting.html.

[62] Richard Wronski, "Metra will test Wi-Fi on 10 rail cars," *Chicago Tribune*, September 25, 2015, http://www.chicagotribune.com/news/local/breaking/ct-metra-Wi-Fi-met-0926-20150925-story.html.

[63] Lynn Horsley and Mark Davis, "Kansas City completes 'Smart City' streetcar line agreement with Sprint and Cisco," *The Kansas City Star*, June 4, 2015, http://www.kansascity.com/news/business/technology/article23109192.html#storylink=cpy.

[64] Hugh Langley, *TechRadar*, "Your city is stupid," September 15, 2015, http://www.techradar.com/news/world-of-tech/future-tech/your-city-is-stupid-1305140?src=rss&attr=all.

codes the stations accordingly." This allows riders to modify their routes and avoid problem areas based on real-time data.[65]

Wi-Fi on transit does not merely provide convenience and enhance the rider experience, it can help "decrease inequalities," offers Vanessa Holman, a bus driver for the Miami-Dade County Public Schools, which currently provides Wi-Fi to students on many of its buses. The district currently is planning to triple the number of buses that will provide Wi-Fi access to students, targeting the longer routes, a service that will allow students an opportunity to study or complete homework, even if they do not have a regular Internet connection in their homes.[66]

The Cardinal Community School District in Iowa is likewise planning to "transform school buses into locations for learning," by providing Wi-Fi and outfitting students with tablets equipped with educational apps. The district superintendent praises the new service, noting that it ensures "[even] beyond the school house, the learning never stops." Such services are perceived as particularly valuable in rural districts, where bus transit can take as much as two hours each day and children are less likely to have Internet access in their homes.[67]

2.6.4 Expediting Parking

Cisco Systems reports that the average driver spends 20 minutes looking for a parking space. This not only frustrates drivers, but contributes to traffic, with an estimated 30 percent of city traffic caused by people looking for parking.[68] Wi-Fi innovations can help reduce these delays, alleviate the frustration associated with locating a parking spot, and facilitate parking enforcement.

In cities implementing smart parking solutions, like San Mateo, California, parking spots are equipped with sensors that transmit occupancy data over a Wi-Fi network. When a vehicle exceeds the maximum time limit in a space, the sensor alerts the city department responsible

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[65] Justine Brown, "Can Technology Help Improve Mass Transit Use," *Government Technology*, May 14, 2015, http://www.govtech.com/transportation/Can-Technology-Help-Improve-Mass-Transit-Use.html.

[66] Alex Harris, "Free Wi-Fi on Miami Trains Keeps Riders Satisfied," *Government Technology*, September 15, 2015, http://www.govtech.com/dc/articles/Free-Wi-Fi-on-Miami-Trains-Keeps-Riders-Satisfied.html.

[67] Mark Newman, "Iowa School District Adds Wi-Fi to Buses," *Government Technology*, August 5, 2014, http://www.govtech.com/education/Iowa-School-District-Adds-Wi-Fi-to-School-Buses-.html.

[68] Vito Salvaggio, "Cisco and Streetline Innovate for Smart Parking: Introducing Camera Based Detection and an Integrated Streetline IOT Gateway with Cisco Wi-Fi," Cisco Blog, May 19, 2014, http://blogs.cisco.com/government/cisco-and-streetline-innovate-for-smart-parking-introducing-camera-based-detection-and-an-integrated-streetline-iot-gateway-with-cisco-Wi-Fi.

for ticketing. The sensors also send information to a mobile app, allowing parkers to find available parking spaces more rapidly.[69]

2.7 Automated Meter Reading (AMR)

The City of Corpus Christi, Texas constructed a city-funded network to enable Automated Meter Reading (AMR) in 2002. The network ultimately involved the construction of 120,000 water and gas meters and accompanying Wi-Fi service across 144 square miles of the city. While AMR enabled the city to reduce its meter-reading costs, the system also had enough bandwidth to support 60 Wi-Fi hot spots.

Today, the network facilitates interdepartmental collaboration, enhances public education, and supports scientific research. It enables Internet access at schools, virtual desktops for city workers, and tidal monitoring. It also provides redundancy in the event of a storm. Michael Armstrong, the city's Chief Information Officer touts the network's resiliency benefits: "We have city vehicles and another 100 transportation authority buses outfitted with mobile routers…. I can set up Wi-Fi within an hour if our network is taken down by weather—it makes me sleep a little better at night."[70]

Other cities are realizing similar benefits. Anderson, Indiana deployed a Wi-Fi network to support AMR. The network is expected to save as much as $18 million over a 15-year period, owing to reduced staffing demands. In Lafayette, Louisiana, Wi-Fi supports mobile utility workers who can file reports and access documents like building schematics and city maps from the field, rather than driving back and forth to a central office. Denise Barton, marketing director for the network, explains, "That's why this technology is so important: it connects utilities with their customers like nothing you've ever had before… putting this sort of technology in place is like having a utility meter reader at every home 24 hours a day, seven days a week."[71]

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[69] Michelle Durand, "San Carlos to Expand Streetline Guided Parking Program," *The Daily Journal*, June 9, 2014, http://www.smdailyjournal.com/articles/lnews/2014-06-09/san-carlos-to-expand-streetline-guided-parking-program/1776425124598.html.

[70] Freedman Consulting, LLC, "Toward an Understanding of Best Practices in Community Wireless Networks: A Survey of Select Networks," May 2015, at 35, http://tfreedmanconsulting.com/documents/BestPracticesinCommunityWireless.pdf; Tropos, "Corpus Christi Pioneers Metro-Wide Wi-Fi Mesh Network for AMR."

[71] Jeff Goldman, "Wi-Fi Smart Meters," *Wi-Fi Planet*, May 5, 2008, http://www.wi-fiplanet.com/columns/article.php/3743971/Wi-Fi-Smart-Meters.htm.

2.8 Environmental Management

2.8.1 Conserving Water

Data sensors can detect leaks, allowing cities to determine where repairs are needed. This can reduce waste and make systems more reliable. Globally, more than 30 percent of the water pumped through distribution systems is lost. Leak-detection technology can minimize these losses.[72] Water leak detection offers significant economic benefits. A recent study of smart water technologies found that they could save municipal utilities $7.1 to $12.5 billion annually.[73]

Burbank Water and Power, the public utility for the City of Burbank, California, installed smart water meters that communicate with a citywide Wi-Fi network. These meters report water usage back to utility staff every hour, allowing staff to rapidly respond to unusual spikes in usage, and inform customers of potential leaks. The utility estimates these smart meters save the city approximately 11 million gallons of water annually.[74]

2.8.2 Managing Street and Traffic Lights

In San Diego, California, 70 percent of the time that a traffic light is broken, city officials only know because somebody phones in to report it. Similar statistics exist for cities worldwide. This trend, however, is changing, as cities begin to install sensors in their lights that provide alerts if the light goes out.[75] Similar designs are changing the way cities light their roads and communicate with the public around the world.

Innovative lighting manufacturers are transforming streetlights into platforms for Internet of Things networks. Sensity Systems and Cisco Systems are working with Kansas City to install intelligent streetlights with ambient light sensors, which dim the lights according to conditions—and which could save the city as much as $4 million per year on energy spending.

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[72] Bob Sitkauskas and Russ Vanos, "Transforming Detroit into a Smarter City," *Meeting of the Minds*, September 30, 2014, http://cityminded.org/transforming-detroit-smarter-city-11688.

[73] "Smart city spending: 5 new research reports predict where action will be," Smart Cities Council, October 16, 2015, http://smartcitiescouncil.com/article/smart-city-spending-5-new-research-reports-predict-where-action-will-be.

[74] "Burbank Water and Power American Recovery and Reinvestment Act Smart Grid Program," California Energy Commission, November 2014, http://www.energy.ca.gov/2015publications/CEC-500-2015-010/CEC-500-2015-010.pdf.

[75] Hugh Langley, "Your City Is Stupid," *Tech Radar*, September 25, 2015, http://www.techradar.com/us/news/world-of-tech/future-tech/your-city-is-stupid-1305140 (describing the lighting system in the city of Groningen, Netherlands). For more about why Groningen chose to use Wi-Fi for its applications, see "Groningen as a Smart City," *Smart Cities*, April 2009, http://www.smartcities.info/files/Groningen%20as%20a%20smart%20city%20-%20report%20academy%2016%20april%202009.pdf.

In addition, these street lights connect to a Wi-Fi backhaul network, and can be equipped with a wide range of smart devices, from gunshot sensors to weather monitors. [76] Any number of city departments may decide to use these Wi-Fi-enabled streetlights to collect relevant data, allowing them to perform their services more effectively.

2.8.3 Removing Trash from Waterways

The Healthy Harbor Initiative in Baltimore, Maryland has deployed a solar-powered, Wi-Fi-enabled waterwheel to remove trash from the harbor—with striking results. Though a major tourist destination, the harbor has long been filled with trash and debris, rendering it unsuitable for swimming 60 percent of the time. Several years ago, Baltimore developed a waterwheel that removed 40 tons of waste in its first month of operation and helped the city comply with state and federal environmental laws.

The wheel itself is equipped with a webcam, so that it can record real-time footage of operations as a public relations and education tool.[77] A wireless connection also enables remote operation of the wheel, so that operators can unjam the feeder in the event that logs or branches block trash flow.[78]

2.8.4 Detecting Heat Islands

Wi-Fi can be used to determine where heat islands are located, so that cities can make accommodations to reduce the effect. For instance, data from Wi-Fi-enabled benches in Cambridge, Massachusetts may help cities achieve their climate goals by identifying areas that could benefit from additional tree canopy or other measures (like painting roofs white).[79]

2.9 Public Information Kiosks

With the advent of cell phones, the payphone has become largely obsolete. In fact, since 1997, the number of payphones nationwide has dropped from an estimated peak of about 2.2 million to only 400,000.[80] Wi-Fi allows cities to reclaim this infrastructure—and reinvent it for the 21st century.

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[76] Matt Hamblen, "Just what is a smart city?", *CIO*, October 1, 2015, http://www.cio.com.au/article/585801/just-what-smart-city/?pp=2.

[77] Adam Lindquist, "Water Wheel operating in a rain storm (Baltimore, MD)," *YouTube*, May 16, 2014, https://www.youtube.com/watch?v=v5l7s6wC50g

[78] Colin Wood, "Solar Wi-Fi Enabled Water Wheel Pulls Trash from Baltimore's Inner Harbor," *Government Technology*, July 7, 2014, http://www.govtech.com/local/Solar-Wi-Fi-Enabled-Water-Wheel-Pulls-Trash-From-Baltimores-Inner-Harbor.html.

[79] J.B. Wogan, "Boston Pilots Smart Solar-Powered Benches," *Government Technology*, September 11, 2015, http://www.govtech.com/fs/Boston-Pilots-Smart-Solar-Powered-Benches.html.

[80] Matt Rocheleau.

The reimagining of this public infrastructure is best illustrated by the LinkNYC payphone project, an effort to convert 11,000 outmoded payphones to interactive, touch-screen kiosks. Former New York City Mayor Mike Bloomberg launched the precursor initiative in 2012, announcing a "Reinvent Payphones" competition to help the city identify alternative uses for its payphones when the contract for their use expired in 2014. The city received more than 125 proposals.[81]

The selected New York project lead, CityBridge, introduced kiosks that will serve as Wi-Fi hotspots, providing speeds up to 1 Gigabit for 150 feet—speeds greater than what is available through most residential and business connections.[82] The first Link kiosks debuted in Manhattan in mid-January 2016.[83] These beta sites, and the thousands of kiosks that will be installed citywide, will allow citizens to communicate with the city—through their own devices or the touchscreen tablet. They will also allow the city to communicate with its citizens—by providing directions, details about community events, and public service announcements. Beyond this, the reinvented payphones will allow citizens to speak to one another. The kiosks' integrated tablets will enable free nationwide calling. And these amenities will be available to all New Yorkers, reducing the digital divide.

New York is not alone in trying to reinvent its outmoded payphones. Boston is likewise converting some of its former payphones into hotspots. In a 24-hour period during a 2013 pilot with 15 phones, 18,000 mobile devices noticed the Wi-Fi network, 2,000 devices connected, and more than 200 people spent an average of 17 minutes each using the Internet connection. Building on this success, the city initially created Internet hotspots at 400 other downtown phone locations, focusing on areas that attract a large number of pedestrians, commuters, business professionals, and tourists. Recognizing, however, the ability of the hotspots to level the playing field for all residents, the city will then turn its focus to low-income neighborhoods, creating hot spots for those who might not otherwise be able to afford Internet access.[84] As Jeff Carlson, vice president and general manager of RCN Boston explains, "The partnership is giving new life to telephone booths that have almost become extinct due to the evolution of the cell phone."[85]

2.10 Public Infrastructure

Other infrastructure is likewise being reimagined, with Wi-Fi helping it to work harder. In July 2014, for example, Boston Mayor Marty Walsh announced the City's decision to install several

[81] Samantha Murphy Kelly.
[82] "Creating Connected Communities," LinkNYC, http://www.link.nyc/.
[83] Rebecca Greenfield, "New York's Super-Fast Wi-Fi Is Live, and Free," *BloombergBusiness*, Jan. 19, 2016, http://www.bloomberg.com/news/articles/2016-01-19/new-york-s-super-fast-wi-fi-is-live-fast-and-free.
[84] Matt Rocheleau.
[85] Matt Rocheleau.

interactive benches ("Soofas") as an "early adopter." The Soofas include solar-powered devices to charge cell phones, along with a variety of sensors to assess air quality, ambient heat, and pedestrian traffic. Mayor Walsh explains, "Your cell phone doesn't just make phone calls," Walsh said, "why should our benches just be seats?"[86]

Like many innovative municipal Wi-Fi applications, the project relies on public engagement to be successful. Boston is soliciting recommendations from the public to determine where to locate the Soofas and to offer names for the individual installations.[87] The City received over 120 unique locations,[88] and is beginning to install additional units.[89]

The hallmark of urban Wi-Fi is the ability to support this kind of two-way communication. The Soofas are not merely docking stations for cell phones—they both provide and collect data to help guide urban development. In the future, embedded sensors will be able to identify unique Wi-Fi or Bluetooth signals from nearly cell phones, providing data to city planners about pedestrian traffic. That, in turn, can be used when local developers are trying to attract a grocery store or a pharmacy to a neighborhood. Not only will the location be able to offer public amenities like free Wi-Fi, but the company will be able to make a more informed economic decision. Data collected with air-quality sensors embedded in the Soofas will be available online, allowing citizens to identify the cleanest public spaces.[90]

2.11 Public Parks

Many cities provide free Wi-Fi in public parks as a way to ensure equal access to all citizens, regardless of income. In 2013, Google donated $600,000 to the City of San Francisco to build free public Wi-Fi in 31 city parks and recreation centers. The expanded service was intended to "help close the digital divide for low income and homeless persons, who may not otherwise be able to afford Internet access, but own a wireless device, such as a smart phone or tablet."[91]

Elsewhere, free park Wi-Fi has been coupled with programs to provide free devices to low-income residents. For instance, the City of Delray Beach, Florida launched a program offering

[86] "Mayor Walsh Announces High-Tech Solar Powered Benches Coming to Area Parks," Press Release, City of Boston, Mayor's Office, June 27, 2014, http://www.cityofboston.gov/news/default.aspx?id=11695.
[87] *Id.*
[88] "Early Adopters," Soofa, http://www.soofa.co/earlyadopters/.
[89] *See, for example:* http://www.soofa.co/press-release/2015/6/4/the-city-of-cambridge-installs-smart-eco-friendly-urban-furniture-soofa-benches.
[90] J.B. Wogan.
[91] Rachelle Chong, "Google Donates $600k to Build Free Public Wi-Fi in 31 SF Parks and Plazas," *Government Technology*, July 25, 2013, http://www.govtech.com/network/Google-Donates-600k-to-Build-Free-Public-Wi-Fi-in-31-SF-Parks-and-Plazas.html.

free reconditioned personal computers to low-income families, in conjunction with a regional program to deliver free Wi-Fi in public spaces.[92]

2.12 Public Housing

Those who seek to ameliorate the digital divide often focus on rural communities; however, connectivity is also a significant issue in urban areas, particularly for low-income households. These issues were revealed in a 2014 study by Building Blocks for Kids, a collaborative of about 30 government agencies, nonprofits, and community leaders in the Iron Triangle neighborhood of Richmond, California. Critically, the study found that one in three residents does not have access to the Internet at home. It further found that the cost of Internet service and limited digital literacy are the primary barriers to home Internet access.[93] That realization prompted the city to provide free Wi-Fi to the economically distressed community. The Wi-Fi program dovetails nicely with an initiative in area schools to provide a tablet for every student. Free Wi-Fi will now enable children to take those devices home and continue learning outside the classroom.[94]

Recognizing the critical role that connectivity plays, other municipal governments have adopted programs to provide free Wi-Fi to low-income residents, in public housing and elsewhere in their communities.

San Francisco, California was an early adopter, announcing wireless coverage in 12 low-income housing facilities in the Tenderloin neighborhood of the city in 2008, with plans to expand to other low-income housing and senior centers.[95] Today, a partnership between the San Francisco Housing Authority (SFHA) and the City's Department of Technology supports free wireless Internet access to all public housing developments in San Francisco.[96] Similar efforts have been made in major cities across the country,[97] and around the world. For instance, the

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[92] Lisa J. Huriash and Anne Geggis, "Play and plug in: Cities expand free Wi-Fi in parks," *Sun Sentinel*, May 6, 2013, http://articles.sun-sentinel.com/2013-05-06/news/fl-springs-wifi-parks-20130504_1_free-wi-fi-wi-fi-service-internet-service.

[93] Building Blocks for Kids – Richmond Collaborative, "Community Connections: A Roadmap for Advancing Digital Literacy and Access in Richmond's Iron Triangle," January 2014, at 1, http://bbk-richmond.org/wp-content/uploads/2014/01/Community-Connections.pdf.

[94] Colin Wood, "Richmond, Calif., to Expand Free Indoor Wi-Fi Network," *Government Technology*, July 23, 2015, http://www.govtech.com/dc/articles/Richmond-Calif-to-Expand-Free-Indoor-Wi-Fi-Network.html.

[95] Marguerite Reardon, "Meraki teams with San Francisco for free Wi-Fi," *CNET*, September 16, 2008, http://www.cnet.com/news/meraki-teams-with-san-francisco-for-free-wi-fi/.

[96] http://www.sfha.org/Public-Housing---Wi-Fi.html.

[97] *See, for example:* "Community Access Affordable Housing Wireless Networks," *NYC Wireless,* http://nycwireless.net/projects/community-access/ (describing New York City's NeedyNets program providing wireless networks to four community access low-income housing facilities in New York City); "RFP for Wi-Fi

UK launched a Digital Deal to expand access to low-income households, recognizing that one-half of its citizens who are not online live in social housing.[98]

San Antonio, Texas is likewise investing in free Wi-Fi in its public housing to support education and workforce development. The San Antonio Housing Authority is refurbishing office computers with wireless capabilities and distributing them in community rooms at 30 public housing facilities. The project is intended to "provide children with computer tools and Internet for learning; adults with information on educational, job training and employment opportunities; and seniors with information on health and wellness resources."[99]

Simply providing Wi-Fi in low-income housing is not sufficient, as many residents lack devices to connect. Indeed, the 2014 Building Blocks for Kids study found that two-fifths of the households in the community did not own a computer.[100] Mobile Wi-Fi can address this issue. For instance, the New York City Housing Authority's Digital Vans program travels to low-income communities throughout the City on a set schedule,[101] offering access to eight laptops equipped with Microsoft Office software, printers, and Wi-Fi Internet access. Residents may use the resources for as long as the van is open, though they are limited to a 30-minute session when others are waiting. Users who are preparing resumes and cover letters are given a free flash drive to store their materials.[102] Similar efforts are underway in Europe.[103]

2.13 Digital Inclusion

The Internet has become a major gateway to many resources and social services. Unfortunately, low-income populations that stand to benefit the most from such services often lack access to the Internet in their homes. According to 2013 Census data, more than half of

network in Jordan Downs housing development, Los Angeles," *MuniWireless*, December 19, 2014, http://www.muniwireless.com/2014/12/19/rfp-wi-fi-network-jordan-downs/.

[98] "Digital Deal: 12 projects to help social tenants get online," Press Release, Department for Work Pensions, *et al.,* August 9, 2013, https://www.gov.uk/government/news/digital-deal-12-projects-to-help-social-tenants-get-online.

[99] James Aldridge, "San Antonio introducing free Wi-Fi at select public housing projects," *San Antonio Business Journal*, March 26, 2013, http://www.bizjournals.com/sanantonio/news/2013/03/26/san-antonio-introducing-free-wi-fi-at.html.

[100] Building Blocks for Kids – Richmond Collaborative.

[101] New York City Housing Authority Digital Van Map, https://www.google.com/maps/d/viewer?mid=zXqJJh7b8vP8.kW1Voxl-TXj8.

[102] Sarah Rich, "NYC Housing Authority Puts Broadband on Wheels," *Government Technology*, June 21, 2012, http://www.govtech.com/wireless/NYC-Housing-Authority-Broadband-on-Wheels-PHOTOS.html.

[103] Department for Work Pensions.

households making less than $25,000 per year in annual income reported having no access to Internet in their homes.[104]

As illustrated above, the Internet allows local governments to deliver education, health care, and many social services in more effective and affordable ways. However, many of the cost-saving measures will not be fully realized until local governments can shut down their legacy (pre-Internet) systems—which they cannot do until Internet access is truly ubiquitous.

Local governments are addressing the challenge of digital inclusion in a variety of ways. Many of the efforts rely on Wi-Fi networks to provide affordable Internet access to target populations.

For example, some libraries also allow users to check out laptops and tablets, which can access the Internet over the library's Wi-Fi connection. Taking that approach a step further, a number of library systems, including the New York Public Library and Chicago Public Library, have begun to allow residents to check out Wi-Fi hotspots through the library. Rural libraries in Kansas and Maine are also piloting similar Wi-Fi hotspot lending programs.[105] In Kansas City, the library is piloting a program that allows high school students to borrow Wi-Fi hotspots for the full school year. These hotspots use mobile connections to create a local Wi-Fi network, to which multiple devices can connect. Library officials hope that allowing users to bring an Internet connection home with them will help them become more comfortable with technology, and that those residents will eventually sign up for their own Internet service.[106]

Many local governments are building out Wi-Fi networks in targeted areas to serve particularly vulnerable populations. As mentioned above, a number of cities have built Wi-Fi networks in public housing developments and use these networks to provide free or discounted service to residents. Homeless shelters in San Francisco now use Wi-Fi networks to offer free Internet access, allowing people staying in the shelters to use smartphones, tablets, or laptops to check job listings, look for housing opportunities, and communicate with family and friends. [107]

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[104] Tom File and Camille Ryan, "Computer and Internet Use in the United States:2013," American Community Survey Report, Issued November 2014, https://www.census.gov/history/pdf/2013comp-internet.pdf, accessed February 2, 2016.

[105] Timothy Inklebarger, "Bridging the Tech Gap," *American Libraries Magazine*, September 11, 2015, http://americanlibrariesmagazine.org/2015/09/11/bridging-tech-gap-wi-fi-lending/, accessed February 2, 2016.

[106] Jessica McKenzie, "Libraries Hope to Help Close the Digital Divide by Lending WiFi Hotspots," TechPresident, June 27, 2014, http://techpresident.com/news/25155/chicago-and-new-york-public-libraries-hope-help-close-digital-divide-lending-wifi.

[107] Sam Harnett, "A Homeless Man Brings Wi-Fi to San Francisco Shelters," KQED, May 18, 2015, http://ww2.kqed.org/news/2015/05/18/a-homeless-man-brings-wi-fi-to-san-francisco-shelters, accessed February 2, 2016.

In New York City, foster children who complete a digital literacy class are given a laptop and a Wi-Fi hotspot with up to four years of free Internet service. The program is designed to help foster children develop the digital skills they need to perform well in schools, where more and more assignments each year require students to use the Internet.[108]

A number of municipalities are working to help seniors use computers and get online. In Springfield, Massachusetts, the Department of Elderly Affairs runs a Computer Learning Center, where senior citizens can use Wi-Fi-connected devices and receive one-on-one training, focused around their areas of interest.[109] The non-profit Generations on Line has developed digital literacy training software designed to help elderly populations learn how to use computers and tablets to access the Internet. The organization invites anyone with a few tablets and a Wi-Fi connection to use their software and set up a "Sit & Swipe Café" to help elderly members of their community learn how to get online and access services.[110]

While Wi-Fi is not a solution in itself to the challenges of digital inclusion, it is an important tool that municipalities are using to provide low-cost access to segments of society that may otherwise be unable to afford Internet access in their homes.

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[108] Chester Soria, "NYC Foster Kids Get Tech Crash Course to Bridge Digital Divide," Metro, September 21, 2015, http://www.metro.us/new-york/nyc-foster-kids-get-tech-crash-course-to-bridge-digital-divide/zsJoiu---SrCQSEFunUoZ2/, accessed February 2, 2016.

[109] Cecilia Garcia and Bob Harootyan, "Helping Seniors Bridge the Digital Divide," The Benton Foundation, https://www.benton.org/blog/helping-seniors-bridge-digital-divide, accessed February 2, 2016.

[110] "Sip & Swipe," Generations on Line, http://www.generationsonline.org/sipandswipe/, accessed February 2, 2016.

3 LTE-U Interference Threatens Wi-Fi

Long Term Evolution (LTE) technology is the current protocol used by cellular carriers to transmit voice and data. Also known as "4G" technology, LTE currently is deployed only in licensed spectrum. Cellular carriers are seeking more spectrum, however, as more users adopt LTE service, subscribers individually use more devices, and wireless technologies are increasingly used for video and other bandwidth-intensive applications. Cellular carriers see LTE in unlicensed spectrum (LTE-U) as a potential solution for the scarcity of their licensed spectrum.

In the sections that follow, we briefly describe Wi-Fi, LTE, and LTE-U, then discuss the ways in which LTE-U threatens Wi-Fi.

3.1 Licensed and Unlicensed Spectrum Are Used Differently

Soon after people began using radio waves to transmit information at the end of the 19th century, different uses of radio frequencies began interfering with one another. Congress passed the Radio Act of 1912, giving the Secretary of Commerce regulatory authority over radio frequencies. With the passage of the Communications Act of 1934, this authority transferred to the newly created Federal Communications Commission (FCC).[111]

Since its inception, the FCC has sought to fairly and efficiently allocate radio spectrum in a way that serves the public interest according to a command-and-control approach to management. Under Title 47, of the Code of Federal Regulations,[112] all spectrum users must abide by the Commission's Table of Frequency Allocations.[113] For most bands of spectrum, the FCC provides licenses granting one or more users exclusive right to broadcast and receive within certain frequency bounds, in a specific geographic range—thus protecting the licensees from interference from other users.

Initially, when more than one applicant sought permission to use a given band, the FCC had to decide which applicant best served the interest of the American people. In the 1990s, Congress gave the FCC permission to award licenses based on public auctions. Different bands are better suited for different uses—some bands are well suited to carry a signal over long distances, for

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[111] "FCC Regulation of Spectrum–A Brief History," The Aspen Institute Roundtable on Spectrum Policy, 2014, http://csreports.aspeninstitute.org/Roundtable-on-Spectrum-Policy/2014/report/details/0134/Spectrum-2014 (accessed December 29, 2015)

[112] 47 C.F.R. § 2 Subpart B- Allocation, Assignment and Use of Radio Frequencies, http://www.ecfr.gov/cgi-bin/text-idx?SID=c3065b47809eaae7715ec5c1c0fe59b6&mc=true&node=pt47.1.2&rgn=div5#sp47.1.2.b

[113] 47 C.F.R. § 2.106, Table of Frequency Allocations. http://www.ecfr.gov/cgi-bin/text-idx?SID=a57c7275eebe3fbb45c86dcc460fc37d&mc=true&node=se47.1.2_1106&rgn=div8

example, while others offer fast transmission speeds to a large number of users at once; the auctions allow companies to set the price for spectrum based on its economic value. In the AWS-3 auction in early 2015, AT&T spent $18.2 billion for licensed use of 20 MHz with particularly strong signal propagation characteristics.[114] In the U.S., wireless carriers operate in the 700 MHz, 800 MHz, 1.9 GHz, 2.1 GHz, and 2.5 GHz bands.

However, not all spectrum is reserved for the exclusive use of license holders. The FCC has set aside certain bands of spectrum as wireless common under Part 15 of Title 47. Anyone is allowed to send and receive transmissions on these bands, provided they follow certain technical requirements and use only FCC-approved devices. Part 15 of Title 47 allows for a number of unlicensed uses of spectrum, provided users limit total transmission power, not cause harmful interference to other users, and accept any interference caused by other users.[115]

Originally, the unlicensed bands were set aside for industrial, scientific, and medical (ISM) devices, but the FCC opened them up for radio users in 1985. Historically, unlicensed transmissions were limited to 900 MHz, 2.4 GHz, and 5.8 GHz.[116] However, in response to the huge amount of innovation that has taken place in the unlicensed band, the FCC has made hundreds more MHz of spectrum available for unlicensed use, most notably in the 5 GHz range.[117] In 2014, one researcher estimated that the total economic value of unlicensed spectrum was $222 billion.[118]

Given the lack of controls on the use of the bands, the designers of low-power devices that transmit on unlicensed spectrum have had to develop strategies for those devices to coexist with other users. Most notably, many technologies operating in the unlicensed bands, such as Wi-Fi, use a listen-before-talk (LBT) protocol to check whether a channel is free before beginning to transmit. (A more detailed explanation of LBT is provided in Section 3.2.) Although

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[114] Phil Goldstein, "AWS-3 Auction Results: AT&T leads with $18.2B, Verizon at $10.4B, Dish at $10B and T-Mobile at $1.8B," *Fierce Wireless*, January 30, 2015, http://www.fiercewireless.com/story/aws-3-auction-results-att-leads-182b-verizon-104b-dish-10b-and-t-mobile-18b/2015-01-30 (accessed December 22, 2015).

[115] 47 C.F.R. §15.5, http://www.ecfr.gov/cgi-bin/text-idx?SID=c3065b47809eaae7715ec5c1c0fe59b6&mc=true&node=pt47.1.15&rgn=div5#se47.1.15_15

[116] Kenneth Carter, Ahmed Lahjouji and Neal McNeil, "Unlicensed and Unshackled, a Joint OSP-OET Working Paper on Unlicensed Devices and their Regulatory Issues," OSP Working Paper Series, May 2003, https://apps.fcc.gov/edocs_public/attachmatch/DOC-234741A1.pdf (accessed December 22, 2015).

[117] Phil Goldstein, "FCC opens up 100 MHz of spectrum in 5GHz band for unlicensed Wi-Fi," Fierce Wireless, March 31, 2014, http://www.fiercewireless.com/story/fcc-opens-100-mhz-spectrum-5-ghz-band-unlicensed-wi-fi/2014-03-31 (accessed December 22, 2015).

[118] Raul Katz, "Assessment of the Economic Value of Unlicensed Spectrum in the United States," WifiForward, February 2014, http://www.wififorward.org/wp-content/uploads/2014/01/Value-of-Unlicensed-Spectrum-to-the-US-Economy-Full-Report.pdf (accessed December 22, 2015).

U.S. regulators do not require an LBT protocol in the unlicensed bands, most users choose to act as good neighbors in order to ensure that the wireless commons remain available for successful transmissions with minimal interference.[119] As a result, frequencies once dismissed as "junk bands" are now referred to as "innovation bands."

3.1.1 What Is Wi-Fi?

Wi-Fi is one of the most important technologies operating in the unlicensed bands. Originally developed to wirelessly connect computers in a lab, classroom, or office to a local area network, Wi-Fi now enables a huge range of mobile devices to connect to the Internet.

Wi-Fi refers to a wireless local area network (WLAN) based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards. In order to guarantee interoperability, device manufacturers came together to form the Wi-Fi Alliance, which tests and certifies Wi-Fi-enabled devices. The Alliance now includes more than 600 companies from dozens of countries around the world.[120]

The 802.11 standards continue to evolve, enabling new functionality and faster transmission speeds. The most widely adopted versions are 802.11a, 802.11b, 802.11g, and 802.11ac. The most recent version, 802.11ac, uses the 5 GHz unlicensed band and has a theoretical maximum speed of 1.3 Gbps.[121]

Anyone can purchase a Wi-Fi-enabled router and use it to set up a WLAN. Most offices and homes use Wi-Fi routers to connect a range of devices to wired Internet service. Increasingly, cities and cable companies use Wi-Fi base stations in close proximity to one another to create carrier-grade networks that blanket an area with reliable wireless coverage. With more than 20,000 "Wi-Fi certified" products, Wi-Fi has become one of the most widely adopted technologies across the globe.[122] And as Section 2 illustrates, Wi-Fi has enabled innovation in virtually every aspect of local government operations.

3.1.2 What Is LTE?

The first cellular networking technology (1G) used an analog wireless access system to carry voice traffic. The second-generation (2G) technology replaced the analog system with a digital radio network, allowing for more efficient use of spectrum. With the third generation of mobile

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[119] ET Docket No. 13-49; FCC 14-30, April 1, 2014, https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-30A1.pdf (accessed December 22, 2015).
[120] "Who We Are," Wi-Fi Alliance, http://www.wi-fi.org/who-we-are.
[121] "802.11ac: The Fifth Generation of Wi-Fi Technical White Paper," Cisco, http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-3600-series/white_paper_c11-713103.html.
[122] "15 Years of Wi-Fi," Wi-Fi Alliance, https://www.wi-fi.org/download.php?file=/sites/default/files/private/Infographic_15_Years_of_Wi-Fi_0.pdf.

technology, wireless carriers began using an Internet Protocol (IP) system. Instead of providing users with specific channels or fixed timeslots, data is broken into small packets and routed through the 3G network, just like all other networks that use IP.

In order to keep up with rapidly growing demand for mobile data, wireless carriers developed the fourth and latest generation (4G) of cellular technology, commonly called Long Term Evolution (LTE). LTE offers significantly faster download and upload speeds than 3G technologies, allowing customers to use more bandwidth-intensive applications, like streaming video. According to a recent OpenSignal report, U.S. carriers currently offer average download speeds between 5 and 15 Mbps on their LTE networks.[123]

In the U.S., the top five wireless carriers are all building out LTE networks, though they continue to maintain legacy networks that rely on earlier technologies. The LTE standard is designed to operate in licensed bands of spectrum, and only licensed operators are able to use LTE network equipment. Licensed spectrum users can operate LTE transmitters at much higher power levels than Wi-Fi base stations. With protection against interference and the ability to transmit at higher power levels, carriers are able to provide reliable coverage across a multiple-mile radius with a single LTE base station. In practice, carriers use a wide range of network topologies for their LTE networks depending on their spectrum holdings, number of customers, and customers' demand for data. Carriers often use a combination of high-power base stations and much smaller microcells and picocells to ensure adequate coverage and capacity in high-use areas.

3.1.3 What Is LTE–U?

In recent years, carriers report that the demand for mobile data has outpaced the additional spectrum becoming available for use in mobile data networks. As a result, wireless carriers have had to search for ways to increase the capacity of their networks. Recently, they have begun using unlicensed bands of spectrum to supplement the capacity of their licensed bands. As a recent report on LTE unlicensed and Wi-Fi explains:

> "Traditionally mobile operators have been wary of using unlicensed spectrum. In the last few years, though, they have started to warm to its uses as they developed an appreciation of unlicensed spectrum's versatility and potential in serving their subscribers, especially indoors. While estimates vary across regions, in most markets Wi-Fi accounts for more than half of traffic from mobile devices. Offloading cellular traffic into Wi-Fi networks—residential, enterprise, or

[123] "The State of LTE," *Open Signal*, September 2015, https://opensignal.com/reports/2015/09/state-of-lte-q3-2015/.

> hotspot—has been a vital approach for mobile operators under pressure to meet subscriber demand and retain control over profit margins.” [124]

Wireless operators have used a variety of strategies to offload traffic onto Wi-Fi networks. They have implemented data caps and pay-per-bit pricing to encourage customers to connect their mobile devices to Wi-Fi networks when available. They have also set up their own Wi-Fi hotspots, and given customers free capacity on the hotspots to reduce the load on their cellular networks.

In order to more smoothly integrate these bands into their existing LTE networks, the carriers developed a standard called LTE Unlicensed (LTE-U), which extends the LTE standards into the 5 GHz unlicensed band.

An LTE-U-enabled device would continue to connect to the carrier’s base station using licensed spectrum, and this connection would serve as the primary control channel. However, when the device asks to download a large file, like a video, or when the primary network is overloaded, the carrier would have the option of sending data over the 5 GHz unlicensed band using an LTE-U microcell. LTE-U would primarily be used as a downlink, but could be used for uploading data as well. Because the 5 GHz band is subject to power limits, the carriers will need to deploy LTE-U in small-cell topologies, though macrocells may still be used for the licensed LTE network.

By definition, unlicensed spectrum is available to any user that is compliant with the rules of the spectrum (power level and so forth). Individual users of unlicensed spectrum—including Wi-Fi, but also the majority of wireless devices such as television remotes, garage door openers, cordless telephones, baby monitors, and the growing range of smart appliances and devices—are not protected against interference from FCC licensees, but the FCC can and has protected unlicensed users as a group from spectrum degradation caused by the introduction of potentially destructive new technologies.

Technology developers historically have sought to ensure coexistence with other technologies as part of the standards-development process to obviate the need for more stringent regulation while ensuring predictability and robust unlicensed bands.[125]

As we describe below, some LTE-U manufacturers have conducted tests in selected use cases and declared Wi-Fi coexistence a solved problem, but other manufacturers, service providers,

[124] Monica Paolini, “LTE unlicensed and Wi-Fi, Moving beyond coexistence,” presentation, Senza Fili Consulting, June 3, 2015, http://apps.fcc.gov/ecfs/document/view?id=60001076664.
[125] Monica Paolini; LTE-U Forum Technical Report, http://www.slideshare.net/zahidtg/15-105-06112015-google-inc-60001078145 (Jindal).

and stakeholders have raised serious questions about the completeness of the testing and are calling for a more complete testing process and modification of the LTE-U and LAA protocols for the technologies to better coexist.

3.2 LTE-U Can "Talk Over" Wi-Fi Devices Because It Does Not Follow Wi-Fi's "Listen-Before-Talk" Technique

Wi-Fi uses the 5 GHz band in its most recent 802.11ac standard, which began to be available in 2014 and is now the standard Wi-Fi technology. Wi-Fi uses 24 20-MHz channels in the band. A Wi-Fi access point (or hotspot) can use multiple channels at once—this is how it achieves the theoretical top capacity of 1.3 Gbps. When other hotspots are present, the different hotspots typically take only a subset of the channels and leave the others to the other hotspots.

Within a channel, Wi-Fi devices use an LBT technique, in which a device (either an access point or a user device) must listen for an interval of time and verify that no other device is using the channel before starting to "speak." The device speaks for a specified maximum period of time, then stops. It needs to listen again before beginning to "speak" again. If the channel is in use, the device waits a random period of time and then listens again. If the channel is still busy, it waits a multiple of that period of time, then listens again, with the period increasing with each wait.

The LBT technique provides an equitable sharing of the spectrum—essentially an electronic code version of multiple-direction stop signs on city streets.

The rules for use of the 5 GHz spectrum are different in different countries, however, and LBT is not required in the United States, India, South Korea, and China. (It is required in Europe and Japan.) Not surprisingly, the LTE-U industry is approaching development of 5 GHz technologies differently depending on country requirements.

In the United States, the industry plans to deploy LTE-U without LBT in early 2016. In countries that require LBT, the industry is planning to deploy LAA—another variant of LTE that uses unlicensed spectrum and that employs LBT.[126]

Instead of LBT, LTE-U uses the following approach:

1. Sensing to -62 dBm[127] which channels are in use, then using open channels[128]
2. If all channels are in use, selecting one or more channels and beginning transmission

[126] LAA-LTE will not be standardized until LTE Release 13 is competed in early 2016.
[127] Energy levels in this report are measured over the 20 MHz channel.
[128] Jindal, p. 2.

3. Operating with a proprietary, device-specific "duty cycle" in which the LTE-U eNodeB (eNB)[129] operates for a given period of time, shuts off, then continuously repeats the cycle

In terms of the "stop sign" metaphor, LTE-U is a technology that drives through the stop sign—perhaps stopping, perhaps not, and in any case, taking no heed of other vehicles on the road.

LAA devices differ from LTE-U devices in that they are being designed to use LBT. LAA devices are proposed to operate as follows:

1. Sensing to -60 dBm which channels are[130] in use, then using open channels

2. If all channels are in use, selecting one or more channels and listening to -60 dBm

3. If the channel appears to be clear, waiting and beginning to transmit; if the channel is not clear, waiting for a period of time, then transmitting when clear

The LAA technology, then, stops at the stop sign. However, its behavior at the stop sign is not necessarily the Wi-Fi behavior, but potentially more aggressive, using other approaches still permitted by the European Telecommunications Standards Institute. These approaches include, rather than an exponentially increasing back-off interval, a fixed interval dependent on the maximum transmit time (known as frame-based equipment, or FBE), and an approach with a fixed back-off interval that, if energy is detected, increases with a factor of a random number times the interval (known as load-based equipment, or LBE).[131]

If the LAA approach is, on balance, more aggressive than the Wi-Fi approach, the analogy to the stop sign is that, rather than waiting its turn, the LAA user stops—but then simply goes through immediately or very shortly after stopping, regardless of who is there or how long they have been waiting.[132]

3.3 Current LTE-U Technologies Will Not Coexist with Wi-Fi

Monte Carlo simulations using the LBE approach preferred by LAA manufacturers show cause for concern when LBE devices share a channel with Wi-Fi devices in a highly congested

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[129] ENodeB (eNB) is the LTE terminology for a base station or cell site.

[130] Based on ETSI LBT requirements, Jindal p. 4-5.

[131] Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive, ETSI EN 301 893 V1.7.1 (2012-06), https://www.etsi.org/deliver/etsi_en/301800_301899/301893/01.07.01_60/en_301893v010701p.pdf, accessed February 2, 2016, p. 23-4.

[132] Moreover, since the proposed listen sensitivity is lower than likely Wi-Fi signals, the LAA driver is also in a vehicle with an obstructed view.

environment: Because of their more aggressive approach to "sharing" the channel, Wi-Fi devices are 88 percent less likely to have the ability to transmit packets, relative to an environment with two Wi-Fi nodes.[133]

Another potentially critical issue is that the sensitivity of the LTE-U and LAA devices is lower than that of Wi-Fi devices. The LTE-U and LAA devices only implement their sharing behavior (i.e., channel selection, duty-cycling, LBT) when they detect signals. Wi-Fi detects signals down to -62 dBm and detects Wi-Fi preambles down to -82 to -90 dBm. LTE-U and LAA only detect down to -60 dBm.[134] LTE-U and LAA, with this lower sensitivity, would thus "talk" in the presence of weak Wi-Fi signals when Wi-Fi would listen and back off.

This type of scenario might happen if a Wi-Fi access point were indoors or in a vehicle[135] and the LTE-U eNB were outdoors—the Wi-Fi devices would detect LTE-U communications and keep quiet, while the LTE-U devices would seize the spectrum, oblivious to the Wi-Fi devices attenuated by the vehicle or building walls. The same scenario might happen outdoors toward the edge of a Wi-Fi access point coverage area, diminishing the effective range of the Wi-Fi access point. (A large majority of Wi-Fi communications occur at less than -60 dBm received power, so this could become a common occurrence.)

There is a healthy level of debate and innovation around LTE-U/Wi-Fi coexistence. Advocates for LTE-U point to a theoretical increase in the utilization of unlicensed spectrum if *only* LTE-U devices use the channel instead of Wi-Fi. However, this increase can only be attained if the current world of user-owned equipment is replaced by equipment that requires a licensed service provider to operate, and requires the user to subscribe to that provider's service.

The LTE-U Forum conducted a series of tests that show this efficiency and also claim to show that LTE-U is a "better neighbor" to Wi-Fi than another Wi-Fi hotspot.[136] However, other researchers identify many parameters that are not investigated in that test, such as different brands of Wi-Fi devices, effect on low signal-level Wi-Fi communications (which constitute a large majority), different parameters other than throughput, and different traffic models, including latency sensitive and multimedia communications, mixtures of indoor/outdoor devices, and mobility.[137] Further work is required and underway.

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[133] Joey Padden "Wi-Fi vs EU LBT: Houston, we have a problem," CableLabs, http://www.cablelabs.com/wi-fi-vs-eu-lbt-houston-we-have-a-problem/, accessed February 2, 2016.
[134] Jindal, Appendices 1 to 3.
[135] GM Beijing, p. 4-5.
[136] LTE-U Forum Technical Report.
[137] Jindal, Wi-Fi Alliance Beijing, GM Beijing.

In particular, there are characteristics of Wi-Fi that are particularly vulnerable to interruption by LTE-U. For example, an LTE-U or LAA device interrupting a Wi-Fi transmission in midstream may be interpreted as a diminishment of signal quality (comparable to an increase in distance or RF attenuation due to a wall or other barrier) and the device may go into a slower mode to compensate.[138] Also, frequent interruptions may keep devices and access points from hearing "beacon" signals, causing devices to disconnect from access points.[139]

Frequent interruptions can render Wi-Fi connections useless for video or voice communications.[140] In the scenarios described below, the real-world effect may be a persistent dropping of communications to computers in a school, in a public safety vehicle, or in a Smart City implementation.

Furthermore, barring requirements in the standards, LTE-U devices can be very effective tools in a carrier strategy to deliberately cripple Wi-Fi use, in the event that carriers wish to do so. At the moment many wireless carriers that are planning to use LTE in unlicensed spectrum also use Wi-Fi, respect Wi-Fi as an important part of the network ecosystem, and do not seem inclined in this direction. However, as was the case with carriers blocking or disrupting applications using deep packet inspection and other evolving technologies, a technological capability may create a significant temptation toward using that capability to undermine competitors.

[138] Jindal, p. 8-11, LTE-U Forum Annex C.
[139] Jindal, p. 12-13.
[140] Jindal, LTE-U p. 11, LTE-U Forum Annex D.

4 LTE-U Interference Threatens Local Governments' Operations and Innovation, and Will Affect Citizens' Daily Lives

Three major scenarios demonstrate how the loss of reliable Wi-Fi can greatly reduce the effectiveness of existing local government systems and create uncertainty and increased cost in new systems:

1. **In-building communications**, where Wi-Fi has become the universal means of connecting computers, tablets, video devices, and the IoT ecosystem. Local governments, schools, businesses, and citizens depend on Wi-Fi for broadband connectivity. Most notably, billions of dollars are being invested creating a robust Wi-Fi environment in schools—an environment that is predicated on a predictable and reasonable level of radio frequency interference from other devices—which would have to be entirely re-engineered and retrofitted if LTE-U devices effectively jammed the systems.

2. **Outdoor communications**, where an existing environment of public safety cameras and public access is rapidly being joined by wireless access points to enable local government staff access and the evolving Smart City environment.

3. **In-vehicle communications**, where Wi-Fi aggregates signals from devices within and near a vehicle to a mobile data router connected to commercial wireless providers (and, in the future, the nationwide FirstNet public safety network). In-vehicle wireless has become an organizing center to connect a growing range of first responder, public safety, and local government field devices, which otherwise would each require an individual cellular device.[141]

We describe these use cases below.

4.1 In-Building Environment

The original use of Wi-Fi was indoors and this remains the majority of its use. Individuals take for granted that they will be able to connect to Wi-Fi in their school, business, or home just as they would expect to be able to plug into power.

From a government perspective, it is now typical for each employee or student to have a computer device, for that device (or devices) to be a laptop or tablet and/or phone, and for

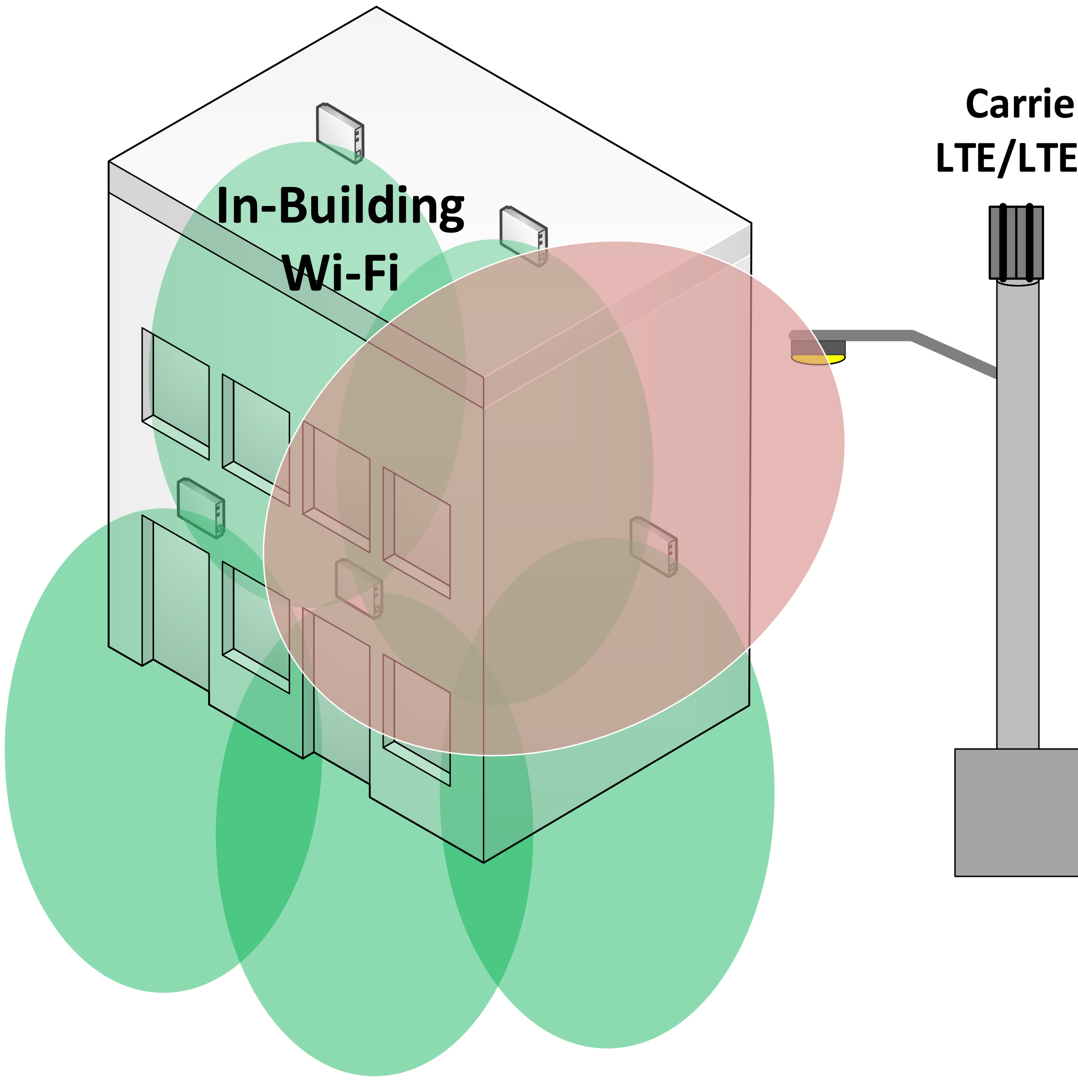
[141] Even in the planning of the FirstNet public safety mobile broadband network, which operates over 700 MHz licensed spectrum, the general concept of operations is for in-vehicle devices to continue to be aggregated via Wi-Fi through a mobile router.

individuals to be able to have ubiquitous coverage for their devices in the building. Wi-Fi is optimized for this level of coverage and for increasing speeds.

K-20 schools are part of this trend, with one-to-one learning, electronic textbooks, and Internet access crucial for learning and testing. Connectivity is required for text, images, and video. Schools are no longer wired to the classroom for conventional television—video is provided in an IP format, over Wi-Fi. Notably, the federal E-rate funding program has a significant focus on Wi-Fi as the final link to the student or teacher.

The widespread use of indoor Wi-Fi may be impacted by both indoor and outdoor LTE-U microcells and picocells and user devices. Therefore a crucial use case is indoor Wi-Fi, for the full range of current and future applications, and how those applications are affected by LTE-U technologies. This would require testing in high-density situations, with the LTE-U eNB and user devices installed both outdoors (for example, on utility poles directly outside the building) and indoors (Figure 1).

Figure 1: Potential Overlap of LTE-U and Wi-Fi in In-Building Environment



It is necessary to determine the degree to which throughput decreases, video is impacted, devices disconnect from Wi-Fi access points, and performance and reliability are affected—and the likely cost of remediating the problems.

Given that the implementation of Wi-Fi in a building may be an investment of tens or hundreds of thousands of dollars, the retrofit or enhancement of a network may be costly. Moreover, carrier implementation of LTE-U and LAA will be an ongoing project, so a likely outcome will be a costly and important project for each government or school building, which will require constant attention.

4.2 Outdoor Environment

Increasingly cities are relying on Wi-Fi to communicate with devices outdoors. This is generally as a complement to other communications technologies, including land mobile push-to-talk radio, cellular voice, and licensed mobile broadband (both commercial and the emerging FirstNet network). However, the proven performance of Wi-Fi has made it a new choice for connectivity. Moreover, the foreseeable increase in the number of devices makes Wi-Fi or other unlicensed technologies a logical choice as an aggregation tool for the connection to a fiber network or cellular device.

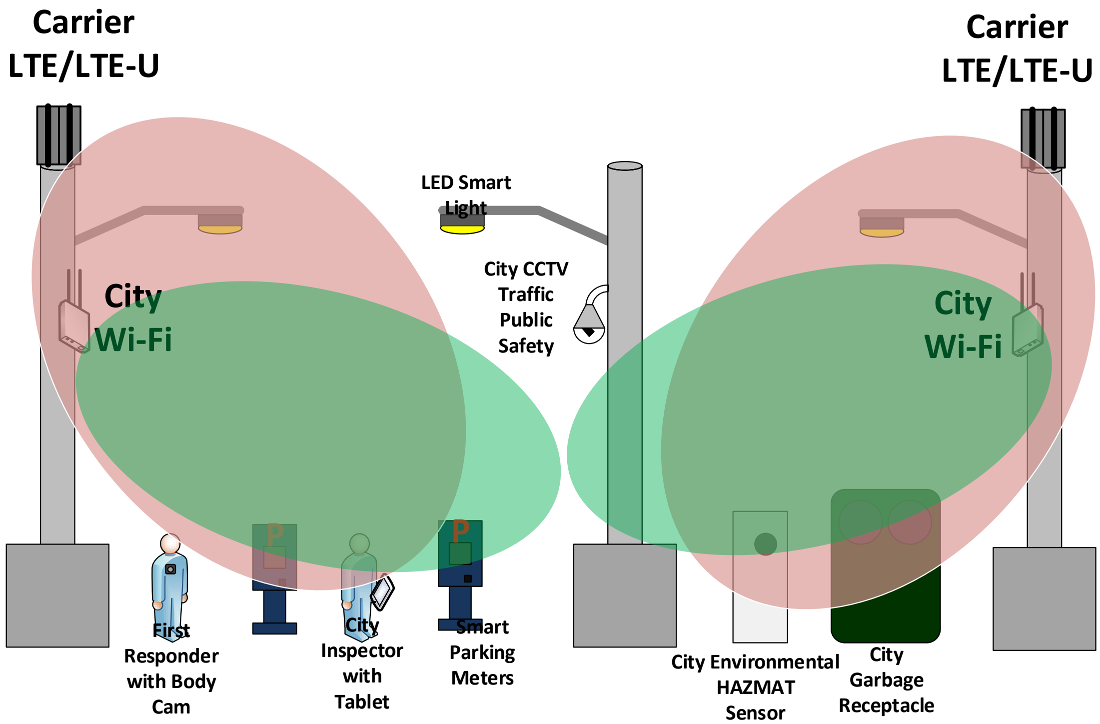
Although fiber provides great bandwidth and reliability, it is too costly to bring to a huge number of devices, and impractical to use to connect to devices that may be temporary or mobile. In this way, Wi-Fi is an ideal extension cord from fixed infrastructure. And while commercial licensed wireless communications can provide flexibility and connectivity, such services can become costly with a large number of devices. Moreover, connecting each device through a commercial network has disadvantages for local governments—there is less visibility into the network, for example, and less ability to manage capacity, prioritize public safety or other critical communications, or ensure continuity of service if private sector infrastructure is damaged.

One critical case study for LTE-U/Wi-Fi coexistence, from the government perspective, is to understand how the placement and operation of LTE-U devices will impact the operation of current and future government communications, including the growing range of Smart City applications. The current approach to outdoor LTE-U deployment is to place microcells on utility poles and on streetlights, where they are in close proximity to local government Wi-Fi access points and the local government devices using Wi-Fi.

Figure 2 **Error! Reference source not found.**illustrates the potential overlap of the LTE-U (red) and Wi-Fi (green) communications. In a congested urban environment, there may be 60 to 100 Wi-Fi devices per access point and 20 to 50 access points per 20 MHz channel.[142] Local governments need to understand whether and how LTE-U will reduce the effectiveness and reliability of Wi-Fi, both in order to properly run their networks and to make appropriate technology choices and budgets for Smart City deployments.

[142] Cable Beijing, p. 17.

Figure 2: Potential Overlap of LTE-U and Wi-Fi in Outdoor Environment



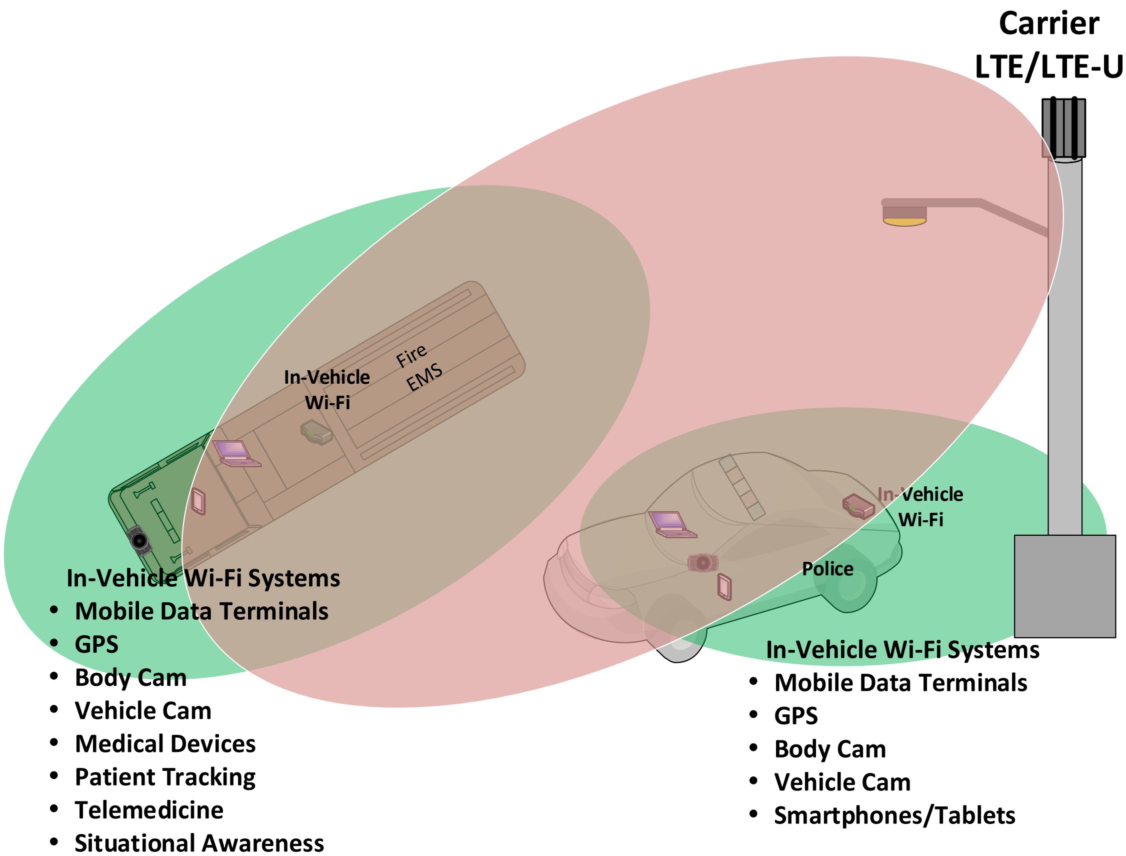
4.3 In-Vehicle Environment

One of the significant uses of Wi-Fi by governments is in vehicles. Wi-Fi provides a local bridge between the vehicle access point and an increasing variety of devices. A police vehicle may have a mobile data computer, a video camera, a GPS tracker, intrusion detection, and other sensors. The officer in the vehicle may also have a body camera or tracking device and may connect a smart phone. A fire vehicle or ambulance environment is similar, but it may also have medical devices, multiple mobile data computers, triaging devices, and vital signs detection for responders. In addition to first responders, other local government staff in municipal vehicles have tablets for recording inspections, digital cameras, and electronic test equipment.

All of these devices are typically bridged thought a mobile data router in the vehicle that connects over a mobile broadband network on licensed frequencies. Large data transfers (e.g., archived video, device updates and backups) may be done through Wi-Fi, connecting with access points outside the vehicle.

The mobile Wi-Fi use case is more complex than the outdoor case (see Figure 3). Devices move in and out of LTE-U coverage areas. The vehicle reduces the ability of the LTE-U eNB to detect the Wi-Fi hotspot. And individuals in the vehicle may have phones or devices that communicate over LTE-U, further increasing the potential for interference.[143]

Figure 3: Potential Overlap of LTE-U and Wi-Fi in In-Vehicle Environment



143 GM Beijing.

5 LTE-U Technologies Should Be Tested, Refined, and Standardized to Ensure that LTE-U Coexists with Wi-Fi—and to Protect Local Government Interests and Innovation

Because of its potential for shutting down Wi-Fi transmission in the 5 GHz bands, LTE-U may seriously impact local government operations, as well as consumers who take for granted that Wi-Fi will allow them to use their laptops or tablets, anywhere in their homes or businesses, and that they can stream video to a TV without wires. LTE-U interference may also make it more challenging for students to effectively use school Wi-Fi—critical now that schools have invested heavily in Wi-Fi to connect the last 100 feet to the student for one-to-one learning and cloud access.

LTE-U interference could have the same effect in an office or industrial environment, where it can impact computers, security cameras, sensors, and office automation. Such interference could also disrupt in-vehicle Wi-Fi, which would have a critical impact on public safety communications.

From the local government perspective, too, LTE-U interference could slow deployment of Smart City devices that rely on Wi-Fi for the last link to the parking meter, sensor, camera, or tablet—and drive up costs by forcing cities to pay for licensed assisted access (LAA) or commercial wireless broadband technologies for each individual device.

There are many contradictory technical conclusions regarding LTE-U interference with Wi-Fi, because 1) metrics, criteria, and test environments are not consistent, and 2) there is insufficient testing in critical use cases for government and public use.

The LTE-U Forum published a test report[144] claiming that an LTE-U eNB is a "better neighbor" than a Wi-Fi hotspot—but that claim is based on only one parameter (throughput), one type of Wi-Fi hotspot, and a limited set of use cases in laboratories. In addition, the LTE-U Forum tests are based on early versions of the equipment that may not match the versions actually deployed. Without further clarification and testing we cannot assume the production versions will have the same results, unless the adopted LTE-U standard incorporates the settings of the test (including duty cycle, on-off time, and the method of seeking unused 5 GHz channels).

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[144] "LTE-U Technical Report Coexistence Study for LTE-U SDL v1.0 (2015-02), LTE-U Forum: Alcatel-Lucent, Qualcomm Technologies Inc., Samsung Electronics & Verizon, http://www.lteuforum.org/uploads/3/5/6/8/3568127/lte-u_forum_lte-u_technical_report_v1.0.pdf, accessed November 17, 2015, (LTE-U Technical Report)

The LTE-U Forum's report is in many cases at odds with another study of simulations performed by 3GPP. The 3GPP study also simulated performance of VoIP applications and a wide range of metrics, and evaluated coexistence under various levels of listening sensitivity and wait intervals.[145]

The LTE-U Forum testing is not fully reflective of reality—focusing as it does on an idealized world where the efficiency of a chosen technology is essentially tested in a vacuum. In the real world, Wi-Fi exists and LTE-U will suddenly appear—so the testing should focus on how to proceed from the current environment to get a workable outcome for all users.

The LTE-U Forum is focused on the industry's needs, not the need for coexistence in unlicensed spectrum. The LTE-U Forum and its testing seeks to help wireless carriers make a choice about their own deployments (i.e., carrier Wi-Fi versus carrier LTE-U); it is not focused on local government network operators or other important users who are not wireless carriers with licensed spectrum.

There is a way to avoid LTE-U being deployed in a destructive way and to stay with the precedent set by other users in unlicensed bands (e.g., Bluetooth, ZigBee). This is for the LTE-U Forum to present LTE-U technology to a standards body to perform the testing and make the adjustments needed to make it possible for LTE-U, Wi-Fi, and other technologies to coexist. Such coexistence would follow the recommendations made by the technology and wireless user communities, with particular emphases on risks to government, public safety, and educational needs.

Many in the wireless industry have suggested approaches to a more complete testing regimen in a standards setting rather than through limited closed groups, as well as approaches to coexistence that better accommodate Wi-Fi and other existing technologies. We agree that such approaches would better protect local governments and their constituents. These approaches should include:

1. Establishing a neutral test environment, where different models of equipment can be transparently tested, with common assumptions, to demonstrate what works and what does not work[146]—using real LTE equipment, not simply signal generators simulating the equipment, with real on-off intervals and real sensing of channel usage and transmission. (At present, only LTE-U vendors have access to equipment for testing.)

[145] 3GPP TF 36.889, p. 73.
[146] IEEE Beijing, p. 50-53.

2. Allowing sufficient time to perform tests to finalize the standards, and for the standards to be finalized before carriers deploy the equipment.

3. Increasing the sensitivity so that Wi-Fi base station levels are detected and spectrum sharing activated lower than -62dBm. IEEE suggests Energy detection (ED) less than -77 dBm or preamble detection at -82 dBm and energy detection at -62 dBm.[147]

4. Using an LBT mechanism for access to the spectrum in all environments—even though it is not required by regulations in the U.S.

5. Adjusting the listening interval before talk to better harmonize with Wi-Fi 802.11-like processes, such as Category 4 LBT defined by 3GPP.[148]

6. Considering how using the UNII–II spectrum band and other potential spectrum can help solve the problem of limited spectrum (i.e., if LTE-U is a reaction to spectrum scarcity, consider ways to increase the spectrum without blocking current users of unlicensed spectrum).

7. Incorporating the technological advantages of the LTE-U protocol into a version or technology that does not require coordination through a licensed band—enabling the general public to be operators as well as users, and enabling the benefits of LTE technology to make their way into the Wi-Fi roadmap.

8. Considering other modifications that may emerge based on the testing—for example, modifications to enable Wi-Fi to continue to deliver latency-sensitive traffic and maintain its availability, such as including an effective listening interval or gap inside LTE-U transmission intervals—or making the LTE-U duty cycle more consistent with Wi-Fi.

[147] IEEE Beijing, p. 21.

[148] 3GPP TR 36.889 V13.0.0 (2015-06), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Licensed-Assisted Access to Unlicensed Spectrum; (Release 13), http://www.3gpp.org/DynaReport/Meetings-R1.htm#R1-81, accessed November 18, 2015, p. 73., with Category 4 defined on p. 53.