ASSESSMENT OF THE FUTURE ECONOMIC VALUE OF UNLICENSED SPECTRUM IN THE UNITED STATES

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Telecom Advisory Services, LLC

Authors

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Telecom Advisory Services LLC (TAS) is an international consulting firm specialized in providing high-level consulting services in business, policy, and financial strategies to telecommunications and technology companies, governments and international organizations. Its clients comprise some of the largest private sector telecommunications and technology companies in the world, ands international organizations such as the International Telecommunication Union, the World Bank, the United Nations Economic Commission for Latin America, the GSMA, the FTTH Council (Europe), and the Corporación Andina de Fomento. TAS has also provided consulting services to the governments of Colombia, Mexico, Costa Rica, Peru, Ecuador, Brazil, and United Arab Emirates.

This study was commissioned by Wi-Fi Forward, an ad hoc, broad-based group of companies, organizations and public sector institutions working to alleviate the Wi-Fi spectrum crunch and to support making Wi-Fi even better by finding more unlicensed spectrum. The author is solely responsible for the views and content of the study.

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EXECUTIVE SUMMARY

A recently completed paper by this author[1] provided an estimate of the economic value of unlicensed spectrum in the United States. The estimate was based on the adoption of technologies relying on unlicensed bands as of the end of 2013, which, by definition, comprised only widely adopted technologies, such as Wi-Fi and RFID. The study concluded that the technologies currently operating in unlicensed spectrum bands in the United States generated a total economic value of $222.4 billion in 2013 and contributed $6.7 billion to the nation's GDP. However, the study did not make an estimate of unlicensed spectrum's **future** economic value. An approximation to this question is critical when considering future designation of unlicensed bands. The estimate of future economic value is based on two drivers: 1) future adoption of technologies that are already widely diffused (for example, tablet worldwide shipments, currently at 221 million, are estimated to reach 386 million by 2017), and 2) deployment of emerging innovations, such as machine-to-machine communications and agricultural automation.

We estimate that the combined value of these two drivers in the United States by 2017 amounts to at least $547.22 billion in economic surplus annually and $49.78 billion in contribution to the annual GDP (see Table A).

Table A. United States: Summary of Future Economic Value of Unlicensed Spectrum (2013-2017) (in US$ billions[2])

Drivers	Technologies and Applications	Economic Surplus		GDP Contribution	
		2013	2017	2013	2017
Future value of currently deployed technologies and applications	Wi-Fi Cellular Off-Loading	$ 12.60	$ 22.83	$ 3.102	$ 7.033
	Residential Wi-Fi	$ 36.08	$ 268.74	N.A.	N.A.
	Wireless Internet Service Providers	N.A.	N.A.	$ 1.439	$ 4.80
	Wi-Fi Only Tablets	$ 42.87	$ 47.99	N.A.	N.A.
	Wireless Personal Area Networks	N.A.	N.A.	$ 2.166	$ 1.652
	RFID	$ 130.87	$ 191.46	N.A.	N.A.
	Subtotal	$ 222.38	$ 531.02	$ 6.778	$ 13.485
Value of not yet adopted applications and technologies	High-Speed Wireless		N.A.		$ 4.81
	Machine to Machine		N.A.		$ 31.49
	Smart City deployments		$ 15.1		$ 0.79
	Agriculture automation		$ 1.10		N.A.
	Subtotal		$ 16.20		$ 36.30
Total		$ 222.38	$ 547.22	$ 6.78	$ 49.78

Source: TAS analysis

[1] Katz, R. (February 2014). *Assessment of the economic value of unlicensed spectrum in the United States*. New York, NY: Telecom Advisory Services.

[2] All currency throughout the paper in US dollars, even when it is in reference to global markets.

These values reflect the substantial increased adoption of technologies that have been already widely diffused.

Wi-Fi cellular off-loading: The growth in economic value of cellular traffic off-loading from 2013 to 2017 is driven by an increase in consumer surplus resulting from a seven-fold increase in Wi-Fi traffic across devices, particularly tablets. In addition, the value of cellular off-loading includes the producer surplus resulting from the investment avoidance of cellular carriers that rely on Wi-Fi to complement their networks[3]. On the other hand, the contribution of traffic off-loading to the GDP will increase between 2013 and 2017 as a result of growing utilization of faster Wi-Fi networks (an effect labeled "economic return to speed"), an increase in WISP subscribers (typically located in rural areas not covered by wired broadband networks), and an expansion of the public Wi-Fi service provider business.

Residential Wi-Fi: The primary driver of the increase in economic surplus in residential Wi-Fi results from the explosive adoption of home devices and the corresponding growth in traffic per unit, coupled by the avoidance of in-house wiring investment in a larger installed base of home Wi-Fi equipment.

As discussed in our recently completed paper, tablets are, by definition, primarily Wi-Fi devices (90% of units are not connected to the cellular network) and they lack the capability to connect to the Internet through a wired Ethernet port. Between 2013 and 2017, the installed base of tablets in the United States is projected to grow from 61 million to 190 million, while the unit traffic is expected to grow from 6.33 Gb per month to 35.38 Gb per month[4]. Considering that 43% of the traffic generated by tablets originates at home, the total annual tablet-originated traffic in 2017 will amount to 34.78 billion Gb, growing from 2.01 billion Gb in 2013. Even considering a decline in pricing per Gb transported by cellular networks ($7.61 in 2013 to $6.15 in 2017[5]), if the exponential tablet traffic growth were to rely on cellular networks, it would represent a value of $248.36 billion, an amount saved by relying on Wi-Fi.

With regard to in-house wiring investment avoidance, it is estimated that by 2017, an estimated 83% (or 105 million) of U.S. homes will be equipped with Wi-Fi. Assuming a constant investment of $190 per house, this results in cost savings of $20.35 billion since Wi-Fi provides an approach to supporting the connectivity of home devices.

Wi-Fi only tablets: Wi-Fi only tablets also represent a source of growth in economic value of unlicensed spectrum. In the section above, consumer surplus was estimated

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[3] Since the estimation of 2013 producer surplus was based on the savings incurred by deploying carrier-grade Wi-Fi to complement the full rollout of LTE to support future traffic growth, we have included in the 2017 estimate the producer surplus calculated in the 2013 figure.
[4] *Source: Cisco Visual Networking Index.*
[5] See cellular price forecast model in Katz (2014).

in terms of the savings incurred by U.S. consumers that do not need to rely on cellular networks to connect their devices (smartphones and 3G or 4G-enabled tablets) to the Internet because they use Wi-Fi access. Beyond this, additional economic value is being originated by the margin generated by tablet manufacturers selling their Wi-Fi only products worldwide as well as the consumer surplus calculated by the difference between consumers' willingness to pay and actual prices of tablets. The last two areas are the ones estimated in this domain.

U.S. manufacturers are expected to preserve their global market share of 68% by 2017. Going forward, while LTE tablets will greatly enhance the performance of key tablet usage, the 802.11ac standard will partially overcome this substitution threat. As a result, the share of Wi-Fi only devices shipped in 2017 is expected to reach 82.5%, a slight reduction from 90% today. Likewise, as a conservative estimate, producer surplus and willingness to pay are considered to remain constant although learning curve and scale could yield lower costs and higher application selection could enhance consumers' willingness to pay for tablets. The resulting estimate points to an increase in economic surplus derived from Wi-Fi only tablets sold by U.S. manufacturers globally to rise from $42.87 billion in 2013 to $47.99 billion in 2017.

Wireless Personal Area Networks: Despite the significant increase in applications and shipped wireless devices (with the exception of PCs affected by tablet substitution and therefore will experience a reduction in shipments), total revenues to be generated by wireless personal area network chipsets are expected to decline in 2017 by $500 million from 2013. This is primarily due to the decline in chipset unit cost from $1 to $0.20, due to economies of scale and learning curve. Obviously, a reduction in GDP contribution should result in an increase in consumer welfare driven by the wide adoption of Bluetooth-enabled devices.

RFID in retailing and health care: Five-year forecasts of enterprise RFID equipment and service sales in the United States range between a 19% growth rate in retail apparel and 20% in the health care sector. Assuming a conservative increase in economic value of 10% through 2017, the continued implementation of RFID in the retail and health care industries will result in a total economic value of $191.46 billion by 2017[6].

In summary, the study of applications that have reached wide adoption and impact indicates that the value created by unlicensed spectrum bands, will increase from an economic surplus of $222.38 billion in 2013 to $531.02 billion in 2017, while its

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[6] In order to understand how conservative these estimates might be, research at Harvard Business School indicates that 8% of all retail items are out of stock at any given time, costing more than $69 billion annually to the U.S.US economy. RFID reduces the likelihood of out-of-stocks by 60% to 80% according to ABI Research, as earlier detection of store-level out-of-stocks allows for quicker replenishment of floor merchandise and backroom stock through the retailer's supply chain.

GDP contribution will grow from $6.78 billion in 2013 to $13.48 billion in 2017. That said, as noted by several academics, the innovation incentives generated by this enabling resource will result in the additional impact of still emerging technologies, such as the ones reviewed below.

High-speed wireless: The economic value of high speed wireless data transfer devices operating based on WirelessHD and WiGig technologies could be assessed through two approaches: 1) the value to consumers of gaining access to a technology that complements Wi-Fi in terms adding capability to the existing platform, or 2) estimating the revenues (and consequently GDP contribution) derived from unit shipments. In terms of revenue generation, as more consumer electronics products take advantage of rapid wireless transfer opportunities, annual shipment of high-speed wireless data chipsets is expected to increase significantly. Considering that WirelessHD represents 20% of the total wireless/video display market[7], we can project 2017 revenues to reach $0.69 billion. In addition, by 2017, WiGig chip unit shipments will exceed 1 billion, generating $4.12 billion in revenues.

Machine-to-Machine: Unlicensed spectrum bands are critical to the communication of devices equipped with microcontrollers in order to deliver applications in areas as diverse as environmental management (pollution/air quality monitors, weather stations, water level monitors), urban landscape (street lighting control systems, parking meters), and health care (dialysis machines, defibrillators, ventilators, pacemakers). Enhanced connectivity of devices via unlicensed spectrum could increase their ability to process information and interact with other terminals.

Our assessment of the economic value of machine-to-machine technologies focused on five areas: Advanced Meter Infrastructure, Security, Energy Demand Side Management devices, Telehealth, and wearables. Based on our projection of the total number of machine-to-machine connections, the 2017 market of technologies relying on unlicensed spectrum amounts to $27.8 billion[8]. Similarly, according to the projected diffusion of wearable devices, the U.S. market, currently estimated at $1.05 billion is expected to reach $3.69 billion by 2017.

Smart City deployments: Cities rely on wireless sensor networks to improve municipal management. When these networks are deployed, intelligent sensors can measure many parameters for a more efficient management of a city. Relevant data is delivered wirelessly and in real time to citizens or the appropriate authorities. Smart City applications using wireless sensor networks include the following:

- Citizens can monitor the pollution concentration in each street of the city or they can get automatic alarms when the radiation level rises a certain level;

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[7] Silicon Image, Inc. a leader in WirelessHD appears to generate approximately $132 million in manufacturing and licensing revenues of High Definition wireless chipsets.

[8] Note: To avoid double counting with Zigbee applications addressed in above, we subtracted $835.4 million from the total M2M market.

- Municipal authorities can optimize the irrigation of parks or the lighting of the city;
- Water leaks can be easily detected or noise maps can be generated;
- Vehicle traffic can be monitored in order to modify the city lights in a dynamic way;
- Traffic can be reduced with systems that detect the nearest available parking space; and
- Motorists can get timely information so they can locate a free parking space quickly, saving time and fuel. This information can reduce traffic jams and pollution, while improving the quality of life.

Beyond these effects, Smart Cities can deliver a number of indirect effects in terms of economic growth, competitiveness, and a better quality of life for its citizens. In order to provide some estimates of the economic value derived from the deployment of Smart City infrastructure, it is necessary to break down its multiple benefits. For example, the monetized value of traffic congestion in U.S. cities amounts to approximately $31 billion in public health losses, and $60 billion in wasted time and fuel[9]. While these costs can be addressed through multiple policy initiatives such as congestion pricing and adding highway and public transit capacity, two approaches enabled by wireless sensors relying on unlicensed spectrum -- traffic light synchronization and more efficient response to traffic incidents -- can be positive contributors. Under certain conditions (Pantak, 2013), traffic light synchronization reduces congestion by up to 10% and air pollution up to 20%. This would result in an added economic benefit of $15.1 billion only from the so-called "mobility bonus." In addition to environmental gains, Smart Cities contribute to economic growth. Efficient transportation and improvements in quality of life can attract economic activity to cities, and boost productivity. For example, Shapiro (2005) found that 40% of employment growth in U.S. metropolitan areas is due to improvements in the quality of life, which is partly driven by the deployment of wireless sensor technology.

Beyond the consumer surplus, it would be useful to isolate the value of Smart City sensor technology on the basis of the contribution to GDP of the revenues generated by infrastructure sales. While we recognize this to be a significant underestimation of total economic value, the market research IDTech estimates the global wireless sensor network market to be $450 million, reaching $2 billion in 2021, of which the United States represents 72%. This results in a 2017 GDP contribution of approximately $793 million.

Agriculture automation: Precision agriculture represents a systems-based approach for site-specific management of crop production systems. Efficiency of agricultural machinery is linked to deployment of sensors (grain yield, optical

[9] See Levy et al. (2010) and Schrank (2007).

sensors for weed detection, and control systems for fertilizer spreading) linked to standardized bus systems to transmit data streams. The United States in 2013 had a total of 325 million crop acres, within which the adoption of precision agriculture is likely to reach 50% in 2017. Based on producer benefits of $28 per hectare measured in field research, the producer surplus of agricultural automation could reach $1.105 billion.

In sum, the annual economic value derived in 2017 from technologies operating in unlicensed spectrum bands that are still at the emerging stage of diffusion is estimated at $16.20 billion, also contributing to $36.30 billion to the nation's GDP. These estimates of economic value of future technologies are extremely conservative for several reasons:

- Because low frequency Wi-Fi has not yet been widely adopted, its economic value was not estimated;
- Although machine-to-machine technologies and applications hold enormous potential to facilitate the development of environmentally sustainable cities, the total economic surplus associated with these technologies and applications was not estimated. Only their contribution to GDP, based on unit sales, is reflected in the analysis; and
- The estimate of Smart City sensor networks was conducted only by measuring two areas of benefit derived from alleviating traffic congestion, and the contribution to GDP of infrastructure sales, excluding other sources of value resulting from enhanced citizen welfare.

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The conclusion of the study provides the sum of all future benefits derived from applications and technologies (both currently deployed and emerging), which rely on unlicensed spectrum in the United States. We estimate that the combined value of future diffusion of currently deployed technologies and adoption of emerging technologies in the United States amounts to at least $547.22 billion in economic value and $49.78 billion in contribution to the GDP, a significant increase from the 2013 estimate.

Furthermore, the study demonstrates that traffic from applications and technologies relying on unlicensed spectrum are growing at exponential rates:

- Wi-Fi cellular off-loading traffic is growing at 68% per annum;
- Residential Wi-Fi installed base will grow from 63% of households to 86% by 2017; and
- Average traffic per tablet is growing from 6.33 Gb per month in 2013 to 35.38 Gb in 2017.

In this context, several technological innovations are being developed with the purpose of increasing the efficiency of utilizing unlicensed spectrum. One is the development of full duplex technology in a single channel. The simultaneous use of an uplink and downlink in a single channel would result in a theoretical increase in spectrum capacity, although full deployment of this technology will not be fulfilled before five years. In addition, routers that support smart switching yielding more efficient band usage according to the environment in which communications takes place (high rise apartments requiring high frequency/low propagation versus low density houses) and type of communication (e.g. high bandwidth video streaming vs. low bandwidth device monitoring, such as HVAC) could add significant spectral efficiency.

However, technological advancements alone are not likely to sufficiently address the congestion points in the network. For example, without new spectrum designations, delivering metro (or muni) Wi-Fi will be very challenging in dense urban markets[10]. While traffic carried by public Wi-Fi hotspots has historically been a very small proportion of total wireless data traffic, a number of factors (ease of access, improved internetworking, roaming arrangements, and proliferation of Wi-Fi only devices like tablets) are driving growth in this sector. Research by Wagstaff (2009) and Van Bloem et al. (2011) indicates that in dense device environments, data overheads that are generated to keep connections running consume between 80% and 90% of capacity. In the context of increasing traffic volumes, Wi-Fi is becoming the congestion point in public access networks. According to Aegis (2013), carriers have registered Wi-Fi traffic growth in central city locations up to 6 times higher than on their cellular networks. In fact, this firm believes that in order to accommodate future traffic growth, public outdoor networks (access and meshing) would require 160 MHz of additional spectrum, while public indoor networks would require additional 100 MHz.

Likewise, within residences, network speed is limited by the number of the devices connected, particularly those that are video enabled. According to a study by Williamson et al. (2013), once an 80-100 Mbps broadband link is deployed to a customer premise, the last mile is not the bottleneck any more, while the residential Wi-Fi becomes the congestion point. This is because there is a difference between the advertised speed in a typical Wi-Fi router (150 Mbps) and the delivered speed, which is below 70 Mbps[11]. Along these lines, video traffic is putting considerable pressure on home routers resulting in degradation of streaming capacity. Given that

[10] Saturation is already occurring in the 2.4 GHz band in major urban markets, such as New York City); according to a CableLabs Study (Wi-Fi Spectrum: Exhaust Looms, Rob Alderfer, May 28, 2013), approximately 90 megahertz of W-Fi spectrum will be needed by 2015.

[11] The difference is due in part to the need to assign part of the capacity to the data overheads. In addition, advertised speeds are based on tests that rely on large packets, while the average packet size is much smaller. Finally, range and attenuation are factors to be considered in the reduction of speed. Williamson et al. (2013) estimate that delivered speed is approximately 50% of the advertised.

Wi-Fi shares available capacity across devices, if a typical Wi-Fi household is running multiple devices, the service will degrade and be substantially lower than what could be handled by an ultrafast broadband link.

Aegis (2013) has determined that in the long run (year 2024), access to up to 40 MHz of uncontended spectrum per household may be required. According to this firm, total spectrum requirement to support residential Wi-Fi traffic in this scenario would be up to 210 MHz by 2017. This is partly the result of the fact that the full migration to faster standards such as 802.11ac[12] will require approximately 10 years, which means that the spectrum crunch at the residential level will occur well before full adoption of the more efficient standard[13].

Future unlicensed spectrum designation scenarios have been evaluated in terms of their capability to alleviate any "choke points" derived from exponential traffic growth. First, the designation of the U-NII-4 spectrum for unlicensed use would alleviate future "choke points" of the network. A major goal for 5GHz is to free up the whole band– 5.150-5.925 GHz--so that large channels (80 MHz and 160 MHz) can be used. This portion of the spectrum will be valuable for small cell deployments, including metro Wi-Fi. Second, the designation of portions of the 3.5 MHz band to unlicensed use would alleviate future saturation points for several applications. The Priority Access tier could be very powerful if it enables real quality of service. However, in order for this band to become an effective remedy to saturation, changes in the technical rules for operation are critical[14]. Finally, the availability of additional unlicensed channels below 1 GHz would address future "choke points" for technologies, business models, or applications particularly suited to this lower frequency unlicensed designation. For example, the 600 MHz band could be quite suited to providing wireless broadband connectivity to rural areas and off-loading some residential Wi-Fi traffic. Considering the products that allow for optimization of band allocation, one could envision a residential scenario where low bandwidth applications running at the edge of the Wi-Fi site could be routed in the 600 MHz band (better suited for signal propagation), reserving 2.4 GHz spectrum or 5 GHz for video-streaming.

[12] The latest 802.11ac standard is intended to provide substantially higher speed and one of the ways this is achieved is via wider channels of 80 and 160 MHz Unlike 11n, a fall back to narrower channels on a per-frame basis is mandated in the 11ac draft standard, such that fairness of medium access is offered to legacy 20 and 40 MHz channel devices (Aegis, 2013).

[13] Full substitution of shipments from 802.11n to 802.11ac will be complete only in 2016, but transition at the user level has just started and is projected to end by 2018.

[14] As of now, the FCC proposes to exclude a portion of the national territory (coastal areas) for federal use (naval radar). This rule excludes approximately 60% of the U.S. population. Under this exclusion zone, the question to be raised is whether chipset and equipment manufacturers would consider that such a reduction of a key portion of the addressable market warrants the development of technologies in this band. Potential remedies for this scenario include either reducing the size of the exclusion zones or defining rules that enable commercial users to access the band whenever it is not being used by federal users bands.

What is the economic risk of not making further unlicensed spectrum available? There are three areas of benefit of unlicensed spectrum where the opportunity cost of not designating further bands can be quantified.

First, at the expected rate of traffic off-loading to Wi-Fi, the average speed of mobile traffic in the United States in 2017 would be 21.66 Mbps[15]. The benefit derived from the additional speed resulting from off-loading is what we call the Wi-Fi return to speed. However, if we assume that, due to congestion, the average Wi-Fi speed does not increase to 24 Mbps, as Cisco projects, but stays at current levels (15.43 Mbps), the average speed of all mobile traffic would not change significantly from today. Our analysis showed that according to this scenario, the average speed of wireless networks would decline to 14.05 Mbps, meaning that $ 4.4 billion in GDP would not be realized[16].

Second, existing unlicensed spectrum designations will not accommodate expected future in-home broadband demand. In-home broadband use is growing rapidly, and consumers rely heavily on Wi-Fi to connect a growing number of devices. Cisco predicts that the **average** busy hour traffic per household will be 1.51 Mbps in 2017.[17] But the average busy hour traffic for the top 10% of high-speed broadband users is five times higher than the average — suggesting that the average busy hour traffic for these households will soon be a huge 7.55 Mbps. The top 10% of users already account for 50% of total high-speed traffic[18] and are a strong predictor of what the typical household of tomorrow will demand. In addition to the need to distribute traffic generated by an external broadband connection, households will also require Wi-Fi spectrum to accommodate traffic generated by devices distributing video programming not streamed from the Internet within the house.[19] Assuming that a high-usage household is viewing simultaneously three HD video streams from sources other than the public Internet (and that each of them requires 8 Mbps of bandwidth), this would add 24 Mbps to residential needs. Summing up, the external Internet traffic (7.55 Mbps) and the off-net traffic (24 Mbps) would result in a total estimated traffic per household of 31.55 Mbps. Considering that a portion of that traffic will require data overheads, it is reasonable to assume that the high-usage household — which is our best indicator of the typical household of the future — will require approximately 20 MHz of spectrum by 2017. Total spectrum

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[15] This estimate prorates average Wi-Fi traffic speed, which Cisco predicts will rise to 24 Mbps, and cellular traffic speed, which Cisco predicts will rise to 14.05 Mbps. (source: Cisco VNI)).

[16] Difference between 21.66 Mbps and 15.43 Mbps multiplied by the impact of speed on GDP growth (Bohlin et al, 2012).

[17] According to Cisco VNI, the average busy hour traffic per household in 2017 will be 1.51 Mbps. This forecast represents average per household usage. As shown below, given the distribution of households across usage intensity, this number will be much higher for the top 10% of households.

[18] Source: OFCOM.

[19] A number of "wireless home theatre" products relying on Wi-Fi are being currently offered in several industrialized countries.

requirements are calculated by multiplying this value by 6 visible access points,[20] yielding 120 MHz.

Without more unlicensed spectrum, households will not be able to rely on Wi-Fi for this traffic. If policymakers do not designate additional spectrum for Wi-Fi use, it is reasonable to conclude that (for today's high-usage households and tomorrow's typical household) spectrum constraints would degrade Wi-Fi performance to the point that consumers would likely seek alternative methods of accommodating traffic. Such consumers may decide to deploy inside wiring rather than rely on Wi-Fi to deliver the broadband throughput they require. This costly and inefficient replacement would result in $2.0 billion in reduced savings derived from in-house wiring investment avoidance, assuming that 10% of U.S. households decide to wire their homes rather than rely on Wi-Fi. Additionally or alternatively, consumers may decide to increase reliance on more expensive cellular networks rather than Wi-Fi. Assuming that 5% of the $248.36 billion consumer surplus resulting from tablet reliance on Wi-Fi rather than cellular connectivity would be cancelled out, that would result in approximately $12 billion of value erosion. All in all, the negative impact of not gaining access to additional unlicensed spectrum for residential Wi-Fi usage alone would result in an erosion of $14 billion of the economic surplus stipulated for 2017.

A third area of negative impact under a scenario of limited unlicensed spectrum assignment is service degradation in public places (airports, convention halls, etc.). For example, no additional assignment of unlicensed spectrum could result in the potential disappearance of the Wi-Fi service provider industry since, with lower service quality level, these operators would not be able to compete with cellular service providers: an erosion of $468 million direct contribution to the GDP.

Based on the additional evidence generated in this study, we conclude that any policies focused on unlicensed spectrum must preserve the value generated so far, as well as the capacity to generate economic surplus in the future. Extending designated bands will be extremely beneficial to value creation. Furthermore, the emerging body of evidence of congestion within the unlicensed spectrum points out the risks of not extending the spectrum designated for unlicensed use.

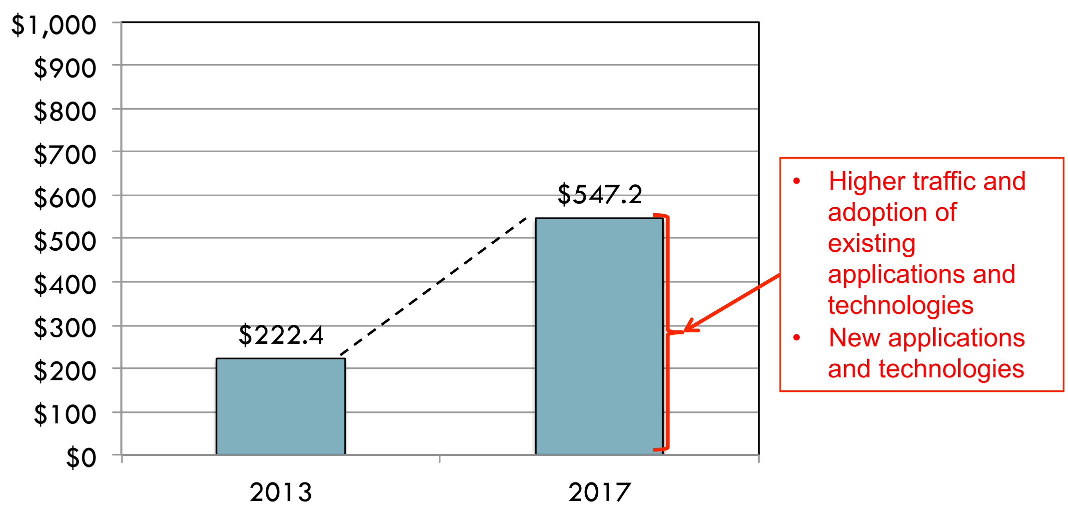
[20] Under this scenario, multiple access points are required to provide higher signal quality throughout a residence; Aegis (2013) estimates six per high usage dwelling.

I. INTRODUCTION:

A recently completed paper by this author[21] provided an estimate of the economic value of unlicensed spectrum in the United States as of 2013. The economic estimate was based on the adoption of technologies as of the end of 2013 and, by definition, encompassed only widely adopted technologies and applications (Wi-Fi cellular off-loading, residential Wi-Fi, wireless Internet service providers, Wi-Fi only tablets, Bluetooth, ZigBee, WirelessHART, and RFID applications in retailing and health care industries). The study concluded that the technologies currently operating in unlicensed spectrum bands in the United States generated a total economic value of $222 billion in 2013 and contributed $6.7 billion to the nation's GDP.

However, a question that still needs to be addressed, particularly in assessing whether to preserve or expand unlicensed spectrum designations, is how much value we can expect unlicensed technologies to contribute to the economy in the future. Such quantification is based on two drivers: 1) future adoption of technologies already widely diffused (for example, tablet worldwide shipments, currently at 221 million, are estimated to reach 386 million by 2017), and 2) adoption of emerging innovations, such as machine-to-machine communications and Smart City sensors (see Figure 1).

Figure 1. Current and Future Economic Value of Unlicensed Spectrum



Source: TAS analysis

Forecasting future value derived from current uses is relatively straightforward. It entails primarily projecting adoption curves, while estimating pricing trends and scale and/or learning effects on the cost side. On the other hand, estimating value derived from future innovations is not that easy. In the words of Milgrom et al., "the

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[21] Katz, R. (February 2014). *Assessment of the economic value of unlicensed spectrum in the United States*. New York, NY: Telecom Advisory Services.

primary benefits of unlicensed spectrum may well come from innovations that cannot yet be foreseen"[22]. As stated by several researchers, one of the fundamental dimensions of value of unlicensed spectrum is that of providing an environment conducive to the development of innovative technologies and business models[23].

The following study will tackle the two domains of current innovations and emerging applications and technologies. It begins by estimating the value to be derived by currently adopted innovations using the year 2017 as the anchoring point in time in the future. We chose this year as the prediction point because technology predictions that are more than three years out have limited value given the range of uncertainties regarding innovation and adoption pace. It then moves to the new technologies and applications. Part II presents the estimates of future value of current technologies, while Part III tackles the estimation of economic value of emerging technologies and applications that rely on unlicensed spectrum. A final conclusion will summarize all the estimates, aiming to yield a final future value for the specific metrics used in the prior study: surplus value and GDP contribution.

II. ASSESSMENT OF THE FUTURE VALUE OF UNLICENSED SPECTRUM BASED ON CURRENTLY ADOPTED TECHNOLOGIES AND APPLICATIONS

The February study referred to above estimated that the technologies operating in unlicensed spectrum bands in the United States generated a total economic value of $222.4 billion in 2013 and contributed $6.7 billion to the nation's GDP (see Table 1).

[22] Milgrom, P., Levin, J. and Eilat, A. (2011). *The case for unlicensed spectrum*. Stanford Institute for Economic Policy Research Discussion paper No. 10-036, p. 2.
[23] Milgrom et al., 2011, Thanki, 2012; Carter, 2006, among others.

Table 1. United States: Summary of Economic Value of Unlicensed Spectrum (2013) (in $ billions)

	Effect	Economic Value			GDP
		Consumer Surplus	Producer Surplus	Total Surplus	
Wi-Fi Cellular Off-Loading	Value of free Wi-Fi traffic offered in public sites	$ 1.902	N.A.	$ 1.902	N.A.
	Benefit of total cost of ownership required to support future capacity requirement with Wi-Fi complementing cellular networks	N.A.	$ 10.700	$ 10.700	N.A.
	Contribution to GDP of increase of average mobile speed resulting from Wi-Fi off-loading	N.A.	N.A.	N.A.	$ 2.831
	Sum of revenues of service providers offering paid Wi-Fi access in public places	N.A.	N.A.	N.A.	$ 0.271
	Subtotal	$ 1.902	$ 10.700	$ 12.602	$ 3.102
Residential Wi-Fi	Internet access for devices that lack a wired port	$ 22.510	N.A.	$ 22.510	N.A.
	Avoidance of investment in in-house wiring	$ 13.570	N.A.	$ 13.570	N.A.
	Subtotal	$ 36.080	N.A.	$ 36.080	N.A.
Wireless Internet Service Providers	Aggregated revenues of 1,800 WISPs	N.A.	N.A.	N.A.	$ 1.439
Wi-Fi Only Tablets	Difference between retail price and manufacturing costs for a weighted average of tablet suppliers	N.A.	$ 34.885	$ 34.885	N.A.
	Difference between willingness to pay for entry level tablet and prices of iPad and Android products	$ 7.987	N.A.	$ 7.987	N.A.
	Subtotal	$ 7.987	$ 34.885	$ 42.872	N.A.
Wireless Personal Area Networks	Sum of revenues of Bluetooth-enabled products	N.A.	N.A.	N.A.	$ 1.739
	Sum of revenues of ZigBee-enabled products	N.A.	N.A.	N.A.	$ 0.267
	Sum of revenues of WirelessHART-enabled products	N.A.	N.A.	N.A.	$ 0.160
	Subtotal	N.A.	N.A.	N.A.	$ 2.166
RFID	RFID Value in retailing	$ 26.26	$ 68.58	$ 94.84	N.A.
	RFID Value in health care	$ 4.03	$ 31.96	$ 35.99	N.A.
	Subtotal	$ 30.29	$ 100.54	$ 130.83	N.A.
TOTAL		$ 76.26	$ 146.13	$ 222.38	$ 6.707

Source: TAS analysis

Considering the fact that most of these technologies have already been widely adopted, it is fairly straightforward to estimate their contribution to the economic value of unlicensed spectrum in the United States in 2017.

II.1. The future value of Wi-Fi for cellular off-loading:

The economic value of Wi-Fi for cellular off-loading for 2013 was estimated in four areas:

- **Consumer surplus**: The difference between the consumer's willingness to pay and the price paid for the service; along these lines, if a consumer accesses the Internet in a public hot-spot for free, surplus would equate to the monetary value he would pay to a cellular operator for gaining equal access;
- **Producer surplus**: In light of the explosive growth in data traffic, wireless carriers operating in licensed bands deploy Wi-Fi facilities to reduce both capital and operating expenses while dealing with congestion challenges; since they monetize the Wi-Fi access they provide, surplus measures the difference in capital and operating expenses for the off-loaded traffic;
- **Return to speed**: Since Wi-Fi accessibility allows, in general, faster access to the Internet than cellular networks do, higher speeds have a positive contribution on the economy in terms of increased efficiency and innovation;
- **New business models**: Wi-Fi allows for the entry of service providers of paid Internet access in public places (such as Boingo and iPass); they generate new revenues that would not exist if unlicensed spectrum bands were not available.

The estimate of consumer surplus in 2017 is based on projecting total Wi-Fi traffic and factoring in the portion of it that is conveyed through public free and "guest" sites (see Table 2).

Table 2. United States: Total Free Wi-Fi Traffic (2013-2017)

		2013	2017
Total Wi-Fi Traffic (in Exabytes per month)			
	Smartphones	0.08	0.54
	Tablets	0.28	4.82
	Laptops	0.30	0.61
	Total	0.67	5.97
Total Free Traffic (in Exabytes per month)		0.03	0.26
Total Free Traffic (in Exabytes per year)		0.35	3.10
Total Free Traffic (in Gigabytes per year)		372.12	3,323.38

Source: Cisco; TAS analysis (Appendix 1)

Consumer surplus is calculated, in turn, by multiplying the total free traffic by the difference between what the consumer would have to pay if s/he were to utilize a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site) (see Table 3).

Table 3. United States: Consumer surplus of free Wi-Fi Traffic (2013-2017)

	2013	2017
Total Free Traffic (in million Gigabytes per year)	372.12	3,323.38
Price per cellular gigabyte ($)	7.61	6.15
Cost per Wi-Fi provisioning ($)	2.50	2.50
Consumer surplus per Gigabyte ($)	5.11	3.65
Total Consumer surplus (in $ million)	1,902	12,130

Note: Price per cellular gigabyte calculated by averaging the most economic "dollar per GB" plan of four major U.S. wireless carriers between 2010 and 2013 and extrapolating price decline curves
Source: TAS analysis

The estimate of producer surplus is based on the portion of capital investments (and potential incremental network operations and maintenance operating expenses) that service providers can avoid when they shift allocations from cellular network to carrier-grade Wi-Fi. Since the estimate for 2013 was based on the savings incurred by full deployment of carrier-grade Wi-Fi complementing the rollout of LTE to accommodate future traffic growth, we believe the 2017 producer surplus should be the same as the 2013 figure (see Table 4).

Table 4. Total Cost of Ownership of LTE Only Versus LTE+ Wi-Fi Off-Load

	LTE Only	LTE + Wi-Fi Off-Loading	Delta %/$
Total CAPEX	$ 8.5 billion	$ 5.7 billion	32.9 %/$ 2.8 billion
Total OPEX (*)	$ 48.7 billion	$ 40.8 billion	16.2 %/ $ 7.9 billion
TCO	$ 57.2 billion	$ 46.5 billion	18.71 %/$ 10.7 billion

(*) Opex to capex ratios assumed from LCC San Diego case
Source: LCC Wireless (2012); Thanki (2012); TAS analysis

To measure the economic value of Wi-Fi speed, our analysis focused on measuring the speed of wireless networks by 2017 if they did not have faster Wi-Fi technology as a complement. In this case, we considered the total traffic without differentiating between points of access (residences or public places). Our analysis begins by quantifying the speed differential between average cellular and Wi-Fi access. By factoring offloading effects in relation to cellular we can then understand speed increases and apply the Bohlin et al. (2013) model to estimate the impact of increased speed on GDP[24] (see Table 5).

[24] For a full description of methodology, see Katz, R. (February 2014). *Assessment of the economic value of unlicensed spectrum in the United States*. New York, NY: Telecom Advisory Services. February.

Table 5. Estimate of Speed Differential for Total U.S. Traffic (in megabits per second) (2013-2017)

	2013	2017
Average speed of cellular networks (Mbps)	3.43	14.05
Average Wi-Fi speed (Mbps)	13.32	24.00
Average speed of weighted average of cellular and Wi-Fi traffic	10.15	21.60
Speed decrease (average speed of cellular/average weighted average speed)	-66.21%	-34.96%
Model coefficient	0.30%	0.30%
Decrease in GDP per capita	-0.20%	-0.10%
GDP per capita (current prices)	51,248	61,134
Wi-Fi Traffic (% Total Traffic)	8.79%	31.37%
GDP Reduction (in $ millions) (current prices)	-2,831	-6,565

Note: Detailed model and calculations are included in Katz (2014)
Source: Cisco; TAS analysis (Appendix 2)

Finally, to estimate the new business revenues generated by service providers offering Wi-Fi services in public places (airports, hotels) for a fee in 2017, we added up the revenues of all firms operating in this space in the United States in 2013, excluding firms that offer services as a wholesaler, and multiplied the sum by the estimated growth rate of hot-spots in the United States. The analysis assumes that revenue grows at the same rate of hot spot deployment between 2013 and 2017 (72 %) (see Table 6).

Table 6. Compilation of Retail Revenues of Wi-Fi Service Providers in the United States (in $ millions)

Company	Business focus	2013	2017
Boingo	Retail access; wholesale access (to ATT, Verizon); military bases; advertising	$ 105.98	$ 182.69
iPass	Enterprise Wi-Fi services; wholesale access	$ 65.5	$ 112.92
SONIFI (Lodgenet Interactive)	Hotels and Health care (cable and Wi-Fi)	$ 100	$ 172.39
Total		$ 271.5	$ 468.00

Source: Company Annual reports and 10-K reports; Informa; TAS analysis

In summary, cellular traffic off-loading has multiple drivers of economic value. The analyses contained in this section enabled the calculation of annual economic value of Wi-Fi acting as a complement of wireless networks operating in licensed spectrum in 2017 (see Table 7).

Table 7. Summary of Economic Value of Wi-Fi Cellular Off-Loading (2013-2017) (in $ billion)

Effect	Underlying Premise	2013	2017
Consumer Surplus	Value of Free Wi-Fi traffic offered in public sites	$ 1.902	$ 12.130
Producer Surplus	Total cost of Ownership (cumulative CAPEX and OPEX) required to accommodate future capacity requirement with Wi-Fi complementing cellular networks	$ 10.7	$ 10.7
Return to Speed	Contribution to GDP of increase of average mobile speed resulting from Wi-Fi off-loading	$ 2.831	$ 6.565
New Business Revenue	Sum of revenues of service providers offering paid Wi-Fi access in public places	$ 0.271	$ 0.468

Source: TAS analysis

The estimates point to a substantial increase in the value of free Wi-Fi resulting from a seven-fold increase in Wi-Fi traffic across devices.

II.2. The future value of residential Wi-Fi:

Our recently completed paper, which assessed the economic value of residential Wi-Fi in 2013 focused on two benefits:

- Providing Internet access for devices that lack a wired port (e.g. tablets, smartphones, game consoles); and
- Avoidance of investment in in-house wiring.

The underlying premise of this analysis is that in the absence of Wi-Fi, users would have to depend on the cellular network to gain Internet access. This analysis assumed that those devices that have the capacity to connect through a wired port (e.g., personal computers) would, in the absence of Wi-Fi, rely on wired connections. We are left, however, with those devices that do not have the capability of a wired connection (tablets, smartphones, and game consoles). For this reason, estimating economic value would first measure the traffic generated by these devices at home and then would multiply it by the average price charged by cellular carriers (see Table 8).

Table 8. Annual Costs To Be Incurred by Home Traffic Generated by Devices With No Wireline Connectivity (2013-2017)

	2013	2017
Annual Traffic generated by devices with no wireline connectivity		
Smartphones (billion GB)	1.85	11.70
Tablets (billion GB)	4.67	80.68
Game Consoles (billion GB)	0.34	1.32
Total (billion GB)	6.86	93.71
Percent home traffic generated by devices with no wireline connectivity (*)	43.1%	43.1%
Total annual home traffic generated by devices with no wireline connectivity	2.96	40.40
Average price per GB	$ 7.61	$ 6.15
Total cost of tome traffic generated by devices with no wireline connectivity ($ Billion)	$ 22.51	$ 248.39

(*) Note: 43% of use time of these devices takes place at home
Source: Cisco; Park Associates; TAS analysis (Appendix 3)

In addition, residential Wi-Fi allows consumers to avoid paying for wiring to connect all home devices (printers, laptops, storage units, etc.). Assuming constant cost of deploying inside wiring in residence of approximately $190 per household, the avoidance cost of inside wiring is driven primarily by Wi-Fi household diffusion (see Table 9).

Table 9. Cost Avoidance of Inside Wiring (2013-2017)

	2013	2017
Number of Households	114,761,359	126,491,473
Percentage of Wi-Fi Households	61%	83%
Number of Wi-Fi Households	70,004,429	104,987,922
Unit cost of inside wiring	$ 193.80	$ 193.80
Total Cost Avoidance (in $ billions)	$ 13.57	$ 20.35

Source: US Census; Rural Telephone Company; Strategy Analytics; TAS analysis

In sum, the analyses contained in this chapter enabled the estimation of economic value of residential Wi-Fi in 2017 (see Table 10).

Table 10. Summary of Economic Value of Residential Wi-Fi (in $ billion) (2013-2017)

Effect	Underlying Premise	2013	2017
• Internet access for devices that lack a wired port	• Cost required for those devices to access the Internet via cellular networks	$ 22.51	$ 248.39
• Avoidance of investment in in-house wiring	• Cost to wire the residence	$ 13.57	$ 20.35
Total		$ 36.08	$ 268.74

Source: TAS analysis

The primary driver of the seven-fold increase in economic value in residential Wi-Fi surplus is the explosive adoption of tablets and the growing traffic per unit. As discussed in our recently completed paper, tablets are, by definition, primarily Wi-Fi devices (90% of units are not connected to the cellular network), and they lack the capability to connect to the Internet through a wired Ethernet port. Between 2013 and 2017, the installed base of tablets in the United States is projected to grow from 61 million to 190 million, while the unit traffic is expected to grow from 6.3 GB per month to 35.38 GB per month[25]. Considering that 43% of the traffic generated by tablets originates at home, the total annual tablet traffic in 2017 will amount to 34.78 billion GB growing from 2.01 billion in 2013. Even considering a decline in pricing per GB transported by cellular networks ($7.61 in 2013 to $6.15 in 2017), if the exponential tablet traffic growth were to rely on cellular networks, it would represent $248.36 billion. This is the primary driver in the increase in economic value between 2013 and 2017.

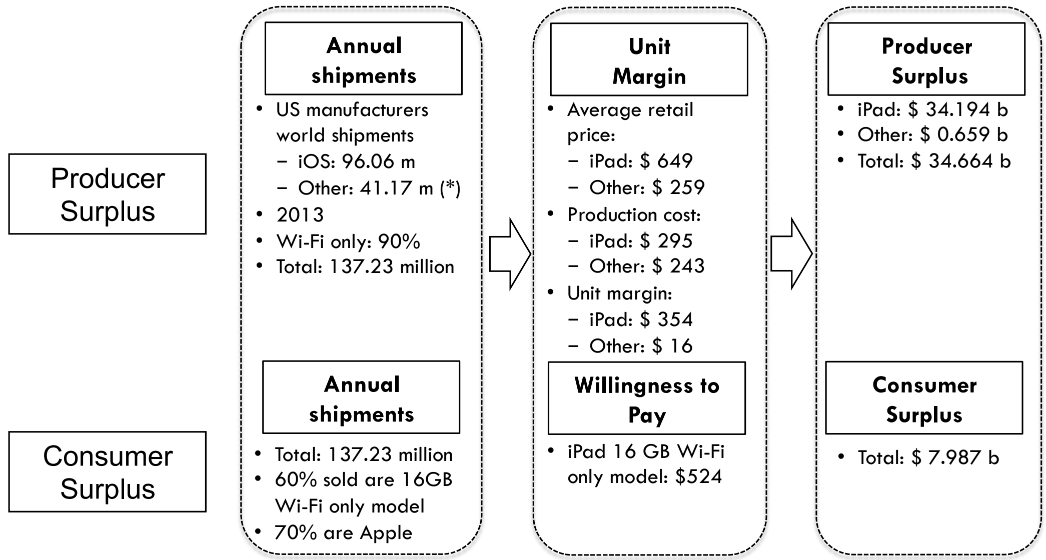
II.3. The future economic value of Wi-Fi only tablets:

Wi-Fi only tablets also represent a source of growth in economic value of unlicensed spectrum. In the section above, consumer surplus was estimated in terms of the savings incurred by U.S. consumers that do not need to rely on cellular networks to connect their devices (smartphones and tablets) to the Internet because they use Wi-Fi access. Beyond this, additional economic value is being originated by the margin generated by tablet manufacturers selling their products worldwide as well as the consumer surplus calculated by the difference between consumers' willingness to pay and actual prices of tablets. The last two areas are the ones estimated in this item.

Our prior assessment of the economic value of Wi-Fi only tablets comprised both consumer and producer surplus generated by the purchasing of these devices manufactured by U.S. producers in 2013 (see Figure 2).

[25] *Source: Cisco Visual Networking Index.*

Figure 2. Framework for estimating economic value of Wi-Fi only tablets



The same methodology was applied to estimate the economic value of these devices to be generated in 2017 (see Table 11).

Table 11. Economic value of Wi-Fi only tablets (2013-2017)

	2013	2017
Global tablet shipments (in millions)	221.3	386.3
Share of U.S. manufacturers	68.9 %	68.0%
Global tablet shipments of U.S. manufacturers (in millions)	152.47	262.68
Portion of Wi-Fi only	90%	82.5%
Wi-Fi only global shipments by U.S. manufacturers (in millions)	137.23	216.71
Producer surplus estimates		
Apple shipments (in millions)	96.06	66.31326
Non-Apple shipments (in millions)	41.17	150.39674
Apple margin (in $)	$ 354	$ 354
Non-Apple margin (in $)	$ 16	$ 16
Apple producer surplus (in $ million)	$ 34,196	$ 23,474.89
Non-Apple producer surplus (in $ million)	$ 659	$ 2,406.35
Total producer surplus (in $ million)	$ 34,855	$ 25,881
Consumer surplus estimates		
Apple shipments (in millions)	96.06	66.31326
Non-Apple shipments (in millions)	41.17	150.39674
Apple average retail price (in $)	$ 499	$ 499
Non-Apple average retail price (in $)	$ 199	$ 199
Apple average willingness to pay	$ 524	$524
Non-Apple average willingness to pay	$ 335	$ 335
Apple consumer surplus (in $ million)	2,401	$ 1,658
Non-Apple consumer surplus (in $ million)	5,599	$ 20,454
Total consumer surplus (in $ million)	$ 7,987	$ 22,112
Total economic value	$ 42,872	$ 47,993

Sources: IDC; iSuppli; TAS analysis

U.S. manufacturers are expected to preserve their global market share of 68% by 2017 as predicted by IDC (iOS: 30.6%, Windows: 10.2%, and Android: 58.8%, of which approximately 27% are estimated to be from US manufacturers) [26]. Going forward, while LTE tablets will greatly enhance the usage based on uses such as video streaming, 802.11ac will partially overcome this substitution threat. As a result, the share of Wi-Fi only devices shipped is expected to increase to 65%. Today, only half of users of 3G/4G enabled tablets are signed up for a cellular plan. Therefore, we estimate that total Wi-Fi only tablets in 2017 would be 82.5%, a slight reduction from 90% today.

To calculate producer and consumer surplus, it is necessary to project total market share of Apple versus the rest, since the company's margins are much higher than those of Google, Amazon and HP, among others. IDC projects Apple's market share by 2017 to drop to 30.6% from 45.6%[27]. As a conservative estimate, we project unit prices to remain constant although some analysts expect growing prices as a result of the increase in performance due to enhanced screen resolution. Likewise, as a conservative estimate, producer surplus and willingness to pay are considered to remain constant, although the learning curve and economies of scale could yield lower costs and the higher level of application selection could enhance consumers' willingness to pay for tablets.

The resulting estimate points to an increase in economic surplus derived from Wi-Fi only tablets sold by U.S. manufacturers globally to rise from $42.87 billion in 2013 to $47.99 billion in 2017.

II.4. Future economic value of wireless personal area networks:

Our assessment of economic value of wireless personal area networks in 2013 covered Bluetooth, ZigBee and WirelessHART, which support applications such as home automation and industrial device monitoring. We estimated value by focusing on the size of the 2013 market of the technologies relying on each standard. In this case, the 2017 market for a similar set of applications was estimated (see Table 12).

[26] IDC. Worldwide Quarterly Tablet Tracker (December, 2013).

[27] IDC. Worldwide tablet Shipments Forecast to Slow to Single-Digit Growth Rates by 2017, December 3, 2013.

Table 12. 2013 and 2017 Economic value of wireless personal area networks (in $ million)

Standard	Applications	2013 Value	2017 Growth drivers	2017 Value
Bluetooth	Automotive	$1,161.60	• Size of Bluetooth market (1)	$ 464.64
	Mobile telephony	$192.75	• Smartphone sales: 183 million (2) • Cost of Bluetooth chipset: $ 0.20 (3)	$ 36.60
	PC & peripherals	$385.03	• PC sales: 356 million (4) • Tablet sales: 250 million (5) • Printer sales: 725 million (6) • Cost of Bluetooth chipset: $0.20 (3)	$ 266.20
Zigbee		$267.00	• 2012-17 Growth in Zigbee market: 33% (7)	$ 835.44
WirelessHART		$160.00	• US share of global WirelessHART market: $185 million (8)	$ 50.00
Total		$2,166.38		$ 1,652.00

Note 1: 2017 value excludes Health and wellness because this category will be covered under wearable technologies in section III.3.
Source: (1) Yole Development; (2) IDC; (3) Wireless Connectivity; (4) (5) IDC; (6) Technavio; (7) ONWorld; (8) IDTech; TAS analysis.

As noted, despite the significant increase in applications and shipped devices (with the exception of PCs, which will exhibit a decline in shipments as a result of tablet substitution), total revenues to be generated by wireless personal area network chipsets is expected to decline in 2017 by $500 million from 2013. This is primarily due to the decline in chipset unit cost. When Bluetooth chips first appeared on the market, they cost around $20. Ten years later, that price had fallen to $1, driven by the volume of a billion chips per year. Over the coming years, as it follows the same volume path, unit pricing is projected to fall to less than 20 cents[28].

II.5. Future economic value generated by the WISP industry:

In our recently completed study, the economic value of the WISP industry was based on the total revenues generated by the sector[29]. This was calculated as a function of the number of subscribers (3,000,000) and the lowest ARPU identified ($39.99 per

[28] Source: Wireless Connectivity, July 6, 2010.
[29] This is certainly a conservative estimate since it excludes the consumer surplus derived from the value generated by residential customers in the areas of telecommuting, and access to agriculture and educational services.

month), both for 2013. To calculate the revenues for 2017, the WISP association estimates a subscriber count of 8 million and an ARPU of $50.00 month[30]. This would yield a total revenue generation of $4.8 billion.

II.6. The future economic value of RFID:

The future value of RFID technology is dependent on its level of adoption among enterprises. To remain comparable with the February 2014 paper by this author, we estimate the penetration of RFID technology for only two sectors in 2017: retailing and health care. In the prior study, it was reported that by 2013, more than 50% of US retailers had already adopted RFID. Similarly, adoption of RFID in health care was estimated between 23% (pharmaceutical distributors), 40% (hospitals) and 50% (pharmaceutical manufacturers). Assuming that cost savings and consumer benefits remain constant, a key driver of growth in consumer value is an increase in enterprise adoption.

Forecasts of RFID adoption by different market research firms consistently point to increasing penetration:

- IDTechEx predicts that the market for RFID goods and services will grow from $7.88 billion in 2013 to $19.0 billion in 2018 and that primary growth will occur in retail apparel item level tagging, and asset tracking/inventory, two segments that have a wide impact on retailing and health care. The firm predicts a compound annual growth rate (CAGR) of 19%. (IDTechEx).
- Markets and Markets predicts that the global hospital and pharmaceutical RFID asset management market will likely grow from $2.6 billion in 2012 to $6.7 billion in 2017, resulting in a CAGR of 20.9%. (Markets and Markets).
- The global RFID market, estimated at $5.6 billion in 2010, is expected to grow to $24.1 billion in 2021, resulting in a CAGR of 11%. (Das & Harrop, 2010).

Based on these estimates, but assuming a conservative increase in economic value of 10% through 2017 driven by increased purchasing and usage of RFID devices[31], the continuing implementation of RFID in the retail and health care industries will generate by 2017 total economic value of $191.46 billion (see Table 13).

[30] Number provided by the WISP Association based on an informal poll among its members.
[31] While the average of forecasts is 17%, they all refer to the purchasing of RFID goods and services, which should not equate to producer surplus.

Table 13. United States: RFID Economic Value in Retail and Health Care (2017) (in $ billions)

Sector	Producer Surplus	Consumer Surplus	Total
Retailing	$ 100.40	$ 38.44	$ 138.85
Health Care	$ 46.70	$ 5.90	$ 52.60
Total	$ 147.11	$ 44.35	$ 191.46

Source: TAS analysis

In order to understand how conservative these estimates might be, research at Harvard Business School indicates that 8% of all retail items are out of stock at any given time, costing more than $69 billion annually to the U.S. economy. RFID reduces the likelihood of out-of-stocks by 60% to 80%, according to ABI Research, as earlier detection of store-level out-of-stocks allows for quicker replenishment of floor merchandise and backroom stock through the retailer's supply chain. Similarly, according to University of Texas researchers, retailers lose more than $60 billion annually to shrinkage[32]. In its RFID pilot program, the METRO Group found a benefit of 18% reduction in shrinkage, while other estimates are around 30%.

II. 7. Total future economic value of technologies currently adopted:

To sum up, the economic value derived in 2017 from already widely adopted technologies operating in unlicensed spectrum bands in the United States is estimated at $531 billion. The contribution to the nation's GDP is at least $13 billion (see Table 14).

[32] In the retailing sector, shrinkage refers to a reduction in inventory due to shoplifting, employee theft, paperwork errors, and supplier fraud.

Table 14. United States: Summary of Future Economic Value of Unlicensed Spectrum (2017) (in $ billions)

	Effect	Economic Value			GDP
		Consumer Surplus	Producer Surplus	Total Surplus	
Wi-Fi Cellular Off-Loading	Value of free Wi-Fi traffic offered in public sites	$ 12.13	N.A.	$ 12.13	N.A.
	Benefit of total cost of ownership required to support future capacity requirement with Wi-Fi complementing cellular networks	N.A.	$ 10.7 (1)	$ 10.7	N.A.
	Contribution to GDP of increase of average mobile speed resulting from Wi-Fi off-loading	N.A.	N.A.	N.A.	$ 6.565
	Sum of revenues of service providers offering paid Wi-Fi access in public places	N.A.	N.A.	N.A.	$ 0.468
	Subtotal	$ 12.13	$ 10.7	$ 22.83	$ 7.033
Residential Wi-Fi	Internet access for devices that lack a wired port	$ 248.39	N.A.	$ 248.39	N.A.
	Avoidance of investment in in-house wiring	$ 20.35	N.A.	$ 20.35	N.A.
	Subtotal (*)	$ 268.74	N.A.	$ 268.74	N.A.
Wireless ISPs	Aggregated revenues of 1,800 WISPs	N.A.	N.A.	N.A.	$ 4.80
Wi-Fi Only Tablets	Difference between retail price and manufacturing costs for a weighted average of tablet suppliers	N.A.	$ 25.881	$ 25.881	N.A.
	Difference between willingness to pay for entry level tablet and prices of iPad and Android products	$ 22.112	N.A.	$ 22.112	N.A.
	Subtotal	$ 22.112	$ 25.881	$ 47.993	N.A.
Wireless Personal Area Networks	Sum of revenues of Bluetooth-enabled products	N.A.	N.A.	N.A.	$ 767.44
	Sum of revenues of ZigBee-enabled products	N.A.	N.A.	N.A.	$ 0.83
	Sum of revenues of WirelessHART-enabled products	N.A.	N.A.	N.A.	$ 0.05
	Subtotal	N.A.	N.A.	N.A.	$ 1.652
RFID	RFID Value in retailing	$ 38.44	$ 100.40	$ 138.85	N.A.
	RFID Value in health care	$ 5.90	$ 46.70	$ 52.60	N.A.
	Subtotal	$ 44.35	$ 147.11	$ 191.46	N.A.
TOTAL		$ 347.33	$ 183.69	$ 531.02	$ 13.485

(1) Already captured in 2013 estimates; therefore, should be the same.
Source: TAS analysis

These estimates represent an increase of $308 billion from the 2013 numbers for economic value and $6.7 billion in GDP contribution (see Table 15).

Table 15. United States: Summary of Future Economic Value of Unlicensed Spectrum (2013-2017) (in $ billions)

	Economic Surplus		GDP Contribution	
	2013	2017	2013	2017
Wi-Fi Cellular Off-Loading	$ 12.60	$ 22.83	$ 3.102	$ 7.033
Residential Wi-Fi	$ 36.08	$ 268.74	N.A.	N.A.
Wireless Internet Service Providers	N.A.	N.A.	$ 1.439	$ 4.80
Wi-Fi Only Tablets	$ 42.87	$ 47.99	N.A.	N.A.
Wireless Personal Area Networks	N.A.	N.A.	$ 2.166	$ 1.652
RFID	$ 130.87	$ 191.46	N.A.	N.A.
Total	$ 222.38	$ 531.02	$ 6.778	$ 13.485

Source: TAS analysis

As mentioned above, the primary growth takes place in residential Wi-Fi as a result of an increase in the tablet installed base and the ever growing traffic per unit. Additionally, economic surplus from RFID use is likely to increase as the technology is more widely adopted.

III. ASSESSMENT OF THE FUTURE VALUE OF UNLICENSED SPECTRUM BASED ON EMERGING TECHNOLOGIES AND APPLICATIONS

The study of applications that have reached wide adoption and impact demonstrates the growing economic value already created by unlicensed spectrum bands. However, as noted by several academics, the innovation incentives generated by this environment allow us to predict the future impact of still emerging technologies. The estimation of economic value of emerging technologies based on unlicensed spectrum is rendered complex by the fact that we lack visibility into what innovation will yield in terms of future applications. However, when considering a timeline of four years, the technologies, applications and business models to be launched can be predicted with some degree of certainty. For this purpose, we interviewed companies active in research and development of products (or components) that would leverage unlicensed spectrum, in order to identify the emerging innovations that could drive a forward-looking estimation of the value of unlicensed spectrum. Once these innovations were identified, we calculated a quantitative estimation of economic benefit. Although this calculation is somewhat more speculative than our estimate of the economic value of technologies that are already widely adopted, these estimates provide a glimpse of future economic value that is at stake if further assignments of spectrum are not fulfilled. This section reviews those applications, and estimates their potential economic value.

III.1. High-speed wireless data transfer technologies

High-speed wireless data transfer technologies rely on the 60 GHz unlicensed spectrum band to deliver a data transfer rate between 6 Gbps and 28 Gbps over a range between 5 and 30 meters. WirelessHD is primarily used for high definition consumer electronic devices, while WiGig supports smartphones, PCs, tablets and related peripherals[33].

At 28 Gbps of theoretical data transfer rate, WirelessHD surpasses HDMI, which is the most utilized HD connectivity technology (10 Gbps). WirelessHD is not yet widely adopted although it will likely replace HDMI in future connectivity of high definition devices[34]. It works with a wide range of devices including laptops, tablets, televisions, Blu-ray players, DVRs, camcorders, gaming consoles and adapter products. The primary value for consumers is the simplification of home theater installation and the elimination of the traditional need to locate source devices in the proximity of the display. As a result, consumers can create a wireless video area network by activating a device control system, which automatically discovers each device in the HD network.

WirelessHD complements conventional Wi-Fi because, by relying on 60 GHz RF technology (which is more than 10X faster than Wi-Fi), it delivers up to 4 Gbps of bandwidth, which is more than enough capacity to transmit FullHD audio and video quality – providing wired-equivalent quality and latency. Furthermore, WirelessHD can handle different wireless technologies, ranging from CDMA to Bluetooth to Wi-Fi.

On the other hand, WiGig (or 802.11ad) products also operate in the 60 GHz frequency band and deliver data content at 7 Gbps speeds with low latency. They also provide security-protected connectivity between nearby devices. Frequent use cases for WiGig complement Wi-Fi and include cable replacement for popular I/O and display extensions, wireless docking between devices like laptops and tablets, and instant sync and backup and simultaneous streaming of multiple, ultra-high definition and 4K videos.

The economic value of high speed wireless data transfer devices operating in WirelessHD and WiGig technologies could be assessed through two approaches: 1) the value to consumers of gaining access to a technology that complements Wi-Fi in terms of adding capability to the existing platform, or 2) estimating the revenues (and consequently GDP contribution) derived from unit shipments.

In terms of revenue generation, as more consumer electronics products take advantage of rapid wireless transfer opportunities, annual shipment of high-speed

[33] Source: http://www.wirelesshd.org/about/specification-summary/.

[34] Companies such as LG, Matsushita, NEC, Samsung, SiBEAM, Sony, and Toshiba have jointly sponsored this technology.

wireless data chipsets is expected to increase significantly. The market research firm HIS projects that by 2018, shipment of high-speed wireless integrated circuits IC will reach 1.7 billion units, including chipsets for smartphones, TVs and mobile PCs. On the other hand, the total wireless/video display market (which includes WirelesHD, WiDi, and WiFi display) was estimated to represent over $1 billion in 2012, growing at 28.03% through 2017 (source: Markets and Markets). Considering that WirelessHD represents 20% of the total wireless/video display market[35], we can project 2017 revenues to reach $0.69 billion.

The WiGig market currently represents $269.9 million, according to the research firm Markets and Markets, and it is expected to reach $4.58 billion in 2019, growing at a CAGR of 111.2%. In 2017, unit shipments will exceed 1 billion, generating $4.12 billion in revenues.

III.2. Low-Frequency Wi-Fi

Low-frequency Wi-Fi operates in the frequency bands between 512 MHz and 698 MHz to deliver broadband over distances of up to 10 miles with high penetration at 20 Mbps download and 6 Mbps upload speeds[36]. The technology can provide broadband in rural areas and extend the range of Wi-Fi everywhere. Low-frequency Wi-Fi relies on empty channels of broadcast television spectrum (known as white spaces) and uses dynamic spectrum sharing that optimizes access to available unused bands.

Users will predominantly use these unlicensed networks to access smart, radio-enabled devices that report their location to an Internet database. The database will dictate the TV white spaces channels to be used and appropriate power level suitable for use in its current location. The database has a list of all protected TV stations and frequencies across the country, so the devices can avoid interference with TV broadcasts and wireless signals. This technology is truly dynamic – as different TV channels become available, devices can opportunistically switch from one group of channels to another.

Given the emerging adoption of this promising technology, it remains difficult to estimate its economic value at this time.

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[35] Silicon Image, Inc. a leader in WirelessHD appears to generate approximately 132 million in manufacturing and licensing revenues of High Definition wireless chipsets.

[36] Low-frequency Wi-Fi operates in the frequency bands between 512 MHz and 698 MHz. Some have estimated that low-frequency Wi-Fi will enable fixed, higher-power access points to deliver broadband over distances of up to 10 miles with high penetration of up to 20 Mbps download and 6 Mbps upload speeds (Steven J. Vaughan-Nichols, What is "Super-Wi-Fi?", ZDNet.com (Feb. 5, 2013), available at http://www.zdnet.com/what-is-super-wi-fi-7000010802/), although further testing will be required to fully explore the throughput rates possible in this band.

III.3. Machine-to-machine communications

Unlicensed spectrum bands are critical to the communication of devices equipped with microcontrollers in order to deliver applications in areas as diverse as environmental management (pollution/air quality monitors, weather stations, water level monitors), urban landscape (street lighting control systems, parking meters) and health care (dialysis machines, defibrillators, ventilators, pacemakers). Enhanced connectivity of devices via unlicensed spectrum could increase their ability to process information and interact with other terminals.

As of 2012, the number of interconnected devices reached 4 billion, including all handheld mobile terminals at a pairwise interconnected rate of 8 * 1,018 (Thanki, 2012). While forecasts of machine-to-machine devices vary greatly, they all concur in an explosive growth and the increase in pairwise interconnections. Complementing cellular networks, Wi-Fi, Bluetooth Low Energy, and ZigBee are highly suited standards to support a large portion of machine-to-machine interconnection. In fact, a percentage of the total machine-to-machine devices is dependent upon technologies relying on unlicensed spectrum, at least for portion of the traffic. In fact, most home security systems that monitor whether or not windows and doors are open rely on Wi-Fi technology.

For purposes of estimating the economic value of machine-to-machine communications, and to prevent double counting with the estimates of Section II.4, we limit our assessment to four applications: Advanced Meter Infrastructure, Security, Energy Demand Side Management devices and Telehealth. Beyond these four applications, we estimate the economic value of wearables technology.

Advanced Meter Infrastructure systems provide detailed, time-based information regarding the utilization of electric, gas and water meters. The meters have the ability to transmit the collected data through a variety of communications technologies, ranging from Broadband over Power Line, Fixed Radio Frequency and public networks (landline or cellular)(Adke et al., 2011). If relying on unlicensed spectrum, AMI transmits 1-8 kbps per channel over 0.25 miles[37].

Security applications comprise products implementing a wireless link from various entry points, appliances, lights and HVAC systems in the consumer's residence to a central hub in the home. This is accomplished using Intermittent Control Signals spectrum that cannot carry significant data. Information carried includes control signals and occasional data signals (audio, video). These systems are used in homes, small businesses and large corporations. Wireless technology obviates the need for cabling from door and window sensors, motion detectors, smoke detectors, control

[37] Electric Power Research Institute (2007). *Advanced Metering Infrastructure.* Palo Alto, California: EPRI.

panels and hubs.

Smart Home power meters, which utilize Bluetooth-enabled hub devices, can reduce energy costs, helping homeowners to save money and use less energy. As intelligent energy delivery technology advances, two-way communications will allow smart meters to send real-time energy consumption information directly to homeowners, empowering them to conserve energy and save on their utility bills. For example, homeowners will be able to use their Bluetooth-enabled smart phone, tablet or PC to monitor and adjust their heat and air conditioning, even when they're not home. The displays and applications on today's phones and other hub computing devices can allow users to control all the appliances and systems throughout a Smart Home with ease. Energy consumption could also be rendered more efficient by deploying automated sensors with intelligence that allows the sensors to detect whether a home is occupied and adjust thermostats accordingly (learning thermostats).

Smart Homes will also make it easier for people to make sure all their windows and doors are locked. Cars have had wireless remotes for years, allowing drivers to lock and secure them with the touch of a button. Homeowners, however, must walk around and visually check every door and window in their home. Companies that solve these challenges will tap into a huge market of homeowners eager to take advantage of technologies they already have in their car or office.

The telehealth category comprises, among other devices, Medical Implant Communication Service (MICS) band radios, which are very low powered systems used for communications between implanted medical devices (cardioverter defibrillators, neurostimulators, hearing aids and automated drug delivery systems) and nearby (~5m) monitoring equipment.

We developed a simple model based on the forecast of ,machine-to-machine connections in the United States and the average traffic per device for the four applications, excluding wearables which is addressed independently (see Table 16).

Table 16. US M2M Device Forecast (2013-2017)

	2013	2014	2015	2016	2017
Total Connections (million)	95.0	129.0	175.2	311.1	314.9
Connections relying on unlicensed spectrum (in million)					
• AMI	7.1	9.8	11.9	18.2	27.8
• Security	7.8	9.9	12.7	15.2	18.2
• Demand Side Management	4.9	5.8	6.7	7.9	9.2
• Telehealth	2.7	4.4	6.9	8.5	10.6
Total Connections relying on unlicensed spectrum (%)	47.8	48.7	48.2	50.7	54.1
Total machine-to-machine market (billion $)	$ 32.6	$ 36.9	$ 41.7	$ 47.1	$ 53.0
Share of machine-to-machine market relying on unlicensed spectrum (billion $)	$ 15.6	$ 36.9	$ 20.1	$ 23.9	$ 27.8 (1)

(1) Note: to avoid double counting with Zigbee applications addressed in Table 11, we subtracted $835.4 million from the total machine-to-machine market.
Source: ABI Research; IDATE; TAS analysis

In addition to the machine-to-machine applications discussed above, wearable technologies represent an emerging set of uses of unlicensed spectrum. These are devices that can be worn on a person, which have the capability to connect and communicate to the network either directly through embedded cellular connectivity or, primarily, through another device (such as a smartphone) using Wi-Fi, Bluetooth or another technology. These devices include smart watches, smart glasses, heads-up displays (HUD), health and fitness trackers, health monitors, wearable scanners and navigation devices and smart clothing. The growth in these devices has been fuelled by enhancements in technology that have supported compression of computing and other electronics (making the devices light enough to be worn).

The total number of wearable devices in the United States is currently estimated at 9.1 million and projected to reach 42.9 million by 2017 (see Table 17).

Table 17. U.S. Wearable Devices Forecast

	2013	2014	2015	2016	2017
Global Devices (million)	22.0	36.0	58.0	88.0	127.0
Global market (US$ billion)	$ 2.52	$ 5.17	$ 7.14	$ 8.86	$ 10.92
US Devices (million)	9.2	14.3	21.9	31.5	42.9
Wearable Devices (million)					
• Smart Glasses		0.24	1.20	2.30	4.59
• Smart Watches		2.78	9.47	17.5	26.2
• Fitness and Activity Monitors		6.62	6.86	7.65	8.58
• Heart Rate Monitors		4.68	4.38	4.06	3.52
US Market ($ billion)	$ 1.05	$ 2.05	$ 2.70	$ 3.17	$ 3.69

Source: Cisco; ABI Research; TAS analysis

According to the projected diffusion of wearable devices, the U.S. market, currently estimated at $ 1.05 billion, is expected to reach $ 3.69 billion by 2017.

III.4. Smart City deployments for managing public infrastructure:

Wireless sensor networks can enable Smart Cities. These are distributed networks of intelligent sensors that can measure many parameters for more efficient management of the city. The data is delivered wirelessly and in real-time to citizens or the appropriate authorities. There are many examples of applications enabled by wireless sensor networks including the following:

- Citizens can monitor the pollution concentration in each street of the city or they can get automatic alarms when the radiation level rises above a certain level;.
- Municipal authorities can optimize the irrigation of parks or the lighting of the city;.
- Water leaks can be easily detected or noise maps can be obtained;.
- Vehicle traffic can be monitored in order to modify the city lights in a dynamic way;
- Traffic can be reduced with systems that detect the closest available parking space and inform motorists of the space's location. This information saves time and fuel, reducing traffic jams and pollution while improving the quality of life.

Beyond these effects, Smart Cities can deliver a number of indirect effects in terms of economic growth, competitiveness, and a better way of life for its citizens. As stated by Kimachia (2014),

> *"Leaders of smart cities have the tools to analyze data, anticipate problems and resolve them in a timely manner. They can also coordinate resources effectively. The entire*

> *infrastructure in a smart city is viable and ready for constant change. The human services such as social programs, healthcare and education, needed to support the citizen as an individual are also highly developed."*

The resulting economic impact of Smart Cities would include job creation (through the development of manufacturing operations) and industry development in areas such as tourism and services in general.

In order to provide some estimates of the economic value derived from the deployment of Smart City infrastructure, it is necessary to break down its multiple benefits. The effects of Smart City infrastructure deployment could be categorized in five areas:

- Improved mobility: Strong ICT infrastructure and sustainable transport systems;
- Economic growth: High productivity, entrepreneurship and ability to transform;
- Sustainable environment: Sustainable resource management, pollution prevention, and environmental protection;
- Quality of life: Cultural facilities, housing quality, health and safety issues; and
- Better administration: Political strategies and perspectives, transparency and community participation in decision-making.

Within the first category, a study by the Harvard Center for Risk Analysis (Levy et al., 2010) has quantified the impact of traffic congestion on public health resulting from motor vehicle emissions in 83 U.S. cities. The authors estimate a monetized value of public health losses of approximately $31 billion. This amount should be considered beyond the $60 billion cost of wasted time and fuel originating from congestion in the same cities (Schrank, 2007). While these costs can be addressed through multiple policy initiatives, such as congestion pricing and adding highway and public transit capacity, traffic light synchronization and more efficient response to traffic incidents (both enabled by wireless sensors operating in unlicensed spectrum bands) can also be positive contributors. Analysts (Pantak, 2013) estimate that, under certain conditions, traffic light synchronization reduces congestion by up to 10% and air pollution up to 20%. This would result in an added economic benefit of $15.1 billion only from the mobility bonus.

In addition to environmental gains, smart cities contribute to economic growth. Efficient transportation and improvements in quality of life can attract economic activity to cities and boost productivity. Making a city more attractive to live in helps provide business with the labor force to create its products and buyers to consume them, and so fuels economic growth. For example, Shapiro (2005) found that while a causal relationship exists between college graduates and geographic employment, 40% of employment growth in U.S. metropolitan areas is also due to improvements in the quality of life (in other words, quality of life attracts educated workers to those cities). While Shapiro only isolates the effect of consumer related factors (e.g. restaurants) affecting quality of life, it would be reasonable to assert that the latter is driven as well by innovations pertaining to the deployment of Smart City infrastructure.

In addition to the data presented above, it would be useful to estimate the value of Smart City sensor technology on the basis of the contribution to GDP of the revenues generated by infrastructure sales. We recognize this to be a wide underestimation of total economic value. The market research IDTech estimates the global wireless sensor network market to be $450 million, reaching $2 billion in 2021, of which the United States represents 72%. This results in a projected 2017 GDP contribution of $793 million.

III.5. Agricultural automation:

State-of-the-art agriculture requires field machinery capable of precise operations. Precision agriculture represents a systems-based approach for site-specific management of crop production systems. The efficiency of agricultural machinery is enhanced by the deployment of sensors (grain yield, optical sensors for weed detection, and control systems for fertilizer spreading) linked to standardized bus systems that transmit data streams. Each type of sensor is linked to a specific type of machine: combine harvesters, field-spraying machines, and fertilizer spreaders[38]. Wireless sensor networks link a set of devices spread in the environment in order to monitor and manage it based on data gathered on specific physical changes (humidity, etc.). This application allows for the management of operations such as irrigation centers, the control of fertilization, and the coordination of large-scale machinery, such as harvesters, across extended surfaces.

While Global Positioning System technology is at the core of precision agriculture[39], the implementation of sensors is also critical. In fact, Lowenberg-Deboer considers that most of the benefit of precision farming systems will come from whole farm management uses, which would include the use of sensors, remote sensing and telemetry[40]. Sensor networks are dependent on deploying point-to-point and point-to-multipoint network technologies. Point-to-point communications relies on wireless meteorological stations and RFID tags for field information collection. On the other hand, point-to-multipoint communication for data collection relies on 802.15.4 and 61oWPAN (Alberts et al., 2013), as well as Wi-Fi (Keshtagary et al.,

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[38] CONTROL SYSTEMS, ROBOTICS, AND AUTOMATION - Vol. XIX - *Advanced Technologies and Automation in Agriculture* - J. De Baerdemaeker, H. Ramon, J. Anthonis, H. Speckmann and A. Munack.
[39] Without GPS it is impossible to generate yield maps and to use yield data effectively in spatial management.
[40] Lowenberg-DeBoer, J. *Economic analysis of precision farming*.

2012) and ZigBee, which both operate in the 2.4 GHz band.

The impact of agricultural automation can be estimated based on its contribution to the increase in Total Factor Productivity through more efficient use of labor, timeliness of operations (optimization of agronomic windows, reduction of spoilage and harvest losses), and efficient use of inputs (water, seeds, fertilizers) (Reid, 2011). A study conducted by Robertson et al. (2007) aimed at quantifying the economic contribution of precision agriculture, estimated that total benefits ranged from $13 to $28 per hectare resulting primarily from improved fertilizer management and a reduction of overlap of spraying. On the other hand, Swinton and Lowenberg-DeBoer (1999) estimated the net return of precision agricultural management at $47.01 per hectare.

Recognizing that adoption of agricultural automation technology is constrained by the level of capital investment, we considered a 50% of adoption across agricultural acreage in the United States when estimating the producer surplus of this technology[41]. In 2013, the US had a total of 325 million crop acres of which incremental adoption of precision agriculture would reach 50% in 2017. Assuming a range of producer plus benefits between $13 and $28 per hectare, the economic value of agricultural automation would range between $513 million and $1.1 billion. We adopted the high-end benefit number because it is driven by benefit ratios that are closer to other consensus estimates.

III.6. Total future economic value of emerging technologies:

To sum up, the economic value derived in 2017 from technologies still at the emerging stage of diffusion operating in unlicensed spectrum bands is estimated at $16.20 billion, also contributing to $36.30 billion to the nation's GDP (see Table 18).

[41] The USDA estimated that in 1998, approximately 18% of corn and soybean acreage was harvested with yield monitors (Norton and Swinton, 2000), half of which used GPS (Swinton and Lowenberg-DeBoer, 1998), while variable rate fertilizer was used in between 25% and 40% in high value specialty crops (Wang et al., 2009). Similarly, in 2010 Schimmelpfennig and Ebel (2011) estimated that yield monitoring is now used on over 40 percent of US grain crop acres, but very few producers have adopted GPS maps or variable-rate input application technologies. There is considerable uncertainty about the future rate of adoption of these technologies as a result of investment costs, farmer education, maturity of applications and other factors. A projection of 45% adoption of yield monitors and variable rate fertilizers has been mentioned in the research literature (Akridge and Wipker, 1999).

Table 18. United States: Summary of Economic Value of Emerging Applications and Technologies Relying on Unlicensed Spectrum (2017) (in $ billions)

	Effect	Economic Value			GDP
		Consumer Surplus	Producer Surplus	Total Surplus	
High-Speed Wireless	WirelessHD	N.A.	N.A.	N.A.	$ 0.69
	WiGig	N.A.	N.A.	N.A.	$ 4.12
	Subtotal	N.A.	N.A.	N.A.	$ 4.81
M2M	M2M applications relying on unlicensed spectrum	N.A.	N.A.	N.A.	$ 27.8
	Wearable devices	N.A.	N.A.	N.A.	$ 3.69
	Subtotal	N.A.	N.A.	N.A.	$ 31.49
Smart City deployments	Reduce pollution concentration, optimization of park irrigation or lighting, traffic optimization	$ 15.1.	N.A.	N.A.	$ 0.79
Agriculture automation	Increase in Total factor Productivity resulting from improved fertilizer management, and a reduction of overlap of spraying	N.A.	$ 1.10	$ 1.10	N.A.
TOTAL		$ 15.1	$1.10	$ 16.20	$ 36.30

Source: TAS analysis

The estimates of economic value of future technologies are extremely conservative for several reasons:

- Due to the emerging stage of adoption, the economic value of low-frequency Wi-Fi was not estimated;
- Despite the enormous potential to develop environmentally sustainable cities, the economic surplus of machine-to-machine technologies and applications was not estimated, limiting the analysis to contribution to GDP of unit sales;
- The estimate of Smart City sensor networks was conducted by measuring two areas of benefit derived from alleviating traffic congestion, and the contribution to GDP of infrastructure sales. This excludes the primary source of value resulting from enhanced citizen welfare.

IV. FUTURE ECONOMIC VALUE OF UNLICENSED SPECTRUM

The assessment of future economic value of unlicensed spectrum involves two drivers of economic value: 1) future adoption increase in technologies already widely diffused, and 2) adoption of emerging technologies. The combined value of these two drivers amounts to, at least, $547.22 billion in economic value and $49.78 billion in contribution to the GDP.

Table 19. United States: Summary of Future Economic Value of Applications and Technologies Relying on Unlicensed Spectrum (2017) (in $ billions)

	Technologies and applications	Economic Value			GDP Contribution
		Consumer Surplus	Producer Surplus	Total Surplus	
Future value of currently deployed technologies and applications	Wi-Fi Cellular Off-Loading	$ 12.13	$ 10.7	$22.83	$ 7.03
	Residential Wi-Fi	$ 268.74	N.A.	$ 268.74	N.A.
	Wireless ISPs	N.A.	N.A.	N.A.	$ 4.80
	Wi-Fi only tablets	$ 22.11	$ 25.88	$ 47.99	N.A.
	Wireless Personal Area Networks	N.A.	N.A.	N.A.	$ 1.65
	RFID	$ 44.35	$ 147.11	$ 191.46	N.A.
	Subtotal	$ 347.33	$ 183.69	$ 531.02	$ 13.48
Value of emerging applications and technologies	High-Speed Wireless	N.A.	N.A.	N.A.	$ 4.81
	Machine to Machine	N.A.	N.A.	N.A.	$ 31.49
	Smart City deployments	$ 15.1	N.A.	$ 15.1	$ 0.79
	Agriculture automation	N.A.	$ 1.10	$1.10	N.A.
	Subtotal	$ 15.1	$ 1.10	$ 16.20	$ 36.30
Total		$ 362.43	$ 184.79	$ 547.22	$ 49.78

Source: TAS analysis

Achieving this economic value is partially conditioned by the availability of sufficient unlicensed spectrum. This will be explored in the next part of the study.

V. POTENTIAL SPECTRUM SCENARIOS:

This part assesses future potential unlicensed spectrum designation scenarios in terms of their capability to accommodate the traffic growth of current applications in addition of the usage of emerging technologies relying on unlicensed spectrum. In this context, three scenarios were evaluated:

- U-NII-4
- 3.5 MHz
- 600 MHz incentive auction

It begins by outlining potential saturation scenarios or traffic "choke points" in applications relying on unlicensed spectrum. It follows by reviewing technological innovations that could alleviate some congestion. On this basis, it assesses how additional unlicensed spectrum designation could help to address the saturation scenarios.

V.1. Potential saturation scenarios of unlicensed spectrum:

Our recently completed study concluded that traffic from applications and technologies relying on unlicensed spectrum was growing at exponential rates:

- Wi-Fi cellular off-loading traffic is growing at 68% per annum;
- Residential Wi-Fi installed base will grow from 63% current penetration to 86% by 2017;
- Average traffic per tablet is growing from 6.33 Gb per month in 2013 to 35.38 Gb in 2017.

In this context, we expect that current unlicensed spectrum designations will not be able to support the future needs in two particular areas.

V.1.1. High-density urban areas:

Technological advancements would not be enough to address the congestion points in the network. For example, without new spectrum designations, delivering metro (or muni) Wi-Fi will be very challenging in dense urban markets[42]. While traffic carried by public Wi-Fi hotspots has historically been a very small proportion of total wireless data traffic, a number of factors (ease of access, improved internetworking, roaming arrangements and proliferation of Wi-Fi only devices like tablets) are driving growth in this sector. Research by Wagstaff (2009) and Van Bloem et al. (2011) indicates that in dense device environments, data overheads that are generated to keep connections running consume between 80% and 90% of capacity.

In the context of increasing traffic volumes, Wi-Fi is becoming the congestion contention point in public access networks. According to Aegis (2013), carriers have registered Wi-Fi traffic growth in central city locations up to 6 times higher than on their cellular networks. In fact, Aegis believes that in order to accommodate future traffic growth, public outdoor networks (access and meshing) would require 160 MHz of additional spectrum, while public indoor networks would require an additional 100 MHz.

V.1.2. Residential Wi-Fi:

Within residences, network speed is limited by the number of devices connected, particularly those that are video enabled. According to a study by Williamson et al. (2013), once an 80-100 Mbps broadband link is deployed to a customer premise, the last mile is not the bottleneck any more, while the residential Wi-Fi becomes the congestion point. This is because there is a difference between the advertised speed in a typical Wi-Fi router (150 Mbps) and the delivered speed, which is below 70

[42] Saturation is already occurring in the 2.4 GHz band in major urban markets, such as New York City.

Mbps[43]. Along these lines, video traffic is putting considerable pressure on home routers resulting in degradation of streaming capacity. Given that Wi-Fi shares available capacity across devices, if a typical Wi-Fi household is running multiple devices, the service will degrade and be substantially lower than what could be handled by an ultrafast broadband link.

Aegis (2013) has determined that in the long run (2024), access to up to 40 MHz of uncontended spectrum per household may be required. According to Aegis, the total amount of spectrum required to support residential Wi-Fi traffic in this scenario would be up to 210 MHz by 2017. This is partly the result of the fact that the full migration to faster standards such as 802.11ac[44] will require approximately 10 years, which means that the spectrum crunch at the residential level will occur well before full adoption of the more efficient standard occurs[45].

V.2. Technological innovations that could alleviate unlicensed spectrum congestion:

A series of technological innovations are being developed with the purpose of increasing the efficiency of unlicensed spectrum. One of them is the introduction of full duplex in a single channel. The simultaneous use of uplink and downlink in a single channel would result in a theoretical increase in spectrum capacity.

In addition, routers that support smart switching resulting in more efficient band usage according to an environment in which communications takes place (high-rise apartments requiring high frequency/low propagation versus low-density houses) and type of communication (e.g., high bandwidth video streaming vs. low bandwidth device monitoring, such as HVAC) could add significant spectral efficiency.

V.3. Further assignment of unlicensed spectrum:

Assuming that technological innovations would not be able to eliminate all the congestion points in unlicensed bands, it is pertinent to examine three spectrum assignment scenarios that could alleviate these cases.

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[43] The difference is due in part to the need to assign part of the capacity to the data overheads. In addition, advertised speeds are based on tests that relying on large packets, while the average packet size is much smaller. Finally, range and attenuation are factors to be considered in the reduction of speed. Williamson et al. (2013) estimate that delivered speed is approximately 50% of the advertised.

[44] The latest 802.11ac standard is intended to provide substantially higher speed and one of the ways this is achieved is via wider channels of 80 and 160 MHz. Unlike 11n, a fall back to narrower channels on a per-frame basis is mandated in the 11ac draft standard, such that fairness of medium access is offered to legacy 20 and 40 MHz channel devices (Aegis, 2013).

[45] Full substitution of shipments from 802.11n to 802.11ac will be complete only in 2016, but transition at the user level has just started and is projected to end by 2018.

First, the designation of the U-NII-4 spectrum for unlicensed use would help to alleviate future "choke points". A major goal for the 5 GHz spectrum is to free up the whole band - 5150-5925MHz - so that large channels (80MHz and 160MHz) can be used. U-NII-4 will be valuable for small cell deployments including metro Wi-Fi. Also, if complemented by sub-1 GHz unlicensed spectrum, this would significantly improve the economics for access.

Second, the designation of portions of the 3.5 GHz band for commercial use would alleviate future "choke points". A priority access tier, in particular, could be very powerful if it enables real Quality of Service. However, in order for this band to become an effective remedy to saturation depends on the technical rules for operation. As of now, the FCC proposes to exclude a major portion of the national territory (coastal areas) for federal use (e.g. radar). This would preclude operation in areas that are home to approximately 60% of the population. If these exclusion zones are adopted, it is not clear whether the market size will be big enough for chipset and equipment manufacturers to invest in equipment for this band. A potential remedy for this scenario would be to either reduce the size of the exclusion zones or define rules that establish secondary users to access the band when they are not occupied by federal users.

Finally, the availability of additional unlicensed channels below 1 GHz would address future "choke points" in the additional technologies, business models or applications particularly suited to this lower frequency unlicensed designation. For example, the 600 MHz band could be well suited to off-loading some of the residential Wi-Fi traffic. Adding Wi-Fi at 600 MHz would effectively increase its range. Considering the products that allow for optimization of band allocation, one could envision a residential scenario where low bandwidth applications running at the edge of the Wi-Fi site could be routed in the 600 MHz band (better suited for signal propagation), reserving 2.4 GHz and 5 GHz spectrum for video-streaming.

Can the opportunity cost of not making further unlicensed spectrum available be quantified? There are three areas of benefit of unlicensed spectrum where the opportunity cost of not designing further bands could be quantified.

V.3.1. Limited return to speed:

At the expected rate of traffic off- loading, the average speed of mobile traffic in the United States in 2017 would be 21.66 Mbps[46]. The benefit derived from the additional speed resulting from off-loading is what we call the Wi-Fi return to speed. However, if we assume that, due to congestion, the average Wi-Fi speed does not increase to 24 Mbps, as Cisco projects, but stays at current levels[47] (15.43 Mbps), the

[46] Pro-rating Wi-Fi traffic speed at 24 Mbps and cellular traffic speed of 14.05 (source: Cisco VNI]).
[47] This is a conservative assumption, since, under congestion scenarios, Wi-Fi speed could diminish even further.

average speed of all mobile traffic would not change significantly from today. Our analysis showed that if access to faster Wi-Fi is not achieved, the overall speed of transmissions would decline to 14.05 Mbps, thereby foregoing of $4.4 billion in GDP increases[48].

V.3.2. Residential Wi-Fi:

According to carrier and regulator statistics, 10% of high-speed broadband users account for 50% of the total high-speed traffic[49]. The busy hour traffic for these households is five times the average, which would imply an average busy hour rate per unit of approximately 7.55 Mbps by 2017[50]. In addition to the traffic that is generated by an external broadband connection, residential traffic will be increased by off-net devices distributing video programming within the house (24 Mbps), which would result in a total estimated traffic per household of 31.55 Mbps, resulting in a requirement of approximately 20 MHz of spectrum by 2017 for a high usage household. Total spectrum requirements are calculated by multiplying this value by 6 visible access points[51], yielding 120 MHz.

Assuming that additional spectrum for Wi-Fi technology is not available, it is reasonable to consider that, at least for those households with high density of 802.11n legacy devices, performance would be considerably degraded, pushing them to deploy inside wiring. That would result in $2.0 billion in reduced savings derived from in-house wiring investment avoidance (conservatively estimated to 10% of U.S. households). Additionally, as a result of the substantial degradation of residential Wi-Fi, the devices relying on this technology for residential Internet access would have to switch to cellular networks, with the consequent economic burden. Assuming that 5% of the surplus would be cancelled out, that would result in $12 billion of value erosion. All in all, the negative impact of not gaining access to additional unlicensed spectrum for residential Wi-Fi usage would result in an erosion of $14 billion of the economic surplus stipulated for 2017.

V.3.3. Disappearance of Wi-Fi Service provider industry

A third area of negative impact under a scenario of limited unlicensed spectrum assignment is service degradation in public places (airports, convention halls, etc.). For example, no additional assignment of unlicensed spectrum could result in the disappearance of the Wi-Fi service provider industry since, with a lower service

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[48] Difference between 21.66 Mbps and 15.43 Mbps multiplied by the impact of speed on GDP growth (Bohlin et al,., 2012).

[49] Source: OFCOM.

[50] According to Cisco VNI, the average busy hour traffic per household in 2017 will be 1.51 Mbps. This means that high usage households, the average busy hour traffic would be 1.15 Mbps*5=7.55 Mbps.

[51] Under this scenario, multiple access points are required to provide higher signal quality throughout a residence; Aegis (2013) estimates six per high usage dwelling.

quality level, these operators could not compete with cellular service providers; an erosion of $468 million directly contributed to the GDP.

VI. CONCLUSION

This study provides the sum of all benefits derived from future applications and technologies relying on unlicensed spectrum in the United States. We estimate that the combined value of future diffusion of currently deployed technologies and adoption of not yet adopted technologies in the United States amounts to at least $547.22 billion in economic value and $49.78 billion in contribution to the GDP (see Table 20).

Table 20. United States: Summary of Future Economic Value of Applications and Technologies Relying on Unlicensed Spectrum (2017) (in $ billions)

	Technologies and applications	Economic Value			GDP Contribution
		Consumer Surplus	Producer Surplus	Total Surplus	
Future value of currently deployed technologies and applications	Wi-Fi Cellular Off-Loading	$ 12.13	$ 10.7	$22.83	$ 7.03
	Residential Wi-Fi	$ 268.74	N.A.	$ 268.74	N.A.
	Wireless ISPs	N.A.	N.A.	N.A.	$ 4.80
	Wi-Fi only tablets	$ 22.11	$ 25.88	$ 47.99	N.A.
	Wireless Personal Area Networks	N.A.	N.A.	N.A.	$ 1.65
	RFID	$ 44.35	$ 147.11	$ 191.46	N.A.
	Subtotal	$ 347.33	$ 183.69	$ 531.02	$ 13.48
Value of emerging applications and technologies	High-Speed Wireless	N.A.	N.A.	N.A.	$ 4.81
	Machine to Machine	N.A.	N.A.	N.A.	$ 31.49
	Smart City deployments	$ 15.1	N.A.	$ 15.1	$ 0.79
	Agriculture automation	N.A.	$ 1.10	$1.10	N.A.
	Subtotal	$ 15.1	$ 1.10	$ 16.20	$ 36.30
Total		$ 362.43	$ 184.79	$ 547.22	$ 49.78

Source: TAS analysis

Additionally, future unlicensed spectrum designation scenarios have been evaluated in terms of their capability to alleviate any "choke points" derived from exponential traffic growth. First, the designation of the U-NII-4 spectrum for unlicensed use would alleviate future "choke points" of the network. A major goal for 5 GHz is to free up the whole band - 5150-5925MHz - so that large channels (80 MHz and 160 MHz) can be used. This portion of the spectrum will be valuable for small cell deployments including metro Wi-Fi. Second, the designation of portions of the 3.5 MHz band to unlicensed use would alleviate future "choke points" for several applications. The Priority Access tier could be very powerful if it enables real Quality of Service. However, in order for this band to become an effective remedy to saturation, the technical rules for operation are critical. Finally, the availability of additional unlicensed channels below 1 GHz would address future saturation for technologies, business models or applications particularly suited to this lower frequency unlicensed designation. For example, the 600 MHz band could be well suited to providing wireless broadband connectivity to rural areas and off-loading some residential Wi-Fi traffic.

Based on the additional evidence generated in this study, we conclude that any policies focused on unlicensed spectrum must preserve both the value generated so far, as well as the capacity to generate economic surplus in the future. Extending designated bands will be extremely beneficial to value creation. Furthermore, the emerging body of evidence of congestion within the unlicensed spectrum points out the risks of not extending the spectrum designated for unlicensed use.

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APPENDIX 1. Total Free Wi-Fi Traffic (2013-2017)

1. Devices	2010	2011	2012	2013	2014	2015	2016	2017	SOURCE
Smartphones	112,888,596	139,344,317	172,000,000	192,751,370	216,006,342	242,066,967	271,271,742	304,000,000	CISCO
Smartphone (Penetration)	36.00%	44.07%	53.96%	59.99%	66.70%	74.16%	82.46%	91.69%	CISCO
Tablets	26,407,591	35,008,499	46,410,709	61,526,599	81,565,710	108,131,526	143,349,784	190,038,569	CISCO (Mail)
Tablets (Penetration)	8.42%	11.07%	14.56%	19.15%	25.19%	33.13%	43.57%	57.32%	TAS
Laptops	235,184,576	237,156,382	239,083,493	240,987,646	242,891,490	244,806,660	246,732,252	248,663,732	DELOITTE
Laptops (Penetration)	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	DELOITTE
Total Devices (Smartphones+Tablets+Laptops)	374,480,763	411,509,198	457,494,202	495,265,616	540,463,542	595,005,153	661,353,778	742,702,301	TAS
Total Devices Per Capita	1.19	1.30	1.44	1.54	1.67	1.82	2.01	2.24	TAS
Portable Gaming Console	42,615,887	46,954,004	51,733,724	57,000,000	62,802,360	69,195,376	76,239,173	84,000,000	PARK ASSOCIATES
Portable Gaming Console (Penetration)	13.59%	14.85%	16.23%	17.74%	19.39%	21.20%	23.17%	25.34%	PARK ASSOCIATES
PC	329,082,731	329,082,731	329,082,731	316,501,079	304,400,454	292,762,467	281,569,428	270,804,328	CISCO (Mail)
PC (Penetration)	105%	104%	103%	99%	94%	90%	86%	82%	TAS
Phone	289,085,114	292,640,736	296,240,090	299,883,715	303,572,155	307,305,961	311,085,691	314,911,910	CISCO (Mail)
Phone (Penetration)	92.19%	92.55%	92.93%	93.33%	93.74%	94.15%	94.56%	94.98%	TAS
M2M Connections	31,111,111	46,666,667	70,000,000	95,042,737	129,044,599	175,210,742	237,892,980	323,000,000	CISCO
M2M Connections (Penetration)	9.92%	14.76%	21.96%	29.58%	39.85%	53.68%	72.31%	97.42%	TAS
2. Average Traffic per Device (Gb per month)									
Smartphones	0.28	0.40	0.56	0.80	1.13	1.60	2.27	3.21	CISCO
Tablet	1.74	2.68	4.12	6.33	9.73	14.97	23.01	35.38	CISCO (Mail)
Laptop	1.43	2.08	2.44	2.88	3.40	4.02	4.74	5.60	CISCO
Portable Gaming Console	0.24	0.31	0.39	0.50	0.64	0.81	1.03	1.31	CISCO
PC	15.40	17.68	20.31	23.33	26.80	30.78	35.35	40.60	CISCO (Mail)
Phone	0.31	0.49	0.79	1.28	2.06	3.31	5.33	8.59	CISCO (Mail)
M2M	0.04	0.05	0.07	0.10	0.14	0.20	0.28	0.39	CISCO
3. Total Traffic per device (Gb per month)									
Smartphones	31,723,574	55,448,934	96,917,969	153,796,072	244,054,142	387,281,830	614,565,337	975,234,375	
Tablets	45,985,183	93,735,136	191,067,541	389,467,671	793,881,922	1,618,230,608	3,298,563,967	6,723,716,751	
Laptop	335,321,758	493,535,400	584,400,375	695,199,712	826,953,359	983,661,915	1,170,044,724	1,391,691,259	
Portable Gaming Console	10,154,567	14,535,566	20,372,953	28,554,596	40,021,933	56,094,477	78,621,647	110,195,581	
PC	5,066,567,473	5,819,415,328	6,684,129,826	7,383,809,800	8,156,730,733	9,010,559,324	9,953,764,811	10,995,702,968	
Phone	88,706,552	144,528,663	235,479,049	383,663,567	625,099,064	1,018,467,409	1,659,378,367	2,703,607,931	
M2M	1,194,306	2,490,943	5,195,313	9,808,199	18,516,840	34,957,830	65,996,676	124,594,727	
Total Traffic (Gb per Month) (Smartphones+Tablets+Laptops)	413,030,514	642,719,470	872,385,884	1,238,463,455	1,864,889,422	2,989,174,353	5,083,174,029	9,090,642,385	
Total Traffic (Gb per Month)	5,579,653,413	6,623,689,970	7,817,563,024	9,044,299,618	10,705,257,992	13,109,253,394	16,840,935,530	23,024,743,592	
3.1 Total Traffic per device (Exabytes per month)									
Smartphones	0.03	0.05	0.09	0.14	0.23	0.36	0.57	0.91	
Tablets (Model)	0.04	0.09	0.18	0.36	0.74	1.51	3.07	6.26	
Laptop (Model)	0.31	0.46	0.54	0.65	0.77	0.92	1.09	1.30	
Portable Gaming Console (Model)	0.01	0.01	0.02	0.03	0.04	0.05	0.07	0.10	
PC	4.72	5.42	6.23	6.88	7.60	8.39	9.27	10.24	
Phone	0.08	0.13	0.22	0.36	0.58	0.95	1.55	2.52	
M2M (Model)	0.00	0.00	0.00	0.01	0.02	0.03	0.06	0.12	
Total Traffic (Exabytes per Month) (Smartphones+Tablets)	0.07	0.14	0.27	0.51	0.97	1.87	3.64	7.17	
Total Traffic (Exabytes per Month) (Smartphones+Tablets+Laptops)	0.38	0.60	0.81	1.15	1.74	2.78	4.73	8.47	
Total Traffic (Exabytes per Month)	5.20	6.17	7.28	8.42	9.97	12.21	15.68	21.44	
Total Trafifc (CISCO)	4.84	5.64	6.62	7.60	8.92	10.85	13.89	19.02	
Mobile devices like smartphones or tablets (CISCO)	0.11	0.21	0.39	0.75	1.41	2.68	5.09	9.65	CISCO
4. Percent Wi-Fi Offloading									
Smartphones	57.11%	58.05%	59.00%	59.97%	60.95%	61.95%	62.97%	64.00%	CISCO
Tablets	76.60%	76.80%	77%	77%	77%	78%	78%	78%	CISCO
Laptop	41.03%	43.91%	47.00%	50.30%	53.84%	57.62%	61.67%	66.00%	TAS
Average	41.03%	43.91%	47%	50%	54%	58%	62%	66%	CISCO
5. Total Wi-Fi Traffic per device (Exabytes per month)									
Smartphones	0.02	0.03	0.05	0.08	0.13	0.21	0.34	0.54	
Tablets	0.03	0.07	0.14	0.28	0.57	1.16	2.37	4.82	
Laptop	0.15	0.22	0.26	0.30	0.36	0.43	0.51	0.61	
Total Wi-Fi (Exabytes per month)	0.20	0.31	0.45	0.67	1.07	1.80	3.22	5.97	
No cost Wi FI (%)	4.32%	4.32%	4.32%	4.32%	4.32%	4.32%	4.32%	4.32%	
No cost Wi Fi (Exabytes per month)	0.01	0.01	0.02	0.03	0.05	0.08	0.14	0.26	
No cost WI Fi (Exabytes per Year)	0.10	0.16	0.23	0.35	0.55	0.94	1.67	3.10	
No cost Wi Fi (Million Gb Per year)	109.83	174.74	248.46	372.12	593.40	1004.71	1790.87	3323.38	

Appendix 2. Economic Impact of Speed Differential

1. Mobile/Wi-Fi Traffic	2012	2013	2014	2015	2016	2017	SOURCE
Average Mobile Connection Speed (Mbps)	2.41	3.43	4.88	6.94	9.87	14.05	CISCO
Wi-Fi Speeds from Mobile Device (Mbps)	11.50	13.32	15.43	17.88	20.72	24.00	CISCO
Speed Gap Wi -Fi vs Mobile (Mbps)	9.09	9.89	10.56	10.94	10.84	9.95	TAS
Average Speed (Mbps)	8.68	10.15	12.09	14.60	17.75	21.60	TAS
Mobile Traffic (Exabytes per month)	0.20	0.32	0.49	0.77	1.21	1.90	#REF!
Total Wi-Fi (Exabytes per month)	0.45	0.67	1.07	1.80	3.22	5.97	TAS
Total Traffic (Exabytes per month)	0.65	0.98	1.56	2.58	4.43	7.87	TAS
Mobile Traffic (Exabytes per year)	2.41	3.78	5.93	9.29	14.55	22.80	TAS
Total Wi-Fi (Exabytes per year)	5.35	8.02	12.78	21.65	38.58	71.60	TAS
Total Traffic (Exabytes per month)	7.77	11.80	18.71	30.93	53.13	94.40	TAS
2. Economic Impact of Wi-Fi Speed							
Speed Wi-Fi over Mobile Speed (Mbps)	9.09	9.89	10.56	10.94	10.84	9.95	TAS
Speed decrease (%)	-72.21%	-66.21%	-59.65%	-52.45%	-44.36%	-34.96%	TAS
Wi-Fi Traffic (% Total Traffic)	6.74%	8.79%	11.95%	16.63%	23.15%	31.37%	TAS
Coefficient of Bohlin	0.30%	Growth in GDP per capita					
Decrease in GDP Per Capita	-0.22%	-0.20%	-0.18%	-0.16%	-0.13%	-0.10%	TAS
GDP Per Capita (Current Prices)	49,922.11	51,248.21	53,327.98	55,837.31	58,436.31	61,133.84	USA BUREAU
Population	313,579,434	316,208,509	318,777,991	321,316,861	323,855,320	326,408,880	USA BUREAU
GDP Reduction (Current Prices)	-2,284,207,081	-2,830,964,976	-3,634,031,416	-4,694,544,449	-5,831,419,302	-6,565,326,374	TAS

Appendix 3. Annual Costs To Be Incurred by Home Traffic Generated by Devices With No Wireline Connectivity (2013-2017)

Total Traffic per Month			2010	2011	2012	2013	2014	2015	2016	2017
Smartphones			31,723,574	55,448,934	96,917,969	153,796,072	244,054,142	387,281,830	614,565,337	975,234,375
Portable Gaming Console			10,154,567	14,535,566	20,372,953	28,554,596	40,021,933	56,094,477	78,621,647	110,195,581
Tablets			45,985,183	93,735,136	191,067,541	389,467,671	793,881,922	1,618,230,608	3,298,563,967	6,723,716,751
Total			87,863,323	163,719,636	308,358,462	571,818,339	1,077,957,997	2,061,606,915	3,991,750,952	7,809,146,706
Total Annual traffic			2010	2011	2012	2013	2014	2015	2016	2017
Smartphones			380,682,884	665,387,212	1,163,015,625	1,845,552,861	2,928,649,702	4,647,381,961	7,374,784,045	11,702,812,500
Gamning Conbsoles			121,854,802	174,426,788	244,475,433	342,655,155	480,263,198	673,133,721	943,459,770	1,322,346,971
Tablets			551,822,192	1,124,821,635	2,292,810,490	4,673,612,048	9,526,583,060	19,418,767,297	39,582,767,607	80,684,601,007
Total			1,054,359,878	1,964,635,635	3,700,301,548	6,861,820,064	12,935,495,960	24,739,282,979	47,901,011,421	93,709,760,478
Split per location										
Location	Hours									
Home	2.6	43.1%								
Friend's home	0.35	5.8%								
At work	0.8	13.3%								
At work remote location	0.4	6.6%								
Retail location (stores, restaurants)	0.38	6.3%								
Public location (parks, schools)	0.45	7.5%								
Travel locations	0.45	7.5%								
On The Go	0.6	10.0%								
	6.03									
Total Annual Trafffic at Home			2010	2011	2012	2013	2014	2015	2016	2017
Smartphones			164,141,874	286,899,959	501,466,107	795,760,769	1,262,767,699	2,003,846,285	3,179,840,550	5,045,988,806
Gamning Conbsoles			52,541,042	75,208,897	105,412,293	147,745,175	207,078,659	290,240,079	406,798,574	570,166,190
Tablets			237,933,283	484,997,720	988,608,172	2,015,156,107	4,107,647,754	8,372,934,490	17,067,196,646	34,789,380,202
Total			454,616,199	847,106,576	1,595,486,571	2,958,662,051	5,577,494,112	10,667,020,853	20,653,835,770	40,405,535,198
Average Price per Gb			$10.28	$9.42	$8.52	$7.61	$7.05	$6.68	$6.39	$6.15
Price per home traffic			$ 4,672,296,843	$ 7,981,379,757	$ 13,600,954,551	$ 22,509,870,715	$ 39,293,937,014	$ 71,279,887,723	$ 131,980,574,122	$ 248,389,076,544