TELECOM
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Assessing the Economic Potential of
10G NETWORKS

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AUTHORS

RAUL KATZ

(Ph.D., Management Science and Political Science, Massachusetts Institute of Technology) is currently Director of Business Strategy Research at the Columbia Institute for Tele-Information, and President of Telecom Advisory Services, LLC (URL: www.teleadvs.com). Before founding Telecom Advisory Services, he worked for twenty years at Booz Allen Hamilton, where he was the Head of the Telecommunications Practice in North and Latin America and member of its Leadership Team.

MR. FERNANDO CALLORDA

(BA, MA, Economics, Universidad de San Andres-Argentina) is a Project Manager at Telecom Advisory Services, LLC and Research Fellow in the National Network of Public Universities in Argentina. He is also a professor of Political Economy at UNLAM and has taught courses of finance in regulated industries.

Telecom Advisory Services LLC (TAS) is an international consulting firm specialized in the development of business strategies and public policies for digital and telecommunications companies, governments, and international organizations. Its clients include leading companies in the digital and telecommunications sectors, as well as international organizations such as the International Telecommunications Union, the World Bank, the Inter-American Development Bank, the World Economic Forum, the UN Economic Commission for Latin America and the Caribbean, the GSMA Association, the CTIA, the NCTA, GigaEurope, the Wi-Fi Alliance, and the FTTH Council (Europe).

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EXECUTIVE SUMMARY

In 2019, the cable industry – led by NCTA–The Internet & Television Association, CableLabs and GIGAEurope – announced the next great leap forward in broadband platforms, called "10G". While many such providers have used recent investments to enable services offering Gigabit connectivity on a widespread basis,[1] the industry's evolution to a future 10G platform promises even greater strides in performance. The roll-out of 10G will allow the emergence of more secure, lower latency broadband connections with dramatically faster speeds that eventually will be capable of delivering near symmetrical download and upload speeds of up to 10 Gbps.[2] In addition, 10G networks will be the backbone of continued technological innovation, enabling a range of applications and use cases, as well as improving existing solutions in industries such as agriculture and telemedicine, bringing significant economic benefits.

These economic benefits were important to the nation's future prosperity pre-COVID, but they may be an increasingly critical lifeline for the country as we adapt and respond to "the new normal", when the value and virtue of robust, reliable and secure broadband networks is brought into even starker relief. The capability of 10G networks will be a critical infrastructure for delivering e-health services, on-line education, and teleworking platforms, all three being a fundamental contributor to the country's digital resilience in the face of the pandemic. Therefore, 10G networks have become not just a discretionary, good thing to do for the country's economy, but rather an infrastructure that can provide the nation with unique value in addressing and overcoming the challenges we face during this new challenge. During the pandemic, we are experiencing a) a more intense use of residential high-speed applications and b) a greater demand for applications that rely on secure, low latency, high-bandwidth capabilities over distributed systems. Along these lines, the 10G transition stands as an important opportunity for the country not only to build out a ubiquitous infrastructure that can support all manner of next generation applications and activity, but also as an important contributor to the country's digital resilience in light of the pandemic.

This study focuses on an assessment of the broader economic benefits associated with this next evolution of cable broadband platforms, which we estimate to **total at least $330 billion in economic output and create more than 676,000 new jobs over 7 years.** The analysis concentrates on three key areas of economic value creation:

Network investment for 10G roll-out will lead to a contribution to the U.S. Gross Domestic Product (GDP) of roughly $126.7 billion and 376,000 job years over seven years.

We use data from S&P Global Market Intelligence to estimate that the investment required for U.S. operators to add 10G capabilities to their networks will equal $81.4 billion. In addition to the direct economic impact yielded by this investment in technology and construction of networks, we find that there will be indirect and induced output of $45.3 billion due to the need of intermediate goods and services to support this evolution of cable broadband platforms. This will result in total GDP impact associated with the migration to 10G of $126.7 billion. In addition,

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[1] In the U.S., according to CableLabs, at the end of 2016, cable operators offered Gigabit service to 9% of U.S. households; by December 2018, 93% of cable operators' footprint, corresponding to 80% of U.S. households were able to offer Gigabit connectivity.

[2] The DOCSIS 4.0 specification, released in March 2020, offers a downstream speed of up to 10 Gbps and an upstream speed of up to 6 Gbps. (see Jones (2020). The 10G roadmap outlines a symmetric 10/10 (down/up) performance to be achieved over time.

we estimate that spending on 10G development will be associated with the creation of roughly 376,000 job years over a seven-year span. Of these, roughly 217,000 job years will be in the construction sector, 51,000 in electronic equipment, 51,000 in other manufacturing sectors, and 57,000 in other industries.

The range of applications and use cases enabled by 10G networks will generate economic benefits in the amount of $131.7 billion in cumulative GDP and 300,000 new jobs.

Spillovers from the increase in network speed enabled by 10G will lead to additional benefits to GDP. Aggregate GDP contribution from the return to speed benefits of 10G services will be $131.7 billion, evolving from $16.8 billion in 2021 to $20.8 billion in 2027. This represents $18.8 billion in average annual contribution. In addition to the GDP growth driven by these spillovers, the migration to 10G will create new jobs, particularly in the service sector. This next evolution of broadband platforms will generate total employment growth of close to 300,000, which equals an average of 43,000 new jobs per year. In particular, it will generate over 1,500,000 service sector jobs. The strong service sector job creation highlights the role of 10G as an enabler of labor shifts between the manufacturing and services sector. A sizeable portion of jobs lost in the future to automation could be gradually replaced by jobs in the services sector, an effect that can be enabled by 10G acting as a general-purpose technology.

The evolution of networks to 10G will generate $71.5 billion in consumer surplus.

Past research indicates that consumers perceive a higher utility value to faster broadband speed and lower latency which, in turn, drives an increased willingness to pay, as these factors increase the value of connectivity to consumers by providing access to a whole new range of entertainment and information applications.[3] Therefore, the migration to 10G will yield an increase in consumer surplus which we estimate to be $71.5 billion between 2021 and 2027, with an average annual value of $10.2 billion.

In total, the aggregate economic contribution of 10G in the United States will be nearly $330 billion.

Overall benefits from this migration to 10G will evolve from $38.2 billion in 2021 to $56.6 billion in 2027. These estimates assume that investment for the migration to 10G will be split evenly over seven years.[4]

Additional economic value may be realized by regulatory changes that will speed and increase incentives for private network investment.

Our estimation of the economic value associated with 10G networks reviewed so far represents a baseline scenario that assumes no specific policy or regulatory intervention aimed at incentivizing

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[3] See Nevo, A., Turner, J., and Williams, J. (2016) “Usage-based pricing and demand for residential broadband”, Econometrica, vol. 84, No.2 (March), 441-443, and Liu, Y-H; Prince, J., and Wallsten, J. (2017). Distinguishing bandwidth and latency in households’ willingness-to-pay for broadband internet speed. Washington, DC: Technology Policy Institute.

[4] See Appendix D. Impact of investment in support of 10G migration on GDP and employment. These efforts to estimate the impact of cable’s investments in 10G may be viewed as conservative as they do not capture the sizeable economic benefits that flow from the development and use of cable’s current generation DOCSIS 3.1 technology. While separate from this analysis, such advances are an important part of cable’s migration to future 10G platforms.

the migration to 10G. However, certain policies could act as a stimulus for the move to this infrastructure. For example, a reduction of sales taxes on purchasing broadband equipment, a reduction of in-kind demands and additional fees to cable operators as well as the elimination of disparities of fees regarding access to passive infrastructure would accelerate the evolution of the cable industry's 10G technology platform. Under one scenario, this acceleration will generate an additional $102 billion in GDP and consumer surplus in the United States. This policy intervention scenario also generates higher average annual new jobs created between 2021 and 2025 than the baseline scenario (179,000 vs. 97,000). The levers in the policy intervention scenario would be designed to also increase investment in the areas with marginal return, suggesting that some areas that would not otherwise be served could benefit from 10G. This could include areas currently unserved or underserved by broadband providers, which could provide additional spillover benefits and increases in consumer surplus.

In summary, the evolution of cable networks to 10G technology represents a critical infrastructure required to build future economies capable of delivering enhanced consumer welfare, bringing substantial societal benefits and additional competitiveness in the United States. In addition, 10G networks represent a way to meet the need for ever increasing speed, lower latency and greater security required by broadband users. Our analysis shows that there are substantial economic benefits from this technological evolution: GDP growth, job creation, support for emerging applications and consumer surplus. More fundamentally, 10G is a key component of an infrastructure aimed at building future networks that are increasingly reliable, resilient and able to assist the country in adapting to changes in demand for and use of the internet that follow from the "new normal" created by the COVID-19 pandemic.

We structured this study around eight chapters, complemented with technical appendices:

- Chapter 1 explains how 10G networks differ in terms of technology, features, and performance from current cable technology, while representing a gradual migration path from DOCSIS 3.1 technology.
- Chapter 2 reviews the theoretical frameworks and methodologies relied upon for conducting the assessment of economic benefits of 10G networks.
- Chapter 3 tackles the impact of the new services that will be enabled by 10G networks, focusing on the delivery of a selected list of enterprise use cases (for example, smart manufacturing and precision agriculture), public services (such as e-health and smart cities), and consumer applications (such as virtual reality and immersive video).
- Chapter 4 presents an estimate, based on input-output analysis, of the impact that the investment in 10G will have on GDP and job creation, primarily in the electronics equipment and construction industries.
- Chapter 5 assesses the economic benefit (or spillovers) of 10G once these networks can support such advanced capability. Our estimates in this case are based on econometric modelling of historical data on the so-called "return to speed."[5]
- Chapter 6 presents our estimation of the increase in consumer surplus as a result of increased service speeds, assuming applications in Chapter 3 are enabled by 10G.
- Chapter 7 adds up the results of our different assessments of economic benefit.

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[5] Research, reviewed in Appendix B, also provides evidence of the affect broadband speed has on GDP growth, job creation and consumer surplus.

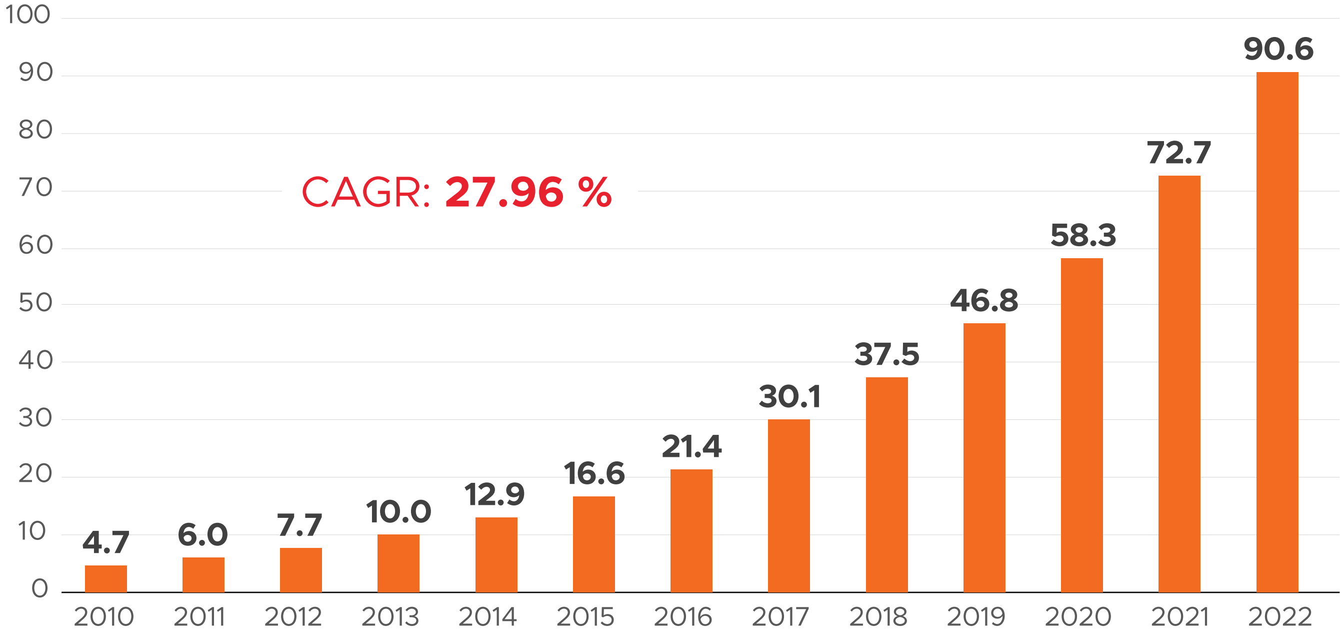
- Chapter 8 outlines some public policy and regulatory stimuli that could accelerate the development of 10G networks and the implications of these incentives on the estimation of economic benefits.
- All analyses and models in support of the calculations included in this study are presented in the corresponding appendices.

TECHNOLOGY, FEATURES AND PERFORMANCE OF 10G NETWORKS

There has been tremendous growth in internet traffic over the last decade; in the United States traffic has been growing at an average annual growth rate of nearly 28% (See Graphic 1-1).

Graphic 1-1

United States: Internet Monthly Traffic, in exabytes[6]



Note: Year end 2020 and projections were developed pre-COVID-19. While recent data indicates that downstream peak growth increased 14.3% and upstream peak grew 27.1% since March 2020, once the initial shock is accounted for, it is estimated that monthly traffic will resume its historical growth (see Ookla/Speedtest).

Source: Cisco Visual Networking Index; Telecom Advisory Services analysis

The increase in the number of devices that rely on the internet (PCs, smartphones, tablets, smart TVs) is one factor driving the growth in traffic. In parallel, the usage per device has increased dramatically. In 2019, each smartphone in the United States generated total traffic of 24.4 GB per month (up from 12.6 GB in 2017). Of this traffic, video represented 70%.[7]

As expected, the growth in internet traffic has been paralleled by an increase in fixed broadband speed. In fact, we estimate that the average broadband download speed has been growing by 29.3% annually (see Graphic 1-2 and Appendix A).[8]

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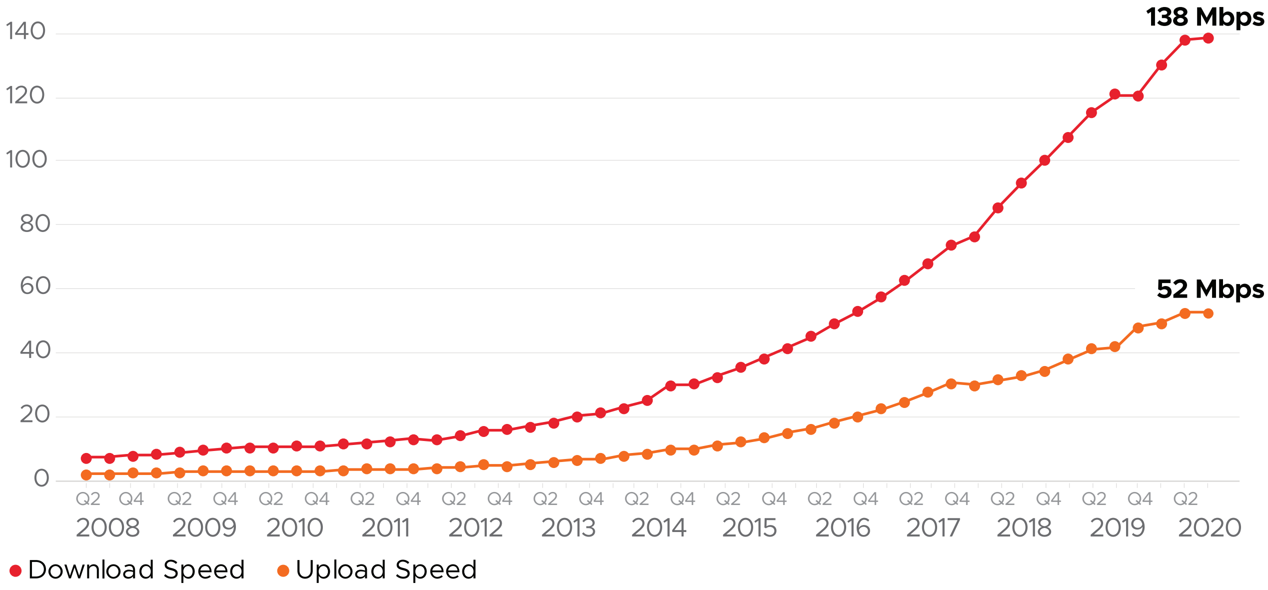
[6] An exabyte is equivalent to 1,073,741,824 gigabytes.

[7] CISCO Visual Networking Index (2018).

[8] The analysis here and in Appendix A is based on Ookla/Speedtest daily internet traffic compiled between 2008 and 2020, as reported in the site. The service measures the bandwidth (speed) and latency of a visitor's internet connection against one of 4,759 geographically dispersed servers located around the world. Each test measures the data rate for the download direction, i.e. from the server to the user computer, and the upload data rate, i.e. from the user's computer to the server.

Graphic 1-2

United States: Fixed Broadband Average Download and Upload Speed (in Mbps)

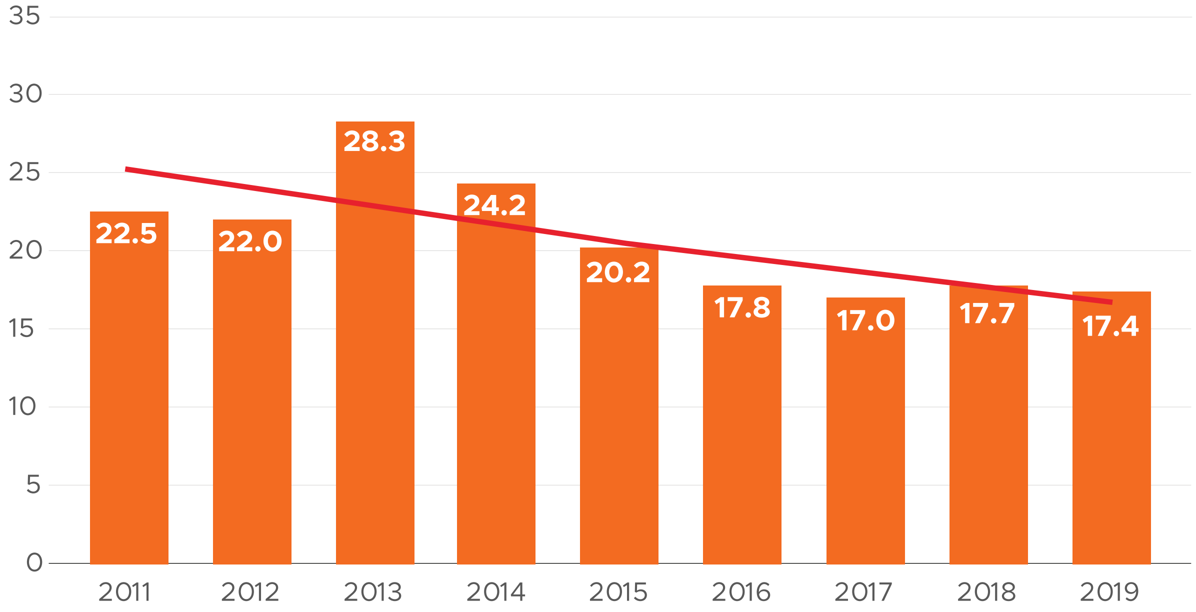


Note: This graphic shows an average of peak upload and download speeds across US wireline providers measured during a speed test.

Source: Ookla/Speedtest; Telecom Advisory Services analysis

Graphic 1-3

United States: Fixed Broadband (cable and FTTx) Peak Average Latency



Note: The values are derived from measurement of sixteen carriers. Each year value is an arithmetic average of all cable and fiber observations within the country.

Sources: FCC. Measuring Broadband America (2012-2020); Telecom Advisory Services analysis.

Network speed and latency are related since transmission technology is one of the factors that reduce the time it takes for packets to travel from the source to the user.[9] This is why the latency for cable and fiber providers has diminished from an average of 22.5 Ms. in 2011 to 17.4 Ms. in 2019. However, as indicated in Graphic 1-3 on the previous page, at faster speed levels, the impact of the speed factor on latency is attenuated.

The communications industry, including both the incumbent telecommunications operators and cable broadband providers, has been increasing the capabilities of its networks to accommodate the growing demand for faster broadband speed and lower latency. While speed, latency and quality of service have been improving significantly, the ever-growing user needs fueled by new applications is pushing for additional network enhancements.

1.1. Technology and features

Since the end of the twentieth century, the cable industry has been deploying successive generations of the international telecommunications standard that allow for the addition of high-bandwidth data transfer over an existing coaxial cable network. Developed originally in March 1997, DOCSIS© (Data Over Cable Service Interface Specification) allows operators to offer higher performance broadband service without having to replace completely their coaxial cable networks.[10]

Cable operators in the United States have been actively migrating to DOCSIS 3.0 and DOCSIS 3.1 technology over the past several years. As of June, 2019,[11] 79% of all households passed by cable broadband were supported by the DOCSIS 3.1 standard and 8% by DOCSIS 3.0. By December 2018, cable gigabit service was available to 93% of housing units passed by cable broadband providers (see Graphic A-4 in Appendix A). Overall, 94.8% of the U.S population in June 2019 had access to fixed broadband speeds of at least 25 Mbps downstream and 3 Mbps upstream; 85.9% had access to speeds of at least 250 Mbps downstream and 25 Mbps upstream.[12]

In January 2019, the cable industry announced an industry initiative, labeled “10G”, that would build on the work the industry has done implementing DOCSIS 3.1 technology. Not only will 10G deliver ten times the current most prevalent maximum speeds offered to consumers, it will be combined with latency of 1 millisecond which is critical for applications, such as industrial IOT and e-health applications, where timeliness is important. In addition, the technology is fully compatible with prior generations of DOCSIS 3.0 and 3.1 technology, which reduces migration costs and minimizes consumer disruption.

The implementation of 10G will require cable operators to drive fiber deeper into their networks. Since the early 1990s, cable operators have relied on network technology that is comprised of a fiber portion connecting a cable head end to an optical node (which converts the optical

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[9] Latency measures the time it takes for a data packet to travel from one point in the network to another. High latency has a negative impact on the service quality of interactive applications. Latency is affected by several factors such as the physical distance data must travel (for example geostationary satellites require data to travel 22,000 miles each way), the number of nodes the data must traverse (which pushes service providers to cache content closer to their end users), and how the network equipment (routers, switches, etc.) buffers and forwards the data. The other two factors driving latency is the network architecture and the capability of the technology to schedule buffers.

[10] DOCSIS comprises two main components: the physical layer (called PHY) and the media access control layer (MAC). The physical layer pertains to the wiring and routing equipment used, as well as the frequency at which data is transmitted through the physical systems. The MAC layer handles the information being processed over the network components.

[11] Federal Communications Commission (FCC) 477 data.

[12] FCC 477 Data.

signal to a radio frequency), and a coaxial cable equipped with amplifiers to enhance the radio frequency signal quality. The deeper fiber is deployed in the cable network, the lower the number of households supported by the node. This increases the capacity available to each user.

Cable operators will use different approaches to tackle their upcoming evolution to 10G network capabilities.[13] The economics for deploying 10G varies depending on the approach to be followed by each cable operator. To implement 10G, operators also will have to install additional electronic equipment to gain more capacity in the fiber link. As more service groups are created, equivalent Cable Modem Termination System (CMTS) capacity must be added. Moreover, upgrades to Digital Optics (10G Ethernet) are required for deploying Distributed Access Architectures, such as Remote PHY. Additionally, operators will need to install new set-top boxes or Digital Terminal Adapters in the customer premise to offer digital video while freeing valuable spectrum and upgrading the modem in the home to be able to receive the new speeds.

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[13] See, for example, https://www.lightreading.com/cable/docsis/cablelabs-kicks-off-pursuit-of-docsis-40/d/d-id/752355.

THEORETICAL FRAMEWORK FOR ESTIMATING THE ECONOMIC CONTRIBUTION OF 10G NETWORKS

In this chapter, we first discuss the economic impact of investment in broadband infrastructure deployment (detailed review of research literature is presented in Appendix B). Second, the effects of speed on economic growth, employment, enterprise productivity, and consumer surplus are summarized. We also discuss the methodologies upon which we rely to estimate each of the economic effects are presented. Finally, we discuss how these methodologies are integrated within a single theoretical framework.

Before describing this methodology in more detail, it is important to note that our economic analysis focuses on impacts anticipated from the industry's expected use of next generation technology in future 10G platforms. As such, in this analysis we make no effort to quantify benefits that may flow today from cable's use of current generation technology (DOCSIS 3.1), even though the performance improvements in networks achieved over the past few years in achieving gigabit connectivity have been substantial and can be viewed as part of the industry's roadmap to full realization of 10G network technology. Furthermore, the research literature reviewed in Appendix B provides substantial evidence of the value of broadband access achieved so far.

2.1 Economic impact of network evolution

As outlined in chapter 1, the evolution of cable broadband platforms to next generation 10G platforms will entail capital spending that will be funded from ongoing capital expenditures which, in turn, will translate into GDP growth and jobs. The migration to 10G will affect the economy and employment in three ways:

- 10G will require investment to upgrade cable's current infrastructure. This translates directly into additional GDP and jobs (technicians, construction workers, manufacturers of telecommunications equipment).
- In addition, these expenditures create indirect spending triggered by upstream buying and selling between suppliers and cable operators (electric supplies, metal products, etc.).
- Finally, the household spending resulting from the income generated from the direct and indirect jobs creates additional "induced" economic effects.

Several studies, discussed in Appendix B, have examined these effects. All these studies calculated multipliers, which measure the total output and employment change throughout the economy resulting from a given amount of investment made in broadband networks.[14]

The impact of broadband investment is typically measured with input-output (I/O) tables.[15]

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[14] Multipliers are of two types. Type I multipliers measure the direct and indirect effects (direct plus indirect divided by the direct effect), while Type II multipliers measure Type I effects plus induced effects (direct plus indirect plus induced divided by the direct effect).

[15] I/O tables measure the interdependence of an economy's productive sectors by considering the product of each industry both as a commodity demanded for final consumption and as a factor in the production of itself and other goods. While I/O tables are a reliable tool for predicting investment impact, they are static models reflecting the interrelationship between economic sectors at a certain point in time and are only infrequently updated. Since those interactions may change, the matrices from one period may overestimate or underestimate the impact of broadband investment in a different period.

2.2. Broadband speed effects on economic growth and other measures of well-being

We discuss the research on the impact of increasing fixed broadband speed on various measures of economic well-being in Appendix B. The research covers economic growth, household income, enterprise activity, job creation and consumer surplus.

- **Economic growth:** Research generally concludes that faster internet access has a positive impact on GDP growth. Among the main findings in the literature is that there appears to be a required minimum threshold of broadband speed needed to generate economic benefits. Furthermore, the relationship linking broadband speed to GDP growth is non-linear. In other words, a jump in speed does not yield a continuous proportional impact in GDP growth.
- **Household income:** Some research indicates that households in advanced economies gain more from faster broadband speed than in emerging countries, although the impact of speed on income may not be as strong due to "reverse causality"; that is, higher speeds can increase income, but higher income also can increase speeds and this is not always considered when estimating these effects.
- **Enterprise activity:** Several studies indicate that faster broadband speeds result in more extensive use of the internet, which leads, in turn, to more enterprise sales and an increase in overall productivity.
- **Job creation:** The impact of broadband on job creation has been found to be channeled through intermediate variables. For example, faster broadband increases regional attractiveness, which in turn attracts new firms to the area and incubates new firms in need of workers.[16] Another set of findings indicates that higher broadband speed leads to an acceleration of innovation and, therefore, the growth of employment primarily in the services sector with little effect in agriculture and manufacturing.[17]
- **Consumer surplus:** The availability of high-speed broadband creates additional value to consumers since it allows access to new applications and improves the digital resilience of household in the context of a pandemic. This additional value increases in turn the consumers' willingness to pay. As in the case of impact on GDP growth, the effect is non-linear. In other words, faster speed does not proportionally yield more consumer surplus.

2.3. Methodologies to assess the economic impact of 10G

Based on the review of the research literature regarding the economic impact of broadband we decided to focus the study on three areas (see Figure 2-1 on the next page):

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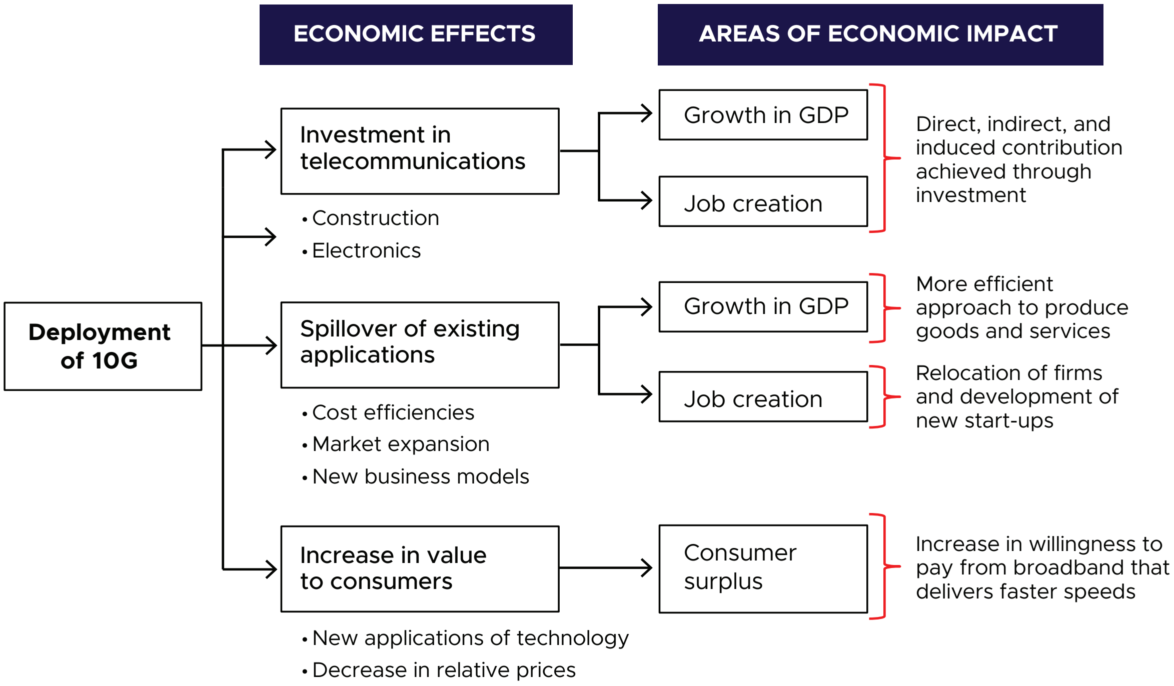
[16] That said, it should be noted since this effect in part enables firm relocation, it could result in a zero-sum game as more workers in one region imply less workers in another.

[17] For example, Hasbi (2017) analyzed panel data on 36,000 municipalities in France between 2010 and 2015 and found that deployment of high-speed broadband (> 30 Mbps) increases company relocation and start-up development in the non-agricultural sector.

Figure 2-1

Economic Contribution of 10G



Source: Telecom Advisory Services

- **The impact of investment needed to migrate to 10G:** as with any infrastructure project, the migration to 10G will require investment with the consequent direct, indirect, and induced contribution to GDP and job creation. Our approach here will be based on I/O analysis.
- **Spillover of existing and future applications:**[18] consistent with past literature on the impact of communications technology, the increasing speeds from 10G will have an impact on cost efficiencies, market expansion, and new product development. These effects translate into growth of GDP as well as new jobs resulting from the development of new business models and firms. Our methodological approach in this case is based on econometric models. Since spillovers materialize as a result of the ongoing increase in broadband speed, it is important to differentiate the portion of the growth in speed that can be attributed to the increase that would have occurred without 10G versus the part that takes place when the migration to 10G infrastructure begins.
- **Consumer surplus:** this is the value that consumers would be willing to pay for a service or a good compared to what they actually pay. Our assessment of consumer surplus will be based on the results of primary consumer research.[19]

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[18] Spillover of new applications and business models not only derive from the "return to speed" (driven by low latency and improved performance) but from new uses of the technology. This last domain comprises not only technologies that are currently under implementation, but also applications that are at an early stage of the development life cycle. For these cases, our analysis will be primarily qualitative although attempts are made to estimate benefits at the sector level.

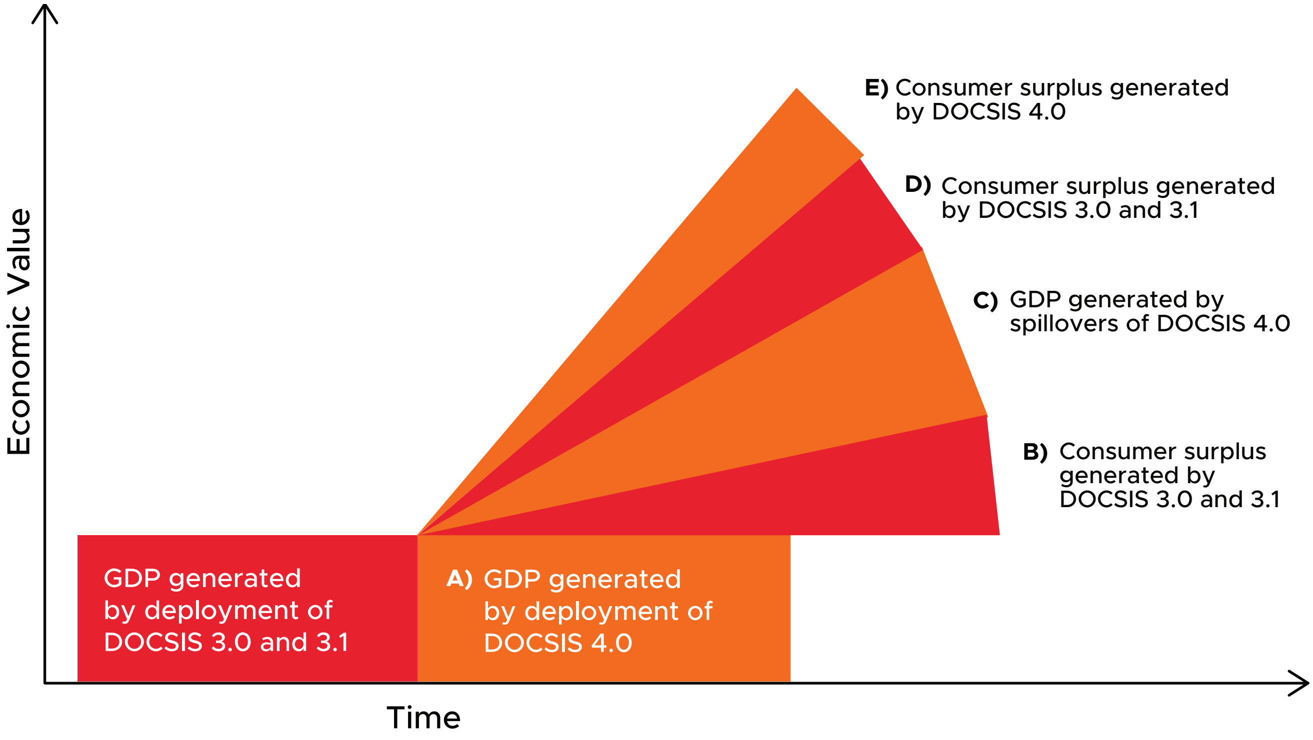
[19] The estimation of consumer surplus will be based on data generated by previous research conducted in the United States, primarily that of Nevo, A., Turner, J., and Williams, J. (2016) "Usage-based pricing and demand for residential broadband", Econometrica, vol. 84, No.2 (March), 441-443., though we also consulted Liu, Y-H; Prince, J., and Wallsten, J. (2017). Distinguishing bandwidth and latency in households' willingness-to-pay for broadband internet speed. Washington, DC: Technology Policy Institute.

The methodologies used for assessing the contribution of 10G in each of these areas are discussed in more detail in Appendix C.

These three effects do not appear simultaneously and need to be assessed in terms of their impact over time (see figure 2-2).

Figure 2-2

Framework for Assessing Economic Value of 10G



Source: Telecom Advisory Services

According to the framework of figure 2-2, the economic value of 10G attributable to DOCSIS 4.0 technology will be estimated by adding the effects depicted in areas A, C, and E. The GDP generated as the network evolves to the DOCSIS 4.0 standard (area A) represents an extension of the construction effect triggered by current capital spending in network modernization. Once the migration to DOCSIS 4.0 technology begins, spillovers and consumer surplus attributed to the increase in speed and quality, like reduced latency attached to the technology, will begin to emerge (areas B, C, D and E). However, to estimate the incremental effects from 10G attributable to DOCSIS 4.0 technology, we need to subtract the economic effects yielded by the average increase in speed resulting from the natural progress of DOCSIS 3.1 technology that would occur in the absence of 10G (areas B and D) from the incremental amount that will occur as a result of 10G (areas E and C).

ENABLEMENT OF EMERGING APPLICATIONS AND USE CASES BY 10G NETWORKS

A fundamental driver of the economic value of 10G resides in its capability to enable innovative applications and use cases. These applications will be deployed within the consumer, enterprise and public services markets, and will have significant impact on enterprise productivity, health care and consumer wellbeing.

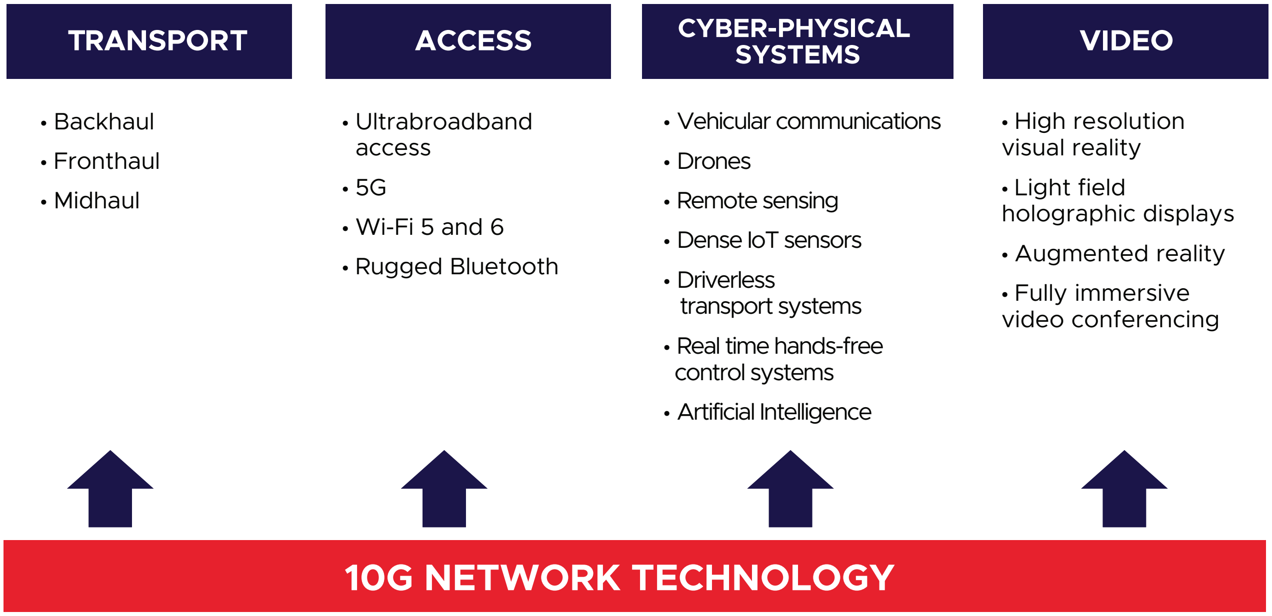
Our analysis of the value of emerging applications is complicated by the fact that the value of 10G functionality cannot be easily disaggregated from the contribution of other technologies (such as augmented reality). As explained below, the emerging applications and use cases that will improve enterprise performance will be implemented and developed within an environment that combines multiple technologies, including 10G. This universe of relevant technologies can be grouped into four areas:

- **Access:** technologies that provide the connectivity to end-user devices.
- **Transport**: technologies that provide high performance transport capacity from nodes and points of signal distribution, such as wireless base stations and Wi-Fi hotspots.
- **Cyber-physical systems:** systems built around the integration of computing power, networking, and physical process. Computers and networks monitoring and controlling physical processes, which in turn, generate feedback loops into computers.
- **Video displays:** devices capable of displaying video signals and integrating them into the delivery of new information.

Within this typology, 10G technology will play a critical role facilitating the flow of information among devices and display components (see figure 3-1).

Figure 3-1

Technologies Contributing to New Applications and Business Models



Source: Telecom Advisory Services

3.1. Consumers

For many forward-looking consumer applications, technical capabilities that can generate a visual experience close to reality as well as the ability to handle extremely high synchronization and "round-trip" speeds will be needed. In the words of an expert,

> ***"....the eye can receive 720 million pixels for each of 2 eyes, at 36 bits per pixel for full color and at 60 frames per second: that's 3.1 trillion (tera) bits! Today's compression standards can reduce that by a factor of 300 and even if future compression could reach a factor of 600 (which is the goal of future video standards), that still means we need 5.2 gigabits per second of network throughput; maybe more."***[20]

10G, with its extremely high throughput and low latency, is ideally suited to facilitate these technologies. More specifically, under these constraints, the use cases reviewed below will require a combination of 5G for high speed mobile connectivity, high speed throughput Wi-Fi routers, and 10G networks for backhaul and, in some cases, fixed connectivity. Beyond the bandwidth requirement, forward-looking consumer applications are very demanding in terms of low latency which 10G will provide. For example, while immersive videoconferencing can function with latency of 100 milliseconds, some of the applications described below require 10 millisecond or less.

This technology has become more critical for consumers in the context of the COVID-19 pandemic. Under complete or partial lockdown conditions, residential consumers have had to rely on broadband to carry out many daily tasks that previously required physical contact, such as working from home and distance learning, requiring video-conferencing and cloud computing. U.S. networks have generally performed well in response to demand spikes observed for both downstream and upstream uses under COVID-19 (and particularly so when compared to the experience in other countries). In the United States, average daily downstream consumption from 9 a.m. to 5 p.m. in the first week of April totaled about 6.35 GB per household, up 42% from 4.46 GB in January, while upstream average usage during business hours rose to 0.39 GB, up 83% compared with 0.22 GB in January. Even considering these dramatic increases, home internet use remains heavily asymmetrical. This is driven by the continued use of video streaming services that require substantial amounts of data to be transmitted to the home. More frequent use of two-way video collaboration tools (e.g., Zoom, Microsoft Teams) and cloud computing do require more upstream usage due to two-way audio and video functionality. However, even with the increased use of these collaboration tools, upstream data usage remained well below a tenth of total data usage over home internet connections.[21] SamKnows also showed a slight drop in download speeds on average of about 1% (see Graphic 3-1 on the next page).

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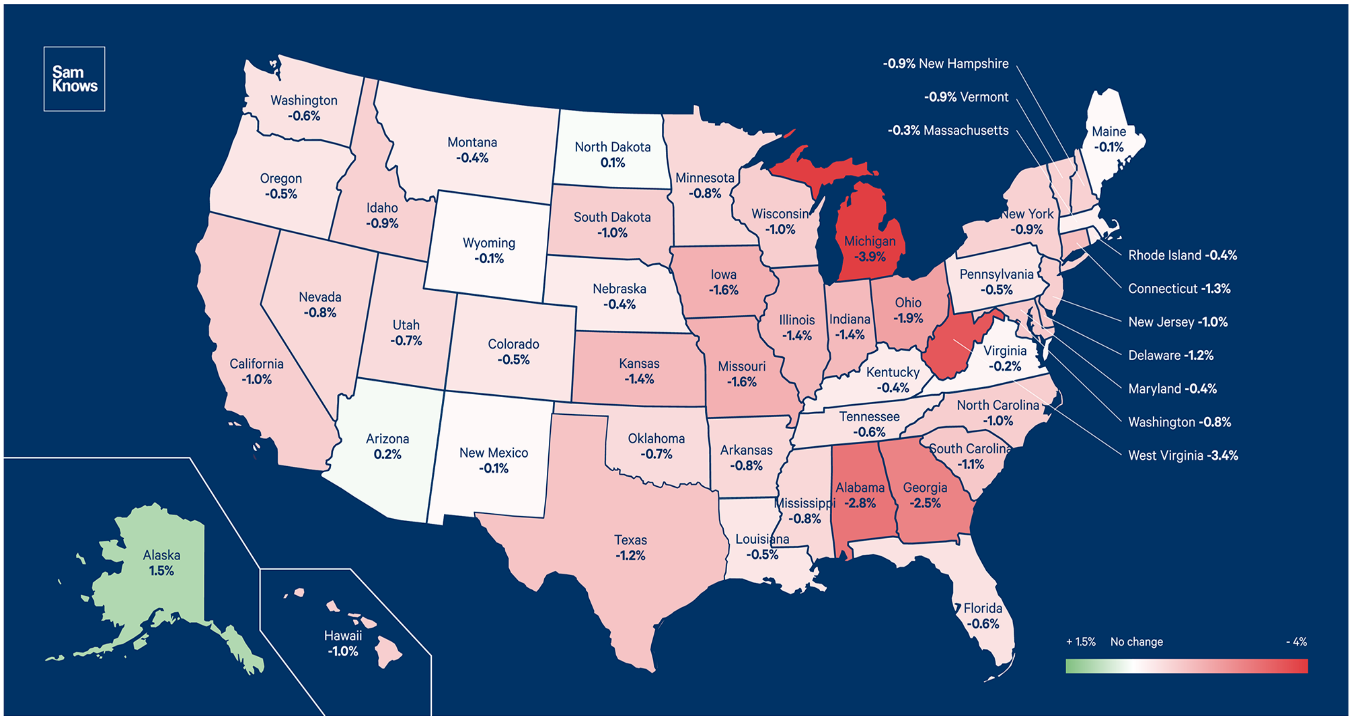
[20] Westphal, C. (2017). Challenges in networking to support augmented reality and virtual reality, Presentation to IETF98 – ICNRG Meeting – 3/30/17.

[21] Openvault (2020). Broadband usage hit record Sunday highs on Easter (April 14).

Graphic 3-1

Percentage Change in Download Speed by US State, March 12–24, 2020



Source: SamKnows

Going forward, changes in consumer behavior and greater reliance on home broadband technology during the pandemic will accelerate demand for next generation technologies like 10G networks that can support faster speeds, lower latency, and the development of newly emerging online applications.

Beyond the increase in traffic driven by existing applications, the new "normal" is putting more pressure on the development of platforms that are better adapted to the current conditions. In the case of distant learning, conventional videoconferencing platforms need to add more functionality for the instructors to sense whether the students are absorbing the concepts or for students to detect whether they are asking too many questions and, therefore, delaying the whole class.[22] Finally, some consumer applications will become even more important to address the social isolation resulting from the pandemic. One of them is the delivery of remote virtual reality platforms aimed at mitigating the isolation of the elderly living under lockdown conditions. Some nursing homes have already adopted virtual reality platforms that provide a 360-degree travel experience,[23] while some providers are delivering a blend of entertainment and therapy VR programming for senior residences. Research has shown that virtual reality can capture memory-care patients' attention longer than traditional senior-living programming.[24]

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[22] Govindarajan, V. and Srivastava, A. (2020). "What the shift to virtual learning could mean for the future of higher ed". Harvard Business Review (March 31).

[23] Lumpkin, L. (2019). A recent college graduate helps nursing-home residents see the world — without leaving home. Washington Post. (October 14).

[24] Read, K. (2019). Virtual Reality lets seniors travel without leaving home. Star Tribune (July 123).

Massively multiplayer online gaming

A massively multiplayer online game (MMOG) involves a large number of players, interacting with the same server. From a technology standpoint, an online multiplayer game is a virtual environment generated by computers, in which users that are geographically distributed perceive a graphical representation of a virtual world and control their virtual character known as avatar. This functionality drives high volumes of data transfers from information exchange, moving characters, and conducting other actions.

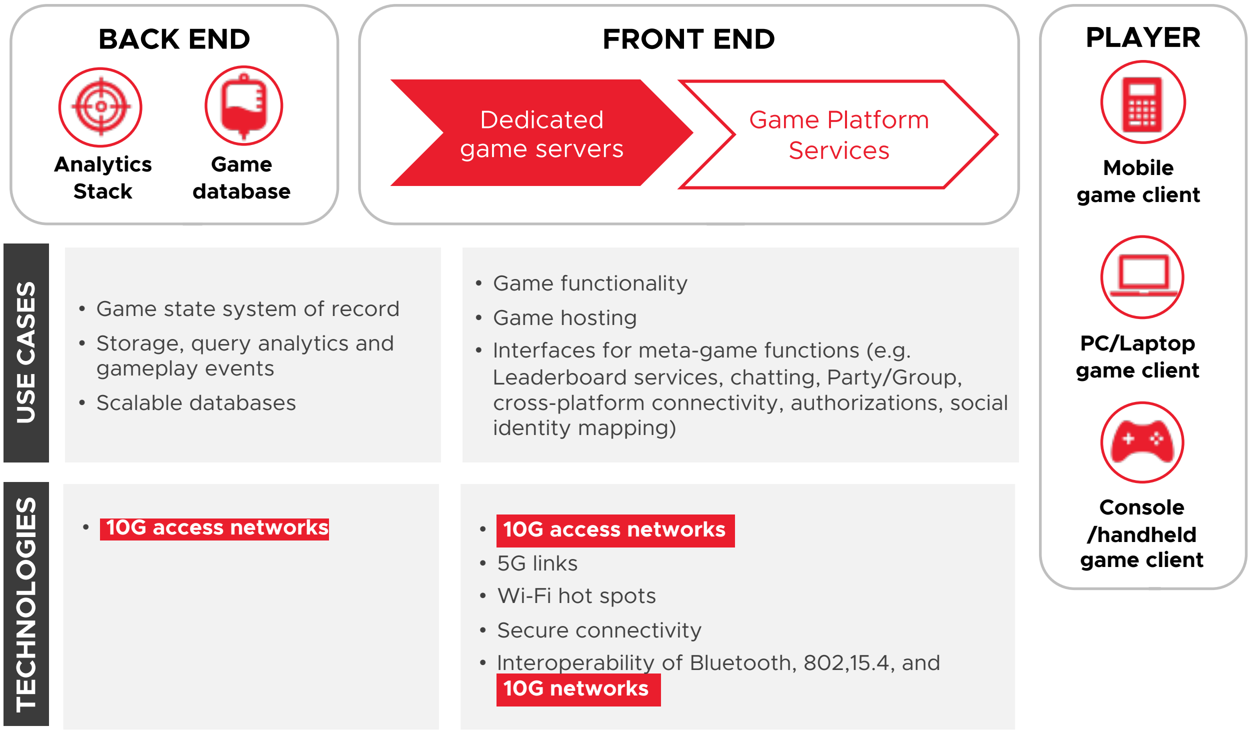
Under a centralized server configuration, MMOG systems require high bandwidth combined with low latency to be delivered in a consistent manner to all users.[25] The more dynamically rich a game environment is, the higher the requirement for bandwidth and research in future development highlight the need for several technical features[26] that could be better delivered by 10G networks:

- Development of a more immersive "world" to lower a player's suspension of disbelief
- Upgrade of the game engine to include collision detection and game physics
- Latency reduction
- More developed graphics and effects

In this context, 10G could become a key enabler of future gaming networking architectures (see figure 3-2).

Figure 3-2

Massive Multiplayer Gaming: Use Cases and Technology Enablers



	BACK END	FRONT END
USE CASES	• Game state system of record • Storage, query analytics and gameplay events • Scalable databases	• Game functionality • Game hosting • Interfaces for meta-game functions (e.g. Leaderboard services, chatting, Party/Group, cross-platform connectivity, authorizations, social identity mapping)
TECHNOLOGIES	• **10G access networks**	• **10G access networks** • 5G links • Wi-Fi hot spots • Secure connectivity • Interoperability of Bluetooth, 802,15.4, and **10G networks**

Source: Telecom Advisory Services

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25 Ali, A. F. et al. "An overview of networking infrastructure for Massively Multiplayer Online Games", pp. 619-628.
26 Achterbosch, L. (2008). "Massively multiplayer online role-playing games: the past, present and future", ACM Computers in Entertainment, Vol. 5, No. 4, article 9.

High throughput enabled by 10G networks can facilitate links between the devices in use and games servers. Alternatively, 10G networks can also serve as the backhaul transport facility operating in the background for remote mobile devices.

As lockdowns and quarantine at home have been dictated around the world to face the coronavirus pandemic, online gaming has emerged as a popular means of addressing social isolation. With the practice of social distancing reducing consumer and business activity to a minimum, gaming offers an engaging distraction for people at home looking for social interaction. In the United States, gaming internet traffic has increased 75%, compared to increases of 12% in digital video traffic[27] since March 2020. New platforms are under development to face this growing need by relying on high throughput broadband networks and cloud computing.[28]

Immersive video/8K entertainment

As video quality continues to improve with higher resolution and more dynamic color and brightness, video streaming is likely to require higher broadband speeds. More intensive usage will likely arise from other applications and services as well. For example, ultra-high definition 8K has twice the horizontal and vertical resolution of 4K UHD with four times as many pixels overall (and sixteen times more than the 1080 HDTV format). While it is difficult to predict overall consumer adoption of this technology, given the lack of available content, if widespread adoption occurs, it will create the need for additional bandwidth. More immersive video technologies, such as higher-resolution virtual reality or light field holographic displays (discussed below), also will require greater bandwidth.

Virtual reality/Augmented reality

Virtual reality (VR) is a computer-generated simulation which makes the user, through sensory stimulation, feel as if he or she is experiencing a real-world scenario. Augmented reality (AR) is defined as the “augmentation” or overlays of a live, direct or indirect view of a physical environment by computer-generated input. It can be delivered on smart phones, tablets or a PC. The technology relies on “markers” that trigger the delivery of animation or digital information to the user device. Its primary applications, so far, are for business and educational purposes.[29]

These technologies will enable the development of a whole new set of consumer services and apps (especially in marketing), which will, in turn, require a large amount of bandwidth for an acceptable user experience. At a basic level, there is the personal movie theater with a head mounted display. From there, it moves into the educational use recreating the experience of a classroom, or a room in a cultural institution, like a museum. A more complex use entails the close to real time delivery of a sports or live event to many users, where each one perceives the experience from a specific field of view. Gaming applications which replicate a virtual environment with interactions between different users in a synchronized manner represent an extension of the MMOG applications reviewed above.

These two technologies - virtual reality and augmented reality - can become very bandwidth intensive and therefore, suited to operate in a broadband environment enabled by 10G. This is

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[27] Hall, S. (2020). How COVID-19 is taking gaming and esports to the next level. World Economic Forum (May 15).

[28] Business Research Company (2020). “Video gaming reaches an all-time high since COVID-19 lockdown initiation”. Cision (May 5).

[29] A simple use case is one where a user captures the image of a real-world object, and the underlying platform detects a marker, which triggers it to add a virtual object on top of the real-world image displaying it on the camera screen (see Pokémon Go).

especially true if the use case is not mobile, although even in mobility applications, 10G would fulfil a backhauling function linking the 5G base station or the Wi-Fi hot spot to the cloud. For example, a “retinal” 360˚ video delivery would require at least 600 Mbps of bandwidth.[30]

In the case of augmented reality, most applications require at least 100 Mbps throughput and latencies of as low as 1 Ms. However, if there is a requirement to extend the dynamic range and resolution that cameras are capable of capturing, the bitrate should increase by orders of magnitude. As an example, a retina level AR display without compression will require several Gbps of throughput to generate a fully immersive experience.[31] Likewise, low latency is a key quality feature of AR technology. For example, 20 Ms. latency produces a perceivable video delay, while even 10 Ms. yields jitter.[32] This issue becomes a concern in enterprise-based applications of augmented reality.

3.2. Enterprises

An enterprise use case is an application based on a combination of multiple technologies aimed at restructuring production processes, driving business value by solving specific operational problems or addressing bottlenecks. Such an application can reduce the time to market for product development, improve responsiveness to changes in demand, increase efficiency in resource management, and/or facilitate the development of new products. As stated above, 10G networks will play a key role as enablers in the delivery of use cases that will make a significant contribution to enterprise productivity.

Precision agriculture and food processing

Precision agriculture represents a systems-based approach for site-specific management of crop production systems. The efficiency of agricultural machinery can be increased through the deployment of sensors (grain yield, optical sensors for weed detection, and control systems for fertilizer spreading) along with remote sensing and telemetry.[33] Sensor networks are dependent on deploying point-to-point and point-to-multipoint wireless network technologies.

This combination of wireless technologies is extremely dependent on deep fiber connectivity, such as the one to be provided by 10G.[34] Satellites are not suited to precision agriculture due to their high latency, capacity limitations, and economics. As mentioned in a report recently published by the United States Department of Agriculture,

> ***“as technology advances and the volumes of data to manage agriculture production grow, higher speeds will likely be necessary, requiring more symmetrical data flows, with a better balance of download and upload speeds and reliability.”***[35]

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[30] Mastrangelo, T. (2016). “Virtual Reality check: are our networks ready for VR?”, Technically speaking

[31] Source: Mushroom Networks.

[32] Source: Mike Wittie, Montana State University.

[33] Lowenberg-DBoer, J. (2000). Economic analysis of precision farming. Federal University of Vicosa, Retrieved from: http://www.ufrrj.br/institutos/it/deng/varella/Downloads/IT190_principios_em_agricultura_de_precisao/livros/Capitulo_7.pdf.

[34] See United States Department of Agriculture (2019). A case for rural broadband: Insights on rural broadband and next generation precision agriculture technologies. Washington, DC, April.

[35] Ibid., p. 3.

Figure 3-3 presents the multiplicity of use cases that can have an impact on the agricultural and food processing value chain as well as the role 10G networks can fulfill in facilitating their implementation.

Figure 3-3

Agriculture and Food Processing: Use Cases and Technology Enablers

Agriculture	**Food Processing**	**Distribution**
• Site-specific management of crop production systems • Sensors linked to standardized bus systems that transmit data streams • Each type of sensor linked to a type of agricultural machine • Sensor networks gather data on specific physical changes (humidity, etc.) • Management of irrigation centers, fertilization control, and coordination of large-scale machinery across extended surfaces	• Fixed asset tracking • Smart warehousing • Efficient spare parts management • Prescriptive supply chain analytics • Centralized inventory management • Supplier and site performance monitoring • Automated purchasing, sourcing, inventory modeling and tracking • Big data process optimization • Predictive maintenance • Condition monitoring	• Inter-organizational communications across supply chain stakeholders • Seamless tracking of deliveries • Smart gateway automation • Blockchain and distributed ledger technology • Combination of wireless sensor networking and location services • Cargo condition-based monitoring solutions • Route optimization platforms
• Global Positioning System • Remote sensing • Telemetry and meteorological stations linked to **10G networks** • Wi-Fi hot spots • Driverless vehicles	• Dense network of industrial IoT • Remote sensing • Driverless transport systems • Augmented reality/virtual reality • Real time hands-free machine control • Drones • Advanced robotics communications • Combination of Bluetooth, 802,15.4, **10G networks** and RFID • Secure indoor connectivity	• Real-time location systems • Wi-Fi hot spots • Rugged Bluetooth connectivity • 5G links and **10G networks** Secure connectivity • Streaming hi-def content to vehicles

Source: Telecom Advisory Services

The economic value of the technologies that will enable precision agriculture can be estimated based on its contribution to the increase in total factor productivity through more efficient use of labor and other inputs (water, seeds, fertilizers) along with improved timeliness of operations (optimization of agronomic windows, reduction of spoilage and harvest losses). In 2017, the Department of Agriculture estimated that precision agriculture was used on 40% of the total of 246.7 million crop acres in the U.S. Based on producer benefits from precision agriculture of $20 per hectare measured in field research, the producer surplus of agricultural automation could reach $798.6 million. By 2020, while the total acreage slightly decreased, the percent adoption of precision agriculture technology increased, which has resulted in higher economic value (see table 3-1).

Table 3-1

United States Agricultural Automation Economic Value (2017-2020)

	2017	2020
Total crop acres (million)	246.7	236.7
Total crop hectares (millions) acres to hectares conversion rate: 0.4047	99.8	95.8
Adoption of agriculture automation as measured by yield monitors (%)	40%	50%
Hectares adopting agriculture automation	39.9	47.9
Producer benefits per hectare	$ 20	$ 20
Economic value of precision agriculture (million $)	**$ 798.6**	**$958.0**

Sources: USDA Census and USDA ERS; Robertson et al. (2007); Norton and Swinton (2000); Wang et al. (2009); Schimmelpfennig and Ebel (2011); Schimmelpfennig (2017); Telecom Advisory Services analysis

However, this estimate provides only a partial view of the economic value to be derived in the whole agriculture and food processing value chain. Digital technologies, enabled by 10G, can play a role in supporting planning decisions as well as facilitating market coordination (such as gaining access to new markets, and developing differentiated products). According to the United States Department of Agriculture, the economic value attributed to ubiquitous high-speed broadband across all agricultural segments (row crops, specialty crops, and livestock) could reach between $18 billion and $23 billion. The contribution of 10G networks in this context is related to the fact that much of this value is derived from the application of Next Generation Precision Agriculture, which is enabled by a range of new digital tools and edge computing requiring high speed symmetrical data flows, only supported by deep fiber deployment in the broadband networks.

Smart logistics

The logistics of supply chains is a complex sequence of coordinated activities, comprising merchandise transport, warehousing, customs operations, payments operations, as well as the operations outsourced to third parties by producers and sellers. The efficient performance of logistics depends on factors ranging from agreements facilitating cross-border commerce to the infrastructure of gateways, roads, and last mile transportation links. Telecommunications is a critical enabler of the efficient functioning of logistics at multiple levels:[36]

- Inter-organizational communications across supply chain stakeholders (suppliers, OEMs, logistics service providers, transportation service providers, supply chain nodes, customs agencies)
- Seamless tracking of deliveries
- Smart gateway automation (cargo handling, paperless processing, customs interfaces)
- Blockchain and distributed ledger technology
- Warehousing robotics

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[36] Source: Klaus Dohrman, DHL.

- Combination of wireless sensor networking and location services
- Cargo condition-based monitoring solutions
- Route optimization platforms

10G networks will enable a portfolio of networking platforms that will facilitate the deployment of smart logistics use cases:

- Interconnect remote sensing devices
- Real-time location systems
- Provide backhaul for Wi-Fi hot spots
- Rugged Bluetooth connectivity
- 5G links operating in the 2.4 GHz band
- Secure connectivity
- Streaming high definition content to vehicles

The deployment of smart logistics use cases has been proven to drive significant economic benefits such as a 5% reduction in supply coordination costs, 5% improvement in on-time delivery of merchandise, and 3% to 25% reduction in raw materials purchasing costs.[37]

Smart manufacturing

Smart manufacturing is defined as the use of advanced technology to increase productivity while also potentially having a positive impact on product quality, worker safety, and improved customer experience downstream.

High-speed broadband is a critical enabler of smart manufacturing at two levels. First, 10G will enable intra-firm manufacturing use cases such as 3D printing/additive manufacturing, 3D digital modelling, modelling simulation and analysis, and cloud-based distributed enterprise resource planning.[38] The second level where broadband plays a critical role is in the facilitation of inter-organizational communication with suppliers of parts and raw materials.

Like the use cases related to smart logistics, given the multiplicity of actors participating in the manufacturing chain, proper orchestration among them requires the ability to share correct and timely information about the status of the different processes.[39] The increasing complexity of manufacturing chains makes it even more necessary to improve coordination between processes and actors.[40] Among the benefits of greater coordination are better inventory control, more efficient use of resources and equipment, cost and time reduction in the different processes, better monitoring of and faster reaction to changes in demand, greater logistical flexibility and better financial results.[41]

High-speed broadband can enable a rich list of both intra-firm and inter-organizational use cases (see table 3-2).

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[37] World Economic Forum (2017). The impact of the Fourth Industrial Revolution on supply chains.

[38] Source: Irene Petrick, INTEL.

[39] Source: Jagjit Sing Srai, Center for International Manufacturing, Department of Engineering, Cambridge University (U.K.)

[40] Source: Christopher and Holweg (2011).

[41] Source: Agustina Calatayud, Inter-American Development Bank.

Table 3-2

Importance of Broadband in Smart Manufacturing Use Cases

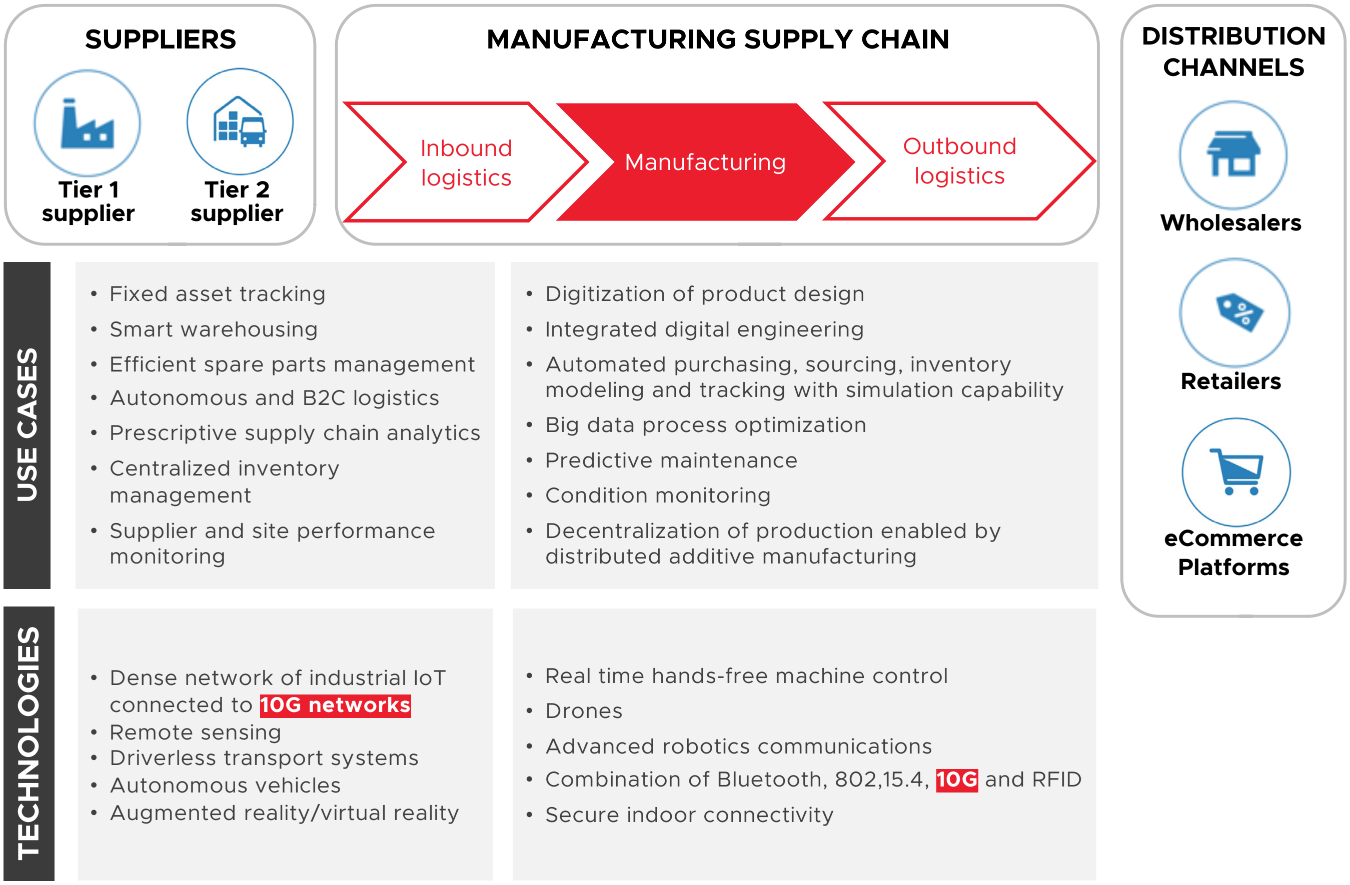
Use case	Importance of broadband as an enabler
Predictive maintenance (detection through temperature, audio signal and/or machine vibrations monitoring, using historical data)	High
Remote assistance using augmented reality	High
Real time asset performance monitoring and visualization	Medium
Digitized standard procedures for line operations with integrated workflow and multimedia sharing	Low
Expanded high-performance computing to reduce product design simulation life cycles	High
Rapid design prototyping through 3-D additive manufacturing	High
Single platform for real time supply chain decisions	Medium
Cost optimization of operations through sensor analysis	High
Enterprise manufacturing intelligence system to upgrade operations management	Medium
Automation and optimization of manual material selection and inventory management	Low
Part traceability from unique digital tag based on surface scanning	High

Source: World Economic Forum (2018). The next economic growth engine: Scaling Fourth Industrial Revolution Technologies in production

Use cases, enabled by high speed broadband, are deployed along all stages of the manufacturing value chain (see figure 3-4).

Figure 3-4

Smart Manufacturing: Use Cases and Technology Enablers



SUPPLIERS

Tier 1 supplier

Tier 2 supplier

MANUFACTURING SUPPLY CHAIN

Inbound logistics

Manufacturing

Outbound logistics

DISTRIBUTION CHANNELS

Wholesalers

Retailers

eCommerce Platforms

USE CASES

- Fixed asset tracking
- Smart warehousing
- Efficient spare parts management
- Autonomous and B2C logistics
- Prescriptive supply chain analytics
- Centralized inventory management
- Supplier and site performance monitoring

- Digitization of product design
- Integrated digital engineering
- Automated purchasing, sourcing, inventory modeling and tracking with simulation capability
- Big data process optimization
- Predictive maintenance
- Condition monitoring
- Decentralization of production enabled by distributed additive manufacturing

TECHNOLOGIES

- Dense network of industrial IoT connected to **10G networks**
- Remote sensing
- Driverless transport systems
- Autonomous vehicles
- Augmented reality/virtual reality

- Real time hands-free machine control
- Drones
- Advanced robotics communications
- Combination of Bluetooth, 802,15.4, **10G** and RFID
- Secure indoor connectivity

Source: Telecom Advisory Services

3.3. Public services

E-Health

E-health use cases built around accessing ultra-fast broadband are predicated on productivity improvement in data download, and support in conducting remote medical procedures. The ongoing pandemic has prompted changes in health care delivery aimed at reducing staff exposure to infected patients, which in turn have raised the importance of digital infrastructure to deliver remote services. While e-health technology is not new, COVID-19 is highlighting the need to adopt platforms relying on high capacity broadband networks such as 10G. Four types of use cases appear to be particularly relevant to enhance the capacity of the health care system to face the pandemic: (i) connectivity for early COVID-19 detection, (ii) remote diagnostics, (iii) tele-surgery, and (iv) remote health care training.

While the first type of use case is still embryonic, its potential is significant. Developed by King's College in the University of London with support of Great Britain's National Institute of Health, the COVID-Collab platform aims at combining the input of multiple wearable devices to detect early symptoms of COVID-19 such as cardiac frequency during resting hours and sleeping patterns.[42] The combination of multiple sensors and transmission of data to processing platforms could be efficiently transmitted through 10G to provide early warning and potentially traceability information.

High capacity broadband is also critical in delivering imaging medical data that requires extremely large bandwidth to be transmitted. As an example, a 2 Gigabyte CT scan requires 11 minutes to be transferred over a 25 Mbps connection.[43] As an alternative, 1 Gbps link reduces the transmission time to 17 seconds. Multi-gigabit connections are allowing a single professional radiology firm in to download and upload massive diagnostic image files. The business organization adopting the technology is structured around a central location of doctors reading diagnostic images. This requires intensive flow of images between image capturing devices and the central location for which 10 Gbps is quite useful.

The third application area in e-health is the ability to conduct remote procedures via the use of ultrafast broadband such as 10G. Originally approved by the FDA in 2000, the da Vinci Surgical system is a robot that performs operations while being remotely controlled by a surgeon from a console.[44] This system also delivers highly magnified, 3D high-definition views of the surgical area and requires stringent synchronization and low latency requirements, both on the display and on the sensors capturing the motion and position of the instruments.[45] While some research indicates that surgeons can adapt to latency of up to 200 Ms,[46] some tele-surgical operations require latencies between 3 and 10 Ms.[47] This 3D high definition imaging, combined with the delivery of extremely precise remote commands, require very high bandwidth. More recently, the Medivis platform integrates augmented reality and holographic visualization to guide surgical navigation.[48] The integration of imaging and virtual reality is also being researched for enhancing certain types of interventions. A study conducted in the Nanjing Medical University of China reports of a platform that relies on computed tomography and MRI images to create a computer-aided design model of the patient to undergo spinal surgery. This CAD image is imported into a computer and relayed to a virtual headset worn by the surgeon. The surgeon sees these 3D virtual images of the patient's spine in combination with the patient's real body in a mixed reality environment. This virtual projection is used to guide accurately needles into the patient's injured vertebra, significantly improving the outcome of the surgery.[49]

Finally, virtual reality-based medical training supported by 10G is a cost efficient option to prepare health care staff for medical emergencies[50] and it can be adapted to provide training for doctors, nurses, and even non-first responders.[51]

In addition to all the applications reviewed above, 10G will provide an efficient connectivity framework between patients, care providers, and monitoring equipment. It will also support the delivery of HD image quality in specialties such as dermatology and wound care. Applications

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[42] Valdovinos, C. (2020). COVID Symptom Tracker. DPL News (August 19).

[43] Similarly, an echocardiogram study would require 10.1 minutes over a 50 Mbps line (see Saunders, J. et al. "Broadband applications: categories, requirements and future networks", First Monday, Volume 17, Number 11).

[44] Source: Jason Buckweitz, Columbia Institute for Tele-Information.

[45] Source: Cedric Westphal, Huawei.

[46] Perez, M. at el. (2016). "Impact of delay on telesurgical performance: study on the robotic simulator dV-Trainer", International Journal of Computer Assisted Radiology and Surgery, April, Volume 11, Issue 4, pp. 581-587.

[47] Zhang, Q. et al. (2018). Towards 5G Enabled tactile robotic telesurgery (Mar 9).

[48] Shieber, J. (2019). Medivis gets FDA approval for its augmented reality surgical toolkit. Techcrunch.

[49] Carfagno, J. (2019). Spinal surgeons perform better when using virtual reality. Docwirenews (August 9).

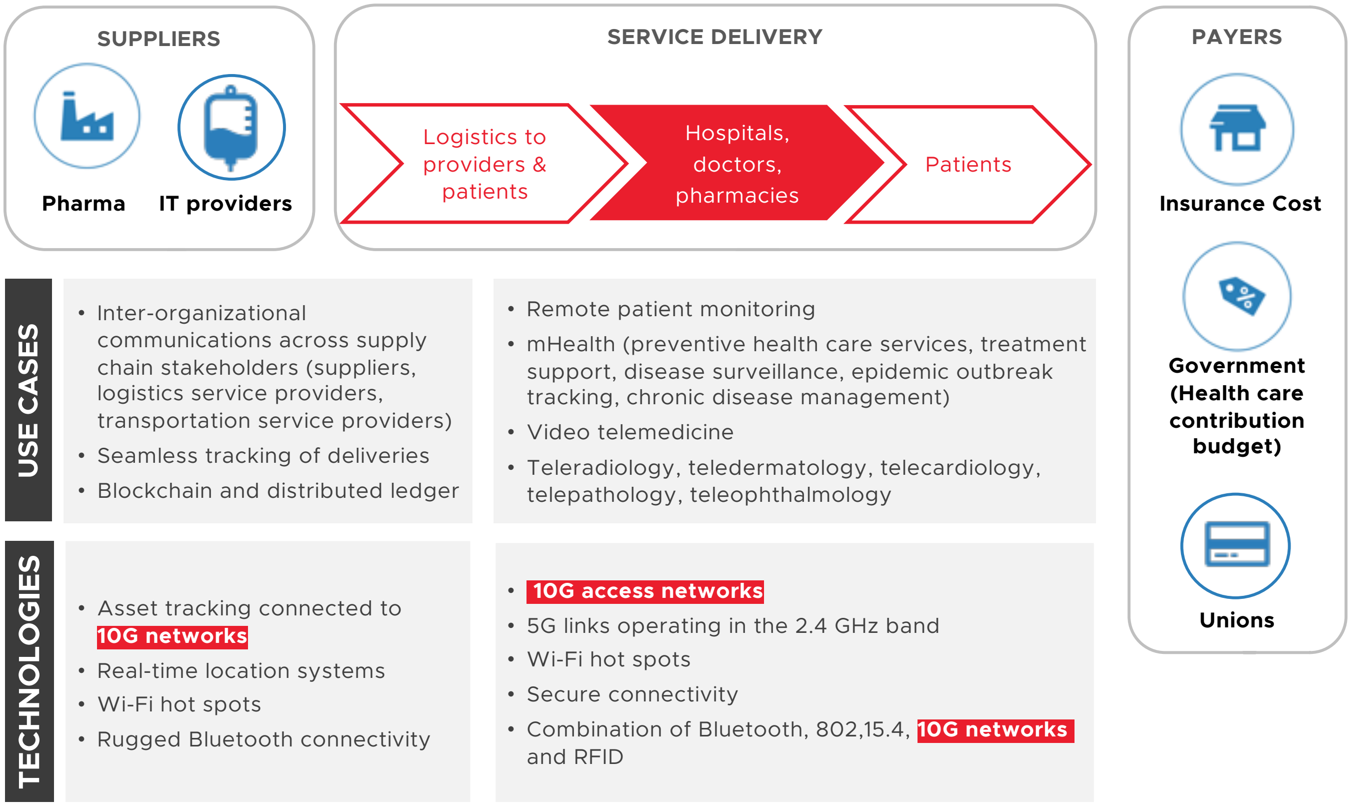
[50] Immersive education: CHLA and Oculus expand VR Medical training programs to new institutions.

[51] Jenkins, A. (2019). Walmart CEO: VR Training Helped Save Lives in El Paso Shooting. Fortune (August 20).

in this area include ubiquitous access to imaging and medical records, advanced telemedicine (including treatment using robotics and AR/VR), and remote clinical care. In this context, 10G will be a critical enabler (see figure 3-5).

Figure 3-5

E-Health: Use Cases and Technology Enablers



	SUPPLIERS	SERVICE DELIVERY
USE CASES	• Inter-organizational communications across supply chain stakeholders (suppliers, logistics service providers, transportation service providers) • Seamless tracking of deliveries • Blockchain and distributed ledger	• Remote patient monitoring • mHealth (preventive health care services, treatment support, disease surveillance, epidemic outbreak tracking, chronic disease management) • Video telemedicine • Teleradiology, teledermatology, telecardiology, telepathology, teleophthalmology
TECHNOLOGIES	• Asset tracking connected to **10G networks** • Real-time location systems • Wi-Fi hot spots • Rugged Bluetooth connectivity	• **10G access networks** • 5G links operating in the 2.4 GHz band • Wi-Fi hot spots • Secure connectivity • Combination of Bluetooth, 802,15.4, **10G networks** and RFID

Source: Telecom Advisory Services

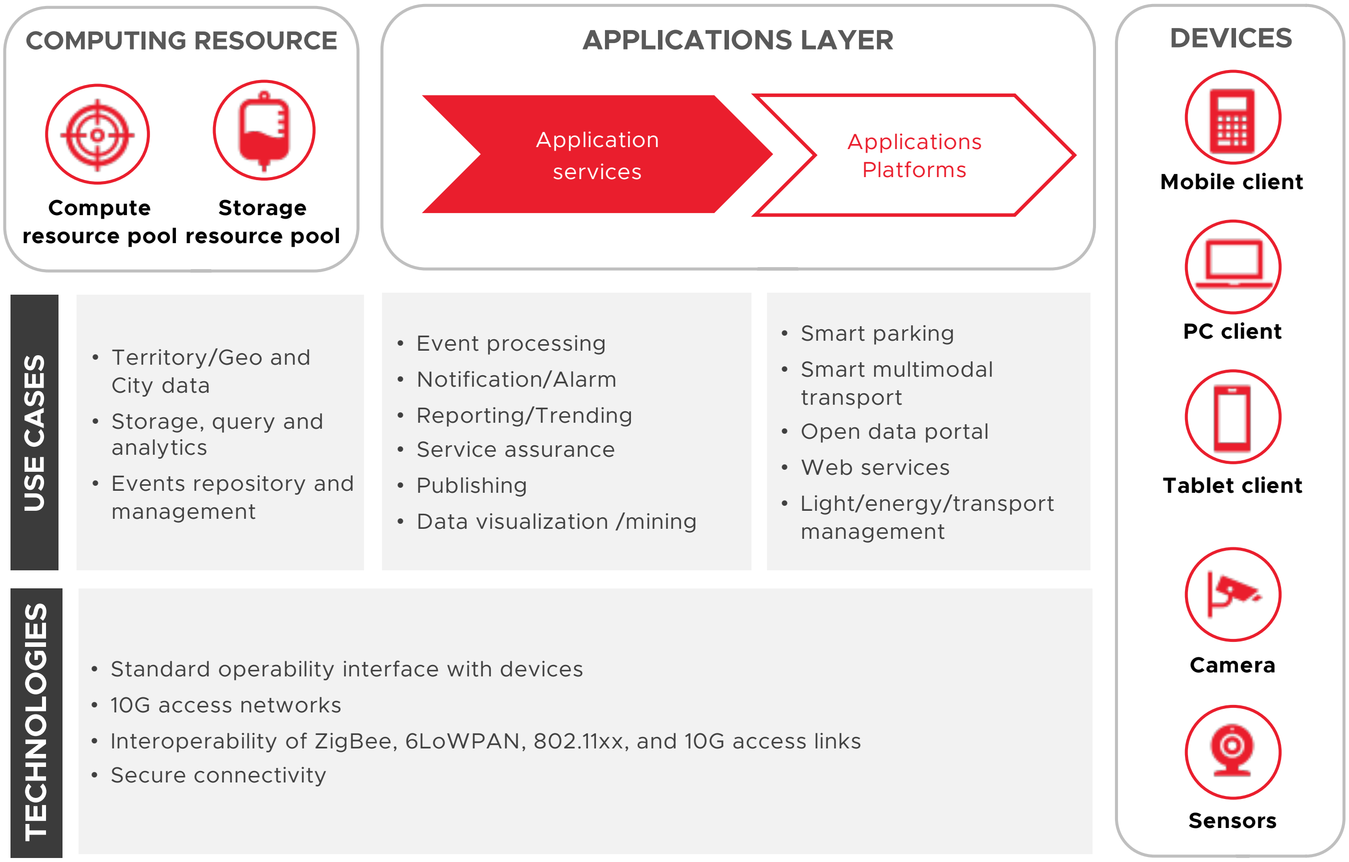
The use of e-health platforms has been stimulated by government support. The Centers for Medicare & Medicaid Services (CMS) have issued multiple waivers providing flexibility (e.g., geographic location, type of health site) during the pandemic and granting payment parity between telehealth and in-person clinical care for Medicare. Similarly, Medicaid external programs administered at the state level and states can choose whether or not to cover telehealth services as an alternative to traditional in-person methods of care.

Smart cities

Many different types of applications and potential new business models coexist under the umbrella concept of “smart cities.” Some of the key technology applications include lighting, security, energy/utilities, physical infrastructure environmental monitoring, and transportation/mobility. 10G networks will play a key role in these applications through interconnection and backhauling of the myriad of wireless devices used to deliver these services (see figure 3-6).

Figure 3-6

Smart City: Use Cases and Technology Enablers



Source: Telecom Advisory Services

Smart city applications require real time, voice and video communications that rely on the use of conventional network protocols such as Bluetooth, Zigbee, and Personal Area Network (PAN) for access.[52] In general, these applications have low bandwidth and low latency requirements. However, the large number of these devices that will be in use will likely require the high capacity backhauling of 10G networks. Additionally, some applications, such as intelligent transportation systems (which require the data to arrive within milliseconds to allow the control systems to react accordingly) require high bandwidth and low latency that 10G can supply.

Smart city applications using wireless sensor networks linked through a 10G backhauling infrastructure include the following:

- Citizens can monitor the pollution concentration in each street, or they can get automatic alarms when the radiation rises to 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 generated;

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[52] Jawhar, I. et al. (2018). "Networking architectures and protocols for smart city systems" Journal of Internet services and applications, 9-26

- Vehicle traffic can be monitored in order to modify the city's traffic lights in a dynamic way;
- Motorists can get timely information to locate a parking space, saving time and fuel. This information can reduce traffic jams and pollution, while improving the quality of life.

For researchers to provide some estimates of the economic value derived from the deployment of smart city infrastructure, it is necessary for them to break down its multiple benefits:

- 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 sustainable environment category, a study by the Harvard Center for Risk Analysis[53] estimates a monetized value of public health losses of approximately $31 billion from traffic congestion and the resulting motor vehicle emissions in 83 U.S. cities. On top of this is a $60 billion cost of wasted time and fuel due to congestion in the same cities.[54] Analysts[55] 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 helps provide business with the labor force to create its products and buyers to consume them. For example, researchers[56] found that 40% of employment growth in U.S. metropolitan areas is due to improvements in the quality of life. While the research 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.

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[53] Levy, J., Buonocore, J. and Von Stackelberg, K. (2010). Evaluation of the public health impacts of traffic congestion: a health risk assessment, Environmental Health, 9:65

[54] Schrank, D., Lomax, T. (2007). The 2007 Urban Mobility Report, Texas Transportation Institute.

[55] Pantak, M. (2013) Do synchronized traffic lights really solve congestion woes?, retrieved from: http://blog.esurance.com/do-synchronized-traffic-lights-really-solve-congestion-woes/#.U6MtvhZy-hN.

[56] Shapiro, J. (2005). Smart Cities: Quality of Life, Productivity, and the Growth Effects of Human Capital. NBER Working Paper 11615, September.

IMPACT OF INVESTMENT IN THE MIGRATION TO 10G

The estimation of the one-time effect of the migration to 10G is based on the total capital investment expected to support the commercialization of this technology, broken down into the sectors that will receive the corresponding spending (primarily electronic equipment and construction). We first estimate the investment per sector, and input this into the corresponding “rows” of the I/O table. This allows us to estimate the impact on value added and employment. These estimates include direct effects (triggered by investment in network infrastructure), indirect effects (generated by the supply of goods and services in support of direct spending), and induced effects (produced by household spending based on the income earned from the direct and indirect effects).

4.1. Capital spending related to the migration to 10G

The aggregate capital spending of the U.S. cable industry is sourced from S&P Global Market Intelligence/Kagan (see table 4-1).

Table 4-1

United States: Total Cable Industry CAPEX (in $ billions)

	2021	2022	2023	2024	2025	2026	2027	TOTAL 2021-2027
Customer Premises Equipment	$4.7	$4.5	$4.3	$4.2	$4.0	$3.9	$3.8	$29.5
Scalable Infrastructure	$4.8	$4.8	$4.8	$4.8	$4.8	$4.8	$4.8	$33.8
Line Extensions	$3.0	$2.9	$2.8	$2.7	$2.5	$2.4	$2.3	$18.7
Upgrade and Rebuild	$1.8	$1.8	$1.8	$1.8	$1.8	$1.8	$1.8	$12.5
Support	$2.5	$2.5	$2.4	$2.3	$2.3	$2.2	$2.2	$16.4
Total	$16.9	$16.5	$16.2	$15.9	$15.5	$15.2	$14.9	$110.9

Note: Due to rounding some totals may not correspond with the sum of the separate values

Source: Kagan (2020). MSOs Capital Expenditures

The calculation of sector investment to be entered in the I/O table is done according to the following rules:

Construction = Line extension + upgrade and rebuild + support

Electronics = Scalable infrastructure

Since the S&P Global Market Intelligence/Kagan CAPEX estimates vary by year, the input estimates change accordingly (see table 4-2).

Table 4-2

United States: Investment to Deploy 10G (in $ billions)

	2021	2022	2023	2024	2025	2026	2027	TOTAL (2021-27)
Construction	$7.3	$7.2	$7.0	$6.8	$6.6	$6.4	$6.2	$47.6
Electronics	$4.8	$4.8	$4.8	$4.8	$4.8	$4.8	$4.8	$33.8
Total	$12.2	$12.0	$11.9	$11.6	$11.4	$11.2	$11.0	$81.4

Note: Due to rounding some totals may not correspond with the sum of the separate values

Source: Kagan (2020). MSOs Capital Expenditures; Telecom Advisory Services

Based on the Kagan numbers, we estimate that the cable industry in the United States will invest $81.4 billion over seven years as it migrates to 10G, of which $33.8 billion will be dedicated to the purchase of electronic equipment (Remote MAC/PHY, Digital optics, nodes, RF amplifiers, TAP replacements and CMTs), and $47.6 billion will be spent on construction.

Estimating the economic impact of the migration to 10G

Our calculation of the impact of the migration to 10G on GDP and jobs is achieved by entering the sector investment (in electronics and construction) in the I/O tables.[57] This analysis will provide an estimate of direct, indirect, and induced GDP and employment for the total investment and on annual basis, with the corresponding multipliers. In addition, we quantify the sectors that will benefit the most from the investment, as well as estimate the portion of the total investment that will be used to the purchase of foreign goods and services (the “leaked” investment). Additional detail of these calculations is presented in Appendix D.

This investment will generate $45.3 billion in additional (indirect and induced) output, resulting in a total GDP impact of $126.7 billion, implying a GDP multiplier of 1.56 (see table 4-3).

Table 4-3

United States: Total One-Time GDP Impact from 10G Investment (in $ billions)

Investment			Indirect + Induced	Total Output	Multiplier
Electronics	Construction	Total			
$33.8	$47.6	$81.4	$45.3	$126.7	$1.56

Source: Telecom Advisory Services analysis

Close to 20% of the total output corresponds to goods imported to United States (see table 4-4).

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[57] The input-output tables were constructed based on US Bureau of Economic Analysis data for 2018 (see Appendix C).

Table 4-4

United States: Domestic vs. Imported Goods of Total One-Time GDP Impact from 10G Investment (in $ billions)

Total Output	Domestic additional production	Imported goods	Percent of imported goods
$126.7	$101.9	$24.9	19.7%

Source: Telecom Advisory Services analysis

Finally, spending on 10G will result in the creation of 376.000 job years over a seven-year span. Of the total jobs, 217,000 job years will be in the construction sector, 51,000 in electronic equipment, and 51,000 in other manufacturing sectors, plus 57,000 in other, non-manufacturing industries (table 4-5).

Table 4-5

United States: Total One-Time Employment Impact from 10G Investment (in job years)

DIRECT JOBS			INDIRECT + INDUCED			Total jobs	Multiplier
Construction	Electronics	Total	Manufacturing	Other	Total		
217,000	51,000	268,000	51,000	57,000	108,000	376,000	1.41

Source: Telecom Advisory Services analysis

The average employment multiplier is 1.41, meaning that for every direct job associated with investment related to the evolution of the platform to 10G, 0.41 jobs will be created among the suppliers to the cable industry, and as a result of induced consumption.

SPILLOVER IMPACT OF 10G NETWORKS ON GDP AND JOB CREATION

As reviewed in chapter 2 and Appendix B, broadband speed has been proven to have an economic impact beyond the GDP and job contribution resulting from the deployment of networks. Denominated "spillovers," this impact reflects the contribution of broadband, especially high-speed offerings, to the whole economy by rendering enterprise operations more efficient, facilitating the reach of new markets, and stimulating the development of new business models. To measure this contribution, we developed two econometric models based on extensive speed data sets for 156 countries between 2008 and 2019 (see Appendix C). The model results indicate that a 1% increase in broadband speed yields a 0.0073 increase in GDP, 0.00232 increase in total new jobs, and 0.01530 increase in service sector jobs.

Spillovers have already materialized as a result of the ongoing increase in average broadband speed yielded by DOCSIS 3.0 and DOCSIS 3.1 technology. However, since we exclude those effects in this analysis, we instead focus on estimates that can be exclusively attributed to the DOCSIS specifications that will follow 3.1. To estimate what the incremental increase in average download speeds will be under DOCSIS 4.0 technology and beyond,[58] we first assume that the natural growth in speeds that has occurred so far within the DOCSIS 3.0 and 3.1 technology contexts would extend in the future absent the introduction of 10G.[59] Then, we develop a projection of average download speed after the migration to 10G begins. For this purpose, it is assumed that by 2027 average speed actually used by consumers will be equivalent to approximately 13% of the weighted average maximum available download speed of 10 Gbps after seven years.[60] Once we complete this forecast, we subtract the evolution of the growth in speed driven by DOCSIS 3.0 and 3.1 technology (a natural extrapolation of the current trend) from the average download speed under 10G to calculate the increase in speed that is exclusively attributed to this technology. We then use this value as the independent variable in economic impact models (that estimate the contribution of speed to GDP growth and employment).

The 10G evolution of broadband networks in the United States will generate spillovers amounting to $ 131.7 billion in cumulative GDP, equivalent to an average of $ 18.8 billion per year (see table 5-1)

Table 5-1

United States: 10G Total Spillover Impact on GDP (in $ billions)

Time period of spillover	Cumulative GDP Impact	Average annual GDP impact	GDP (2027)	Annual GDP impact in 2027 as percent of total GDP
2021-27	$131.7	$18.8	$25.7	0.07%

Sources: International Monetary Fund; Telecom Advisory Services analysis

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[58] The DOCSIS 4.0 specification, released in March 2020, offers a downstream speed of up to 10 Gbps and an upstream speed of up to 6 Gbps (see Jones (2020). The 10G roadmap outlines a symmetric 10 Gbps/10 Gbps (down/up) performance to be achieved over time.

[59] Per Ookla/Speedtest, the fixed broadband average download speed in the second quarter of 2020 in the United States had reached 138 Mbps. An extrapolation was developed based on last two years growth rate (22.00% annual growth)

[60] According to the FCC Report the ratio of average to peak speed in the U.S. in June 2018 is 12.75% (94 Mbps/737.5 Mbps).

This next evolution of broadband platforms will generate total employment growth of close to 300,000, which equals an average of 43,000 new jobs per year (see table 5-2).

Table 5-2

United States: 10G Spillover impact on total new jobs

Time period of spillover	Cumulative total job creation	Average annual new job creation	Labor force 2027	Annual labor force impact in 2027 as percent of total Labor force in 2027 (%)
2021-27	300,000	43,000	164,400,000	0.03%

Sources: BLS; Telecom Advisory Services analysis

Based on the econometric models, we also estimate that the spillovers from 10G will contribute significantly to the creation of service sector jobs. The migration to 10G networks will generate over 1.5 million service sector jobs, equivalent roughly to an average of 220,000 per year (see table 5-3).

Table 5-3

United States: 10G spillover impact on service sector Jobs

Time period of spillover	Cumulative total service sector job creation	Average annual service sector job creation	Service sector Labor force 2027	Annual service sector labor impact in 2027 as percent of total service sector labor in 2027 (%)
2021-27	1,500,000	220,000	129,500,000	0.17%

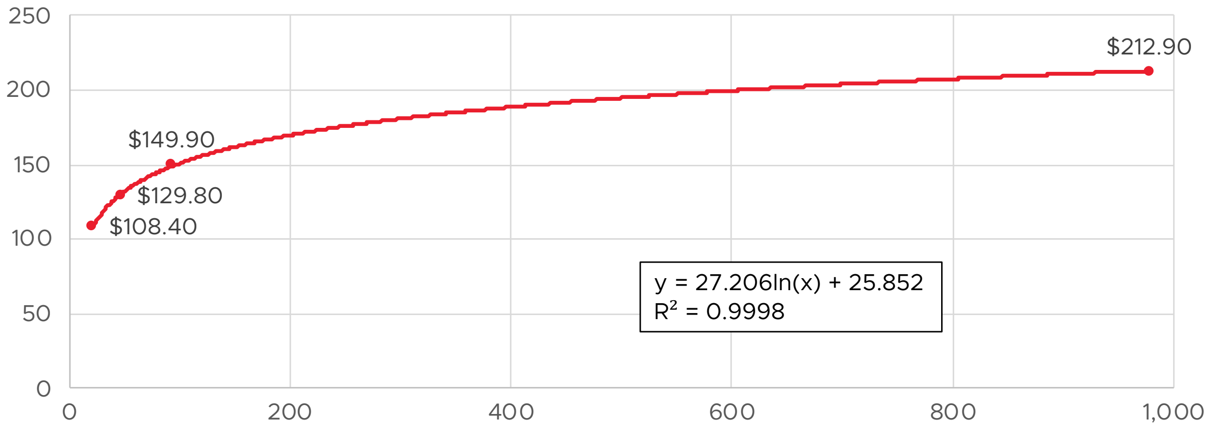
Sources: BLS; Telecom Advisory Services analysis

ESTIMATION OF CONSUMER SURPLUS

Consumer surplus from a technology like 10G is a function of the value users assign from accessing a technology that enables the use of a whole new set of applications with a better experience. The analysis we conducted for the estimation of consumer surplus relies, in part, on data from recent research on the relationship between broadband download speed and the utility/value generated to consumers.[61] The coefficient linking speed to the utility/value of broadband service was then used to estimate the consumer surplus to be derived by 10G (see Graphic 6-1).

Graphic 6-1

Log Curve of Relationship Between Broadband Speed and Consumer Surplus



Note: Based on data points of table VII and table VI of Nevo et al., 2016.

Source: Nevo et al.(2016); Telecom Advisory Services analysis

The migration to 10G will enable a substantial increase in fixed broadband average download speed which, based on research of willingness to pay for additional speed, will yield an increase in consumer surplus (see table 6-1).

Table 6-1

United States: Consumer Surplus Resulting from 10G Migration (in $ billions) (2021-2027)

	2021	2022	2023	2024	2025	2026	2027	Total
U.S.	$2.3	$4.7	$7.2	$9.9	$12.8	$15.7	$18.8	$71.5

Note: Due to rounding some totals may not correspond with the sum of the separate numbers

Source: Telecom Advisory Services analysis

As indicated in table 6-1, the consumer surplus resulting from the migration to 10G will grow from $2.3 billion in 2021 to $18.8 billion in 2027, totaling $71.5 billion.

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[61] Nevo, A., Turner, J., and Williams, J. (2016) "Usage-based pricing and demand for residential broadband", Econometrica, vol. 84, No.2 (March), 441-443, and Liu, Y-H; Prince, J., and Wallsten, J. (2018). Distinguishing bandwidth and latency in households' willingness-to-pay for broadband internet speed.

CONSOLIDATION OF THE ECONOMIC CONTRIBUTION OF 10G NETWORKS

The aggregate economic contribution of 10G is estimated at $329.9 billion (see Table 7-1). More detail about these consolidated results can be found in Appendix G.

Table 7-1

United States: Total Economic Contribution of 10G (in $ billions)

		Total
Network investment	Direct	$81.4
	Indirect and induced	$45.3
	Total	$126.7
Spillovers		$131.7
Consumer surplus		$71.5
Total		$329.9

Source: Telecom Advisory Services analysis

In addition, 10G will contribute to the creation of new jobs (see table 7-2).

Table 7-2

United States: Total Contribution of 10G to Job Creation

		Total
Network investment	Direct	267,200
	Indirect and induced	108,600
	Total	375,800
Spillovers		300,200
Total		676,000

Source: Telecom Advisory Services analysis

The network investment and spillovers of 10G will generate an estimated average of 96,600 jobs per year. Of these jobs, 53,700 will be employed either directly or indirectly in the migration of the networks every year, while spillovers will create an average of 42,900 jobs every year.

Finally, 10G will be an important factor in ensuring that jobs lost in the primary and secondary economies are compensated through new employment in the service sector (see table 7-3).

Table 7-3

United States: Service Sector Jobs

2021	2022	2023	2024	2025	2026	2027	Total
208,900	218,700	220,000	221,200	222,500	223,800	224,900	1,540,000

Source: Telecom Advisory Services analysis

10G networks will contribute a total of 1,540,000 service sector jobs over a seven-year period (or 220,000 per year).[62] As mentioned before, by creating jobs in the service sector to offset some of the jobs in the primary and secondary sectors of the economy that will be lost to automation (estimated at 14% of the labor force in advanced economies over the next two decades by Nedelkoska and Quintini, 2018), 10G will enable a compensating effect for this potential job loss.

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[62] This estimate does not include the jobs to be created by the capital investment in 10G (the so-called network investment), since it includes the resulting spillovers from the increase in broadband speed triggered by 10G deployment. Service sector job creation yielded by investment would be part of the 109,000 indirect and induced jobs (see table 4-3).

PUBLIC POLICY IMPLICATIONS AND ALTERNATIVE SCENARIO

Our estimation of economic value associated with the migration of cable platforms to 10G networks presented above represents a baseline scenario with no policy or regulatory intervention; that is, the private sector cable operators are left to their own devices to upgrade their networks, offer service, and manage new or upgraded subscriptions. As an alternative, we develop a scenario which assumes certain policy interventions that would help serve as an incentive for the migration to 10G.

The levers in the policy intervention scenario would be designed to increase the rate of capital spending, thereby accelerating the migration of 10G and addressing investment in the areas with marginal return, suggesting that some areas that would not otherwise be served could benefit from 10G. This could include areas currently unserved or underserved by broadband providers, which could provide additional spillover benefits and increases in consumer surplus. The increase in speed for these unserved/underserved will be even larger than that realized by consumers who already have access to broadband. Also, since as discussed above, consumer surplus gains are a function of the number of broadband subscribers, if additional households are reached, overall consumer surplus will be higher. Below we review policies and/or regulatory initiatives that could act as an incentive towards accelerating the migration to 10G.

8.1 Provision of tax exemptions to favor the evolution to 10G infrastructure

Taxes tend to raise the required pre-tax rate of return of capital invested and, leaving aside the positive effects taxes can play in the delivery of public services, they tend also to reduce the incentives of a company to make investments and reduce the supply of funds available to finance them.

The mechanisms by which taxes affect investment are complex. In the first place, as stated by Devereux (2006), taxation affects two binary decisions: (a) which businesses invest and (b) in which geographic location to invest. These decisions are even more acute in capital-intensive industries such as communications. According to research on the impact of taxation on capital spending in telecommunications in the United States, a decrease of 1 percentage point in the average weighted states and local sales tax rate affecting initial equipment purchasing in telecommunications and cable (from 4.5% to 3.5% for communications network equipment) would increase investment by 1.82% over the current level of $42.9 billion.[63]

Thirty-four states levy taxes against the acquisition of cable equipment. The amounts can be as high as 10.02% for Louisiana, 9.41% for Arkansas, 9.46% for Tennessee, and 9.18% for Washington. On the other hand, some states have enacted sales tax exemptions. The net effect of this asymmetry is that some states could be prioritized for 10G migration and that those priorities might not be consistent with the goal of efficiently evolving networks to 10G capabilities.

8.2. Reduction of permit fees and other special impositions

Like the role played by sales taxes on equipment purchasing, regulatory permissibility of local

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[63] Katz, R. (2019). Assessment of the economic impact of taxation on communications investment in the United States. New York: Telecom Advisory Services.

franchising authorities to levy in-kind demands and additional fees on data and internet services provided by cable operators represent a threat to infrastructure investment and the related new services (Orszag et al., 2018). Furthermore, levying taxes, fees or in-kind demands on some, but not all, competitors results in competitive asymmetry and further reduces incentives to invest for the competitors subject to the taxes.[64]

As in the tax case discussed above, regulatory changes that reduce ongoing network expansion and improvements will necessarily also reduce any associated consumer welfare gains. Geographic areas that are marginally profitable with respect to network upgrades and investment, such as areas where it is expensive and difficult to build infrastructure, are particularly likely to be impacted by regulatory changes that reduce already marginal returns.

8.3. Elimination of disparities in the usage fees of passive infrastructure

The offering of broadband depends on service providers gaining access to poles (or other passive infrastructure, such as ducts) to deploy their networks. The rate paid to utilize this infrastructure is either regulated by the FCC (or certified state agencies) or is exempted from regulation. An estimated 28% of the U.S. population resides in areas served by municipal and cooperative electric utilities, whose pole attachment rates are not regulated. This results in a situation where attachment rates are substantially higher than those charged by regulated entities. As demonstrated by Connolly (2019), the average annual pole attachment rate charged for access to poles of investor-owned utilities is $6.8 per pole, while the average rate charged by cooperatives and municipalities is $15.4 and $14.9, respectively. With these higher unregulated rates, funds that could be used to either increase coverage in rural underserved areas or enhance service quality in terms of higher speeds in urban and suburban geographies are used instead to pay for excessive pole attachment rates.

Furthermore, many municipalities with unregulated pole attachment rates have launched broadband services in their territory. This gives them an incentive to raise pole rates in order to prevent competition from national or regional operators. In sum, higher unregulated pole attachment rates result in less broadband deployment and reduce competition in broadband services. This situation is detrimental to advancing national broadband goals (e.g. deployment and advanced services such as 10G), with the consequent economic and welfare negative effects. Fees for accessing passive infrastructure should be homogenized in order to eliminate any potential bottlenecks by all utilities whose rates are not regulated.

8.4. Spectrum policy support for Gigabit Wi-Fi extension

As mentioned above, the demand by consumers and businesses for data over the internet has been increasing substantially and is expected to continue to grow. Most of this traffic today is being carried by Wi-Fi and Wi-Fi's share of this traffic is expected to continue to grow.[65] This increase in data traffic on Wi-Fi will be driven by factors such as the large increase in Wi-Fi connected devices, including smartphones and 4K televisions. Demand on Wi-Fi will also be

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[64] Implementation of Section 621(a)(1) of the Cable Communications Policy Act of 1984 as Amended by the Cable Television Consumer Protection and Competition Act of 1992, Third Report and Order, 34 FCC Rcd. 6844 (2019), petitions for review pending, City of Eugene, Oregon et al. v. FCC, Case Nos. 19-4161 et al. (6th Cir.).

[65] According to Cisco, Wi-Fi's share of Internet traffic in 2017 was 50.4% and this is expected to grow to 56.6% of all traffic in 2022. Comments of Cisco Systems, Inc. at 4, ET Docket No. 18-295, GN Docket No. 17-183 (filed Feb. 15, 2019)

increased as the U.S. transitions to 5G wireless networks. because much of the traffic transiting those networks will be offloaded to Wi-Fi.

In 2019, the latest generation of Wi-Fi, Wi-Fi 6 was launched, and the key characteristic of this new technology is its ability to offer speeds of a gigabit and beyond, such as those that will be available with 10G. Next-generation Wi-Fi is critical to 10G deployment plans—as network operators deliver faster wired speeds into the home, Wi-Fi capabilities must keep up so that consumers experience the benefit of 10G on each of their devices. The continued success of Wi-Fi and the ability to deploy next-generation Wi-Fi speeds depends on the availability of sufficient unlicensed mid-band spectrum, under suitable technical rules. The FCC took an important first step in this direction when it opened up 1200 megahertz of spectrum in the 6 GHz band for unlicensed use, including the wide 160-megahertz Wi-Fi channels that can deliver multi-gigabit speeds. However, the FCC should do more to ensure that consumers benefit from 10G and multi-gigabit Wi-Fi. First, the power level adopted for the 6 GHz band is too low to ensure the full benefits of next-generation Wi-Fi. The FCC should enable power levels sufficient to deliver whole-home Wi-Fi coverage. Second, the FCC should enable unlicensed access to the lower 45 megahertz of the 5.9 GHz band to enable a new 160 megahertz channel under technical rules more flexible than adopted for the 6 GHz band, which will allow for a wider range of use cases than those that can be accommodated in 6 GHz.

8.5. Policy interventions that could incentivize the build out of 10G

Deployment of broadband networks in many remote areas is not economically feasible absent government subsidies for deployment. The design of these subsidy programs can have a significant effect on whether, and where, cable operators deploy 10G networks. Two aspects of subsidy policy are important in this context. First, it is critical that the government not provide subsidies to overbuild networks that cable operators have deployed using private capital. A cable operator will be discouraged from investing capital in any broadband network, and especially from upgrading to or deploying 10G networks, in any area where there is a risk that it will face a government-subsidized competitor.

Second, as 10G networks are rolled out, they likely will become the standard deployment model for cable operators even for “greenfield” builds to areas with no existing service. Accordingly, with appropriate policy interventions, 10G networks could become a viable option even for unserved rural areas. One of the benefits of 10G is that it builds on an existing widely deployed network. It would take a lot longer to realize the benefits of a 10 Gbps network if networks were to be developed from scratch. Related to this, Congress could encourage the deployment of 10G by cable operators by no longer requiring that broadband providers obtain designation as an Eligible Telecommunications Carrier by the applicable state agency as a prerequisite to participating in federal universal service support programs. Eliminating this unwarranted obstacle to cable operators’ participation in federal programs would enable cable operators to participate fully in any competitive bidding for future support. potentially bringing 10G to unserved rural areas. In addition, policymakers could encourage future 10G deployment by eliminating excessive fees and inequitable attachment requirements imposed by utility pole owners on cable operators. Access to utility poles and the fair allocation of pole replacement costs are key components in deploying broadband networks, including those capable of providing 10G service. Exorbitant fees and unnecessary delays in accessing poles can hinder cable operators’ ability to upgrade and deploy these networks and may deter such investment entirely in sparsely populated rural areas where the return on investment is limited.

8.6. Effects of these policy interventions on the economic benefits of 10G

Specifically, policy incentives can play a role in accelerating migration by influencing two factors: the timing of the beginning of transition, and the time required for the migration to 10G.[66]

Our current baseline assumptions regarding the 10G deployment timeline are shown in table 8-1.

Table 8-1

Assumptions for Baseline Scenario

Date beginning deployment	2021
Years of deployment	7

We then consider a policy and regulatory intervention scenario that would accelerate the deployment timeline (see table 8-2).

Table 8-2

Assumptions for Policy Intervention Scenario

Date beginning deployment	2021
Years of deployment	5

Under a five-year scenario, we find that the annual contribution of the migration to 10G to the United States GDP will be $25.3 billion, as compared to $18.1 billion due to a consolidation of investment over a shorter time-frame (see table 8-3).

Table 8-3

United States: Total Economic Contribution of 10G Capital Investment (in $ billions)

		2021	2022	2023	2024	2025	2026	2027	Total
Seven-year scenario	Direct	$12.2	$12.1	$11.9	$11.6	$11.4	$11.2	$11.0	$81.4
	Indirect & induced	$6.9	$6.8	$6.7	$6.5	$6.3	$6.1	$6.0	$45.3
	Total	$19.1	$18.9	$18.5	$18.1	$17.7	$17.3	$17.0	$126.7
Five-year scenario	Direct	$16.3	$16.3	$16.3	$16.3	$16.3			$81.4
	Indirect & induced	$9.1	$9.1	$9.1	$9.1	$9.1			$45.3
	Total	$25.3	$25.3	$25.3	$25.3	$25.3			$126.7

Note: Due to rounding some totals may not correspond with the sum of the separate numbers

Source: Telecom Advisory Services analysis

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[66] Ideally, policy incentives could facilitate deployment of infrastructure in those areas with marginal profitability of commercial services. We did not consider this last option.

In addition, by accelerating the migration, an increase in spillovers and consumer surplus will materialize (see table 8-4).

Table 8-4

United States: Total Economic Contribution from Spillovers and Consumer Surplus (in $ billions)

		2021	2022	2023	2024	2025	2026	2027	Total
Seven-year scenario	Spillovers	$16.8	$17.6	$18.2	$18.8	$19.4	$20.1	$20.8	$131.7
	Consumer surplus	$2.3	$4.7	$7.3	$9.9	$12.8	$15.7	$18.9	$71.5
	Total	$19.1	$22.3	$25.4	$28.7	$32.2	$35.8	$39.6	$203.2
Five-year scenario	Spillovers	$40.8	$42.8	$44.2	$45.7	$47.2			$220.6
	Consumer surplus	$5.2	$10.8	$16.6	$22.7	$29.2			$84.5
	Total	$46.1	$53.5	$60.8	$68.4	$76.4			$305.1

Note: Due to rounding some totals may not correspond with the sum of the separate numbers

Source: Telecom Advisory Services analysis

As indicated in table 8-4, the acceleration of the migration timeline yields a higher amount of spillovers and consumer surplus relative to the baseline scenario: on a cumulative basis, the policy intervention scenario generates $ 305.1 billion while the seven-year baseline case yields a total cumulative value of $203.2 billion.

We find similar effects on the employment side (see table 8-5).

Table 8-5.

United States: Total Contribution of 10G to Job Creation

			2021	2022	2023	2024	2025	2026	2027	Total
Seven-year scenario	Network investment	Direct	40,700	40,100	39,200	38,300	37,200	36,300	35,400	267,200
		Indirect & induced	16,600	16,400	16,000	15,500	15,100	14,700	14,300	108,600
		Total	57,300	56,500	55,200	53,800	52,300	51,000	49,700	375,800
	Spillovers		42,300	42,500	42,700	42,900	43,100	43,300	43,600	300,200
	Total		99,600	99,000	97,900	96,700	95,400	94,300	93,300	676,000
Five-year scenario	Network investment	Direct	53,440	53,440	53,440	53,440	53,440			267,200
		Indirect & induced	21,720	21,720	21,720	21,720	21,720			108,600
		Total	75,160	75,160	75,100	75,100	75,100			375,800
	Spillovers		102,600	103,100	103,600	104,200	104,700			518,200
	Total		177,700	178,200	178,700	179,300	179,800			893,700

Note: Due to rounding some totals may not correspond with the sum of the separate numbers

Source: Telecom Advisory Services analysis

The policy intervention scenario generates higher average annual new jobs created between 2021 and 2025 than the baseline scenario (178,800 vs. 96,600). This is caused by two effects: first, the consolidation of capital investment within a shorter timeline, and second, an increase in benefits from spillovers due to the accelerated rate of upgrades in speed.

CONCLUSION

The migration to 10G will result in numerous exciting new applications for both consumers and enterprises. For consumers, 10G will lead to an increase in household digital resilience in terms of providing enhanced access to teleworking tools and distance learning, critical features in the context of pandemics. For businesses, the new use cases will include advances in precision agriculture and food processing, smart logistics, and smart manufacturing. There is also the potential for large benefits in public services such as e-health and smart cities. There are likely many more opportunities that 10G will enable that are not even contemplated at this time. The contribution of 10G also is critical in providing a better capability to adapt and respond to the challenges of the ongoing COVID-19 pandemic.

We estimate the economic benefits from this next generation of cable broadband platforms to total at least $330 billion in economic output and create more than 676,000 new jobs over 7 years. Beyond the direct value derived from investment in network deployment, moving to 10G creates substantial societal and economical value in three areas:

- The impact of investment in 10G will trigger $ 45.3 billion in additional (indirect and induced) output, resulting in a total GDP impact of $126.7 billion.
- GDP and employment spillovers derived from future uses of the technology and applications are estimated to amount to $131.7 billion in cumulative GDP, equivalent to an average of $18.8 billion per year.
- Consumer surplus resulting from faster speeds and better quality such as lower latency is estimated to have a value for the seven years of $ 71.5 billion.

Combined with GDP growth, 10G migration also will create new jobs; we estimate that the migration to 10G networks in all seven years under study will generate more than 676,000 new jobs, equivalent to an average of roughly 97,000 per year.

In summary, the economic benefits attached to the next generation of cable broadband platforms, known as “10G” are substantial. This technology represents the infrastructure required to build future societies capable of delivering enhanced consumer welfare as well as additional national competitiveness. In addition, 10G networks represent a response to the ever-increasing demand for speed required by broadband users.

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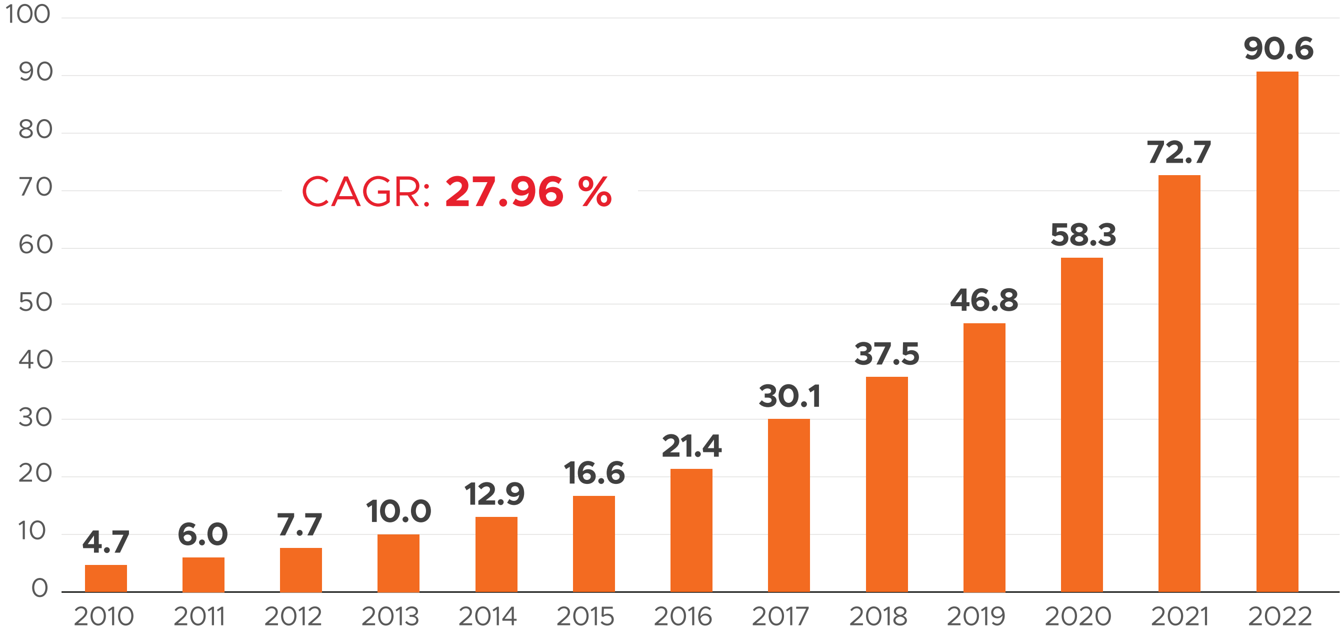
APPENDICES

Appendix A: Trends in Internet Speed, Usage and Latency

There has been tremendous growth in Internet traffic over the last decade. As documented by the Cisco Visual Networking Index, internet traffic in the United States has been growing at an average annual growth rate of nearly 28% (see Graphic A-1).

Graphic A-1

United States: Internet Monthly Traffic (in exabytes[67])



Note: Year end 2020 and projections were developed pre-COVID-19. While recent data indicates that downstream peak growth increased 14.3% and upstream peak grew 27.1% since March 2020, once the initial shock is accounted for, it is estimated that monthly traffic will resume its historical growth (see Ookla/Speedtest).

Source: Cisco Visual Networking Index; Telecom Advisory Services analysis

As expected, the growth in internet traffic has been paralleled by an increase in fixed broadband speed. In fact, we estimate that the average broadband download speed has been growing by 29.3% annually[68] (see graphic A-2).

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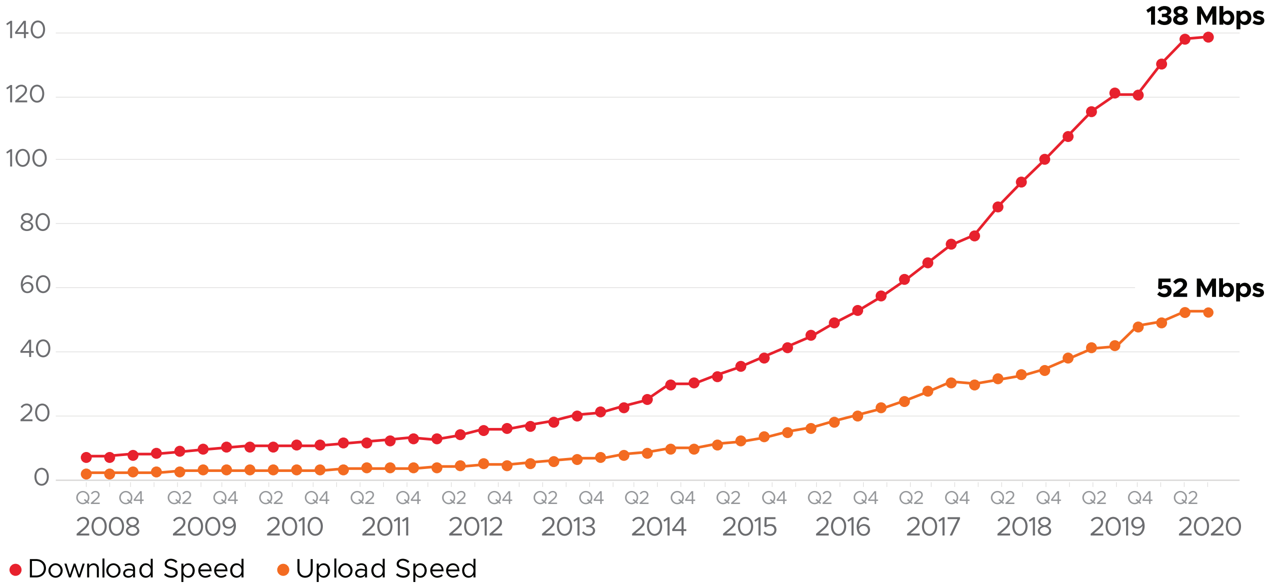
[67] An exabyte is equivalent to 1,073,741,824 gigabytes.

[68] The following analysis is based on Ookla/Speedtest daily Internet traffic compiled between 2008 and 2014 (in 2008, the number of crowdsourced accesses for the United States is approximately 2,000,000, increasing to 12,000,000 by 2014), and monthly data between 2017 and 2020, as reported in the site. The service measures the bandwidth (speed) and latency of a visitor's internet connection against one of 4,759 geographically dispersed servers (as of August 2016) located around the world. Each test measures the data rate for the download direction, i.e. from the server to the user computer, and the upload data rate, i.e. from the user's computer to the server.

Graphic A-2

United States: Fixed Broadband Average Download and Upload Speed (in Mbps)



Source: Ookla/Speedtest; Telecom Advisory Services analysis

Simultaneously, network latency[69] has also been decreasing. Network speed and latency are related since transmission technology, up to a point, is one of the factors that reduces the time it takes for packets to travel from the source to the user.[70] In the United States, the latency for cable and fiber providers has diminished from an average of 22.5 Ms. in 2011 to 17.4 Ms. In 2019 (see Graphic A-3).

The communications industry, comprising both telecommunications operators and cable broadband providers, has been increasing the capabilities of its networks to accommodate the growing demand for faster broadband speed and lower latency. The deployment of DOCSIS 3.0 and 3.1 cable networks combined with FTTx have provided an adequate response to the need for additional fixed broadband speed (see table A-1).

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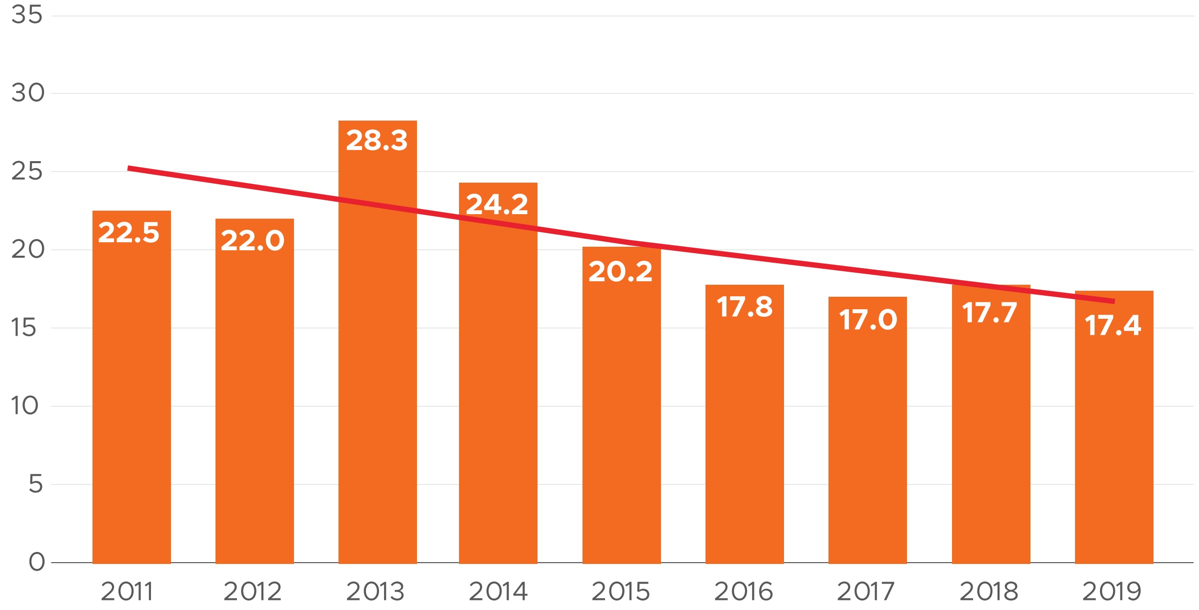
[69] Latency measures the time it takes for a data packet to get from one point in the network to another. High latency has a negative impact on the service quality of interactive applications. It is affected by several factors such as the physical distance data must travel (for example geostationary satellites require data to travel 22,000 miles each way), the number of nodes the data must traverse (which pushes service providers to cache content closer to their end users), and how the network equipment (routers, switches, etc.) buffers and forwards the data.

[70] The other two factors driving latency is the network architecture and the capability of the technology to schedule buffers.

Graphic A-3

United States: Fixed Broadband (cable and FTTx) Peak Average Latency



Note: values are derived from measurement of fifteen specific carriers in the U.S.. Each year value is an arithmetic average of all cable and fiber observations within the country.

Sources: FCC. Measuring Broadband America (2012-20); Telecom Advisory Services analysis.

Table A-1.

United States: Fixed Broadband Download Speed Coverage (percent population that can access broadband with at least indicated speed) (2014-2019)

Download/Upload Speeds	2014	2015	2016	2017	2018	June 2019*
10 Mbps/1 Mbps	93.7%	94.3%	95.8%	96.9%	97.4%	97.7%
25 Mbps/3 Mbps	89.4%	89.9%	91.9%	93.5%	94.4%	94.8%
50 Mbps /5 Mbps	85.2%	88.5%	90.3%	91.6%	92.7%	N/A
100 Mbps/ 10 Mbps	63.5%	67.3%	75.7%	88.6%	90.5%	90.8%
250 Mbps/ 25 Mbps	4.9%	21.2%	43.6%	58.3%	85.6%	85.9%
1 Gbps/ 100 Mbps*	N/A	N/A	7.6%	14.7%	19.5%	22.0%

* FCC Broadband Map
Note: Metrics include download and upload speeds

Source: FCC Broadband Deployment Report 2020; https://broadbandmap.fcc.gov/#/area-comparison?version=dec2016&tech=acfow&speed=1000_100&searchtype=county&searched=y Telecom Advisory Services analysis

Consumers reacted to these improvements in supply by increasing the speed of the service packages they purchased. The number of subscribers in the U.S. accessing broadband with a plan higher than 100 Mbps jumped from 800,000 in 2013 to 40,600,000 (37.5%) in December 2017.[71]

Since the end of the twentieth century, the cable industry has been deploying successive generations of an international telecommunications standard that allows for the addition of high-bandwidth data transfer over an existing coaxial cable TV system. Originally developed in March 1997, DOCSIS (Data Over Cable Service Interface Specification) allows operators to offer higher performance broadband without having to replace completely their coaxial cable networks.[72] There have been three different major iterations of DOCSIS technology over the years: 1.x, 2.x, and 3.x. The original specs, 1.0 and 1.1, had a working limit of 40 Mbps for the downstream speed and 10 Mbps for the upstream speed. DOCSIS 2.0 technology introduced no new capacity for the downstream speed, but it did triple the upstream speed that could be offered. The most significant changes, however, came in 2006 with the introduction of DOCSIS 3.0 technology, which significantly increased hypothetical downstream and upstream speeds to 1 Gbps and 200 Mbps, respectively.[73] Six years later, CableLabs introduced DOCSIS 3.1 technology, an enhancement to DOCSIS 3.0 technology. This generation provided an additional speed enhancement, potentially supporting up to 10Gbps in maximum downstream speed and 2 Gbps in upstream speed. Table A-4 presents the key features and dates of deployment of the different generations of DOCSIS technology.

Table A-4

DOCSIS: Speed Features and Deployment Dates

	DOCSIS 1.0	DOCSIS 1.1	DOCSIS 2.0	DOCSIS 3.0	DOCSIS 3.1	DOCSIS 4.0
Maximum downstream capacity	40 Mbps	40 Mbps	40 Mbps	1 Gbps	10 Gbps	10 Gbps
Maximum upstream capacity	10 Mbps	10 Mbps	30 Mbps	200 Mbps	1-2 Gbps	6 Gbps
Specification date	1996	1999	2001	2006	2013	2019
Commercial Equipment availability	1999*	2001*	2003*	2008	Early 2016	2021
Start of deployment	2000 **	2002 **	2004**	2007	Ongoing	2021

*Based on dates when CableLabs certified the first few modems
**Date when majority of modems were certified

Source: CableLabs

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[71] Federal Communications Commission (2019). Internet Access Services: Status as of December 31, 2017 (August), p. 3. The FCC data in Form 477 has 2.2 million residential subs less than 3 Mbps in 2017, 10.3 million 3 to 10 Mbps, 16.2 million 10 to 25 Mbps, 31.2 million 25 to 100 Mbps and 39 million greater than 100 Mbps

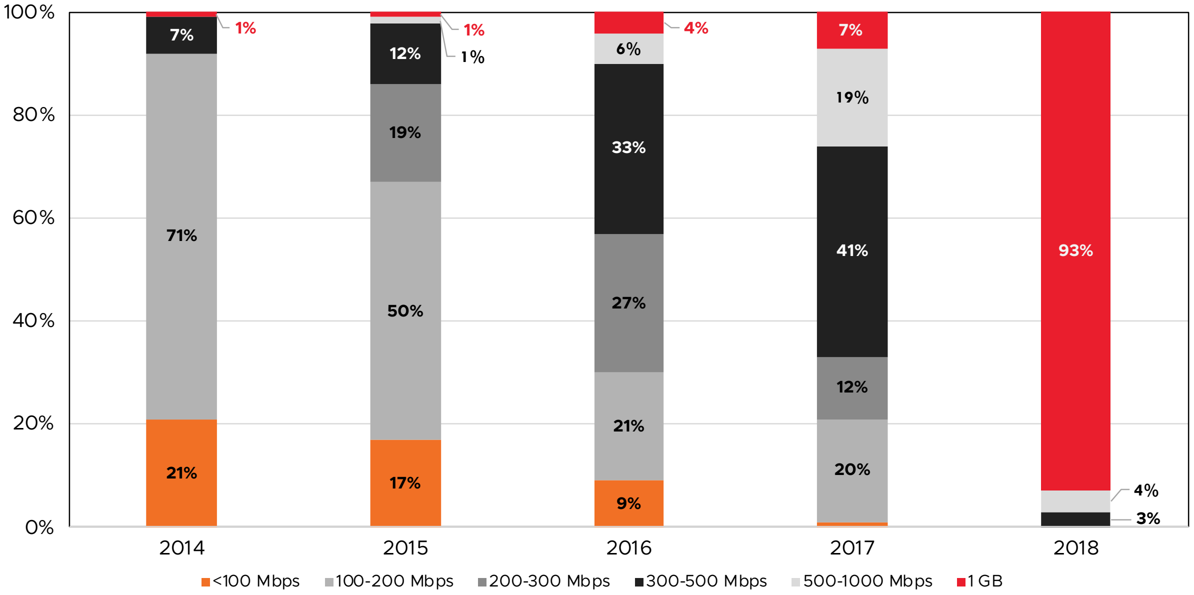
[72] DOCSIS comprises two main components: the physical layer (called PHY) and the media access control layer (MAC). The physical layer pertains to the wiring and routing equipment used, as well as the frequency at which data is transmitted through the physical systems. The MAC layer handles the information being processed over the network components.

[73] DOCSIS 3.0 was enabled by the introduction of channel bonding. Channel bonding allows for the aggregation or combination of several downstream and upstream channels to deliver these much-improved speeds. With this technique, the more channels that are present, the better, so for instance, while a 16 downstream by 4 upstream set-up is fast, a 24 x 8 system can be even faster.

Cable operators in the United States have been actively deploying DOCSIS 3.0 and DOCSIS 3.1 technology over the past few years. In the United States, as of June, 2019,[74] 79% of all households passed by cable broadband were supported by the DOCSIS 3.1 and 8% by DOCSIS 3.0 technology. By December 2018, cable Gigabit service was available to 93% of housing units passed by cable broadband providers (see Graphic A-4).

Graphic A-4

United States: Cable Speed Coverage (percent of passed housing units)



Source: FCC Form 477 Data (Dec. 2014, Dec. 2015, Dec. 2016, & June 2018); CableLabs' Analysis (end of 4Q2018

Appendix B: Previous Research on the Economic Benefits of Broadband

B.1. Economic impact of network investment

As outlined in chapter 3, the migration to 10G will entail capital spending which will translate into GDP growth and jobs through three effects. In the first place, the investment related to 10G will translate directly into additional GDP and jobs (such as telecommunications technicians and construction workers). In addition, this investment creates indirect spending triggered by upstream buying and selling between suppliers and cable operators (electric supplies, metal products, etc.). Finally, the household spending resulting from the income generated from the direct and indirect jobs creates additional "induced" economic effects.

Six national studies have estimated the impact of broadband network construction on job creation and GDP. All these studies relied on I/O analysis and assumed a given amount of capital investment: for example, $63.6 billion needed to reach ubiquitous broadband service, defined as DSL and cable modem service available at the time in the United States (Crandall et al. 2003) (see Table B-1).

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[74] Federal Communications Commission 477 data.

Table B-1

Economic Impact of Network Deployment

Country	Authors – Institution*	Objective	Results
United States	Crandall et al. (2003) – Criterion Economics	Estimate the employment impact of broadband deployment aimed at increasing household adoption from 60% to 95%, requiring an investment of $63.6 billion	Creation of 60,656 jobs per year over nineteen years **Total jobs:** 1.159 million (including 546,000 for construction and 665,000 indirect)
	Atkinson et al. (2009) – ITIF	Estimate the impact of a $10 billion investment in broadband deployment	**Total jobs:** 498,000 jobs if investment achieved in one year (including 64,000 direct, 166,000 indirect and induced, and 268,000 in network effects)
	Katz and Suter (2009)	Estimate the impact of investing $6.39 billion for broadband deployment, of which 2.5 billion would be in wireless technology	**Total jobs:** 127,800 direct and indirect jobs
Switzerland	Katz et al. (2008) – Telecom Advisory Services / Polynomics	Estimate the impact of deploying a national broadband network requiring an investment of CHF 13 billion	**Total jobs:** 114,000 over four years (including 83,000 direct and 31,000 indirect)
United Kingdom	Liebenau et al. (2009) – London School of Economics	Estimate the impact of investing $6.4 billion to achieve the target of the "Digital Britain" Plan	**Total jobs:** 280,000 jobs if investment achieved in one year (including 76,500 direct, 134,500 indirect and induced, and 69,500 in network effects)
Germany	Katz et al. (2010)	Estimate the impact of investing EUR 20.243 billion for implementing the 2014 Broadband Strategy	**Total GDP:** EUR 20.2 billion in investment and EUR 52.32 billion in additional output **Total jobs:** 304,000 jobs (including 158,000 direct, 71,000 indirect and 75,000 induced

Source: Compiled by Telecom Advisory Services

B.2. Broadband speed and economic spillovers

The research on the impact of increasing fixed broadband speed, first and foremost, has focused on GDP growth. This research generally concludes that faster internet access has a positive impact on GDP growth.

Two types of effects explain this causal relationship. First, faster broadband contributes to an improvement in productivity resulting from the adoption of more efficient business processes, such as improved marketing of excess inventories and optimization of the supply chain. Second, faster connectivity yields an acceleration of the rate of introduction of new products, services, and the launch of innovative business models.

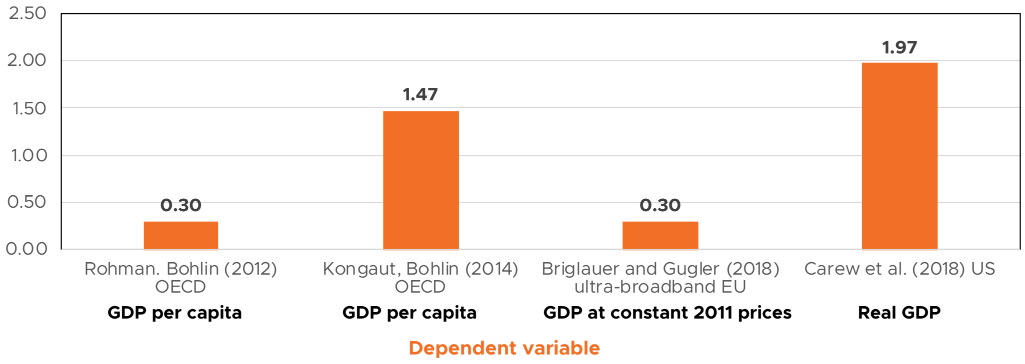
An early study that assessed the impact of broadband speed on GDP (Rohman, Bohlin, 2012) looked at 33 OECD countries and concluded that a 100% increase (or doubling) of speed yields a 0.30% increase in GDP. Following on this study, Kongaut and Bohlin (2014) used a similar approach but differentiated between high and low-income OECD countries and determined that an increase in broadband speed of 100% yields an increase in GDP per capita of 1.47% for a general sample of countries.

Two studies completed in 2018 provided additional evidence of broadband speed impact on GDP. Briglauer and Gugler (2018) looked at data for 27 EU member states between 2003 and 2015. In this case, a 100% increase in basic broadband adoption was found to increase GDP by about 1.5%, while 100% increase in "ultra-fast"[75] broadband adoption lead to an incremental increase of 0.4-0.5% of GDP. That said, these results are driven from ordinary least square models. A two-stage least square regression testing the impact of ultra-fast broadband penetration found a small (0.3) but significant effect over and above the effects of basic broadband on GDP. In another iteration, Carew et al. (2018) concluded that a 100% increase in speed equates to a 1.97% in real GDP.

As indicate in Graphic B-1, while all studies conclude that broadband speed has an impact on GDP, the range of contribution varies. Some of the difference is explained by the methodologies used. For example, Carew et. al (2018) did not include broadband adoption as an independent variable which means that the effect of speed subsumes broadband penetration. In other cases, part of the difference in effects can be explained by the variance in average broadband download speed at the time of the study: for example, when Rohman and Bohlin (2012) conducted their study, average broadband download speed was 8.3 Mbps.

Graphic B-1

Studies Measuring the GDP Impact on Broadband Speeds (impact of 100% increase in speed on GDP) (%)



Source: Compiled by Telecom Advisory Services

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[75] The authors define "ultrafast" as fiber-optical (wireline) infrastructure in the "last mile" of access networks or on the upcoming mobile (wireless) broadband generation technology ("5G"), that offer various bandwidth levels from at least 30 Mbps to several Gbps depending on the individual network technologies.

B.3. Broadband speed and household income

While broadband speed has been consistently found to have a positive effect on economic growth, the evidence of a positive contribution of internet speed to household income is less conclusive. Rhoman and Bohlin (2013) concluded that there are positive benefits from broadband speed on income, though those are not linear and continuous, but nonlinear and stepwise. Furthermore, the authors found that the impact for lower speed is greater in three large emerging countries (Brazil, India and China) and for higher speeds it is greater in OECD countries. The authors found that for the same increase in upgrade in speeds (0.5 Mbps to 4 Mbps), the income effect is bigger in OECD countries than BIC countries ($322 per month vs $46 per month). On the other hand, Ford (2018) analyzed U.S. data and found no economic payoff from a 15 Mbps speed difference.

B.4. Broadband speed and enterprise productivity

The contribution of broadband speed to enterprise productivity has been researched by sector. In a study of Irish firms, Haller et al. (2019) found significant productivity gains from broadband availability in two services industries: Information & Communication services and Administrative & Support Service Activities. The effects measured for these two sectors were large, equivalent to about a third of the typical variation in productivity. Smaller effects were found in other sectors. These results suggest the benefits of broadband for productivity depend heavily upon sectoral and firm characteristics. Cariolle et al. (2017) studied firms in 62 countries, using World Bank data, and detected a large impact of broadband speed on a firm's average annual sales and sales per worker.

B.5. Broadband speed and job creation

Research on the impact of broadband speed on employment, which takes place through firm relocation and start-up incubation, is fairly conclusive. Whitacre et al. (2014) looked at United States counties between 2001 and 2010 and identified a positive impact of broadband speed on unemployment reduction. In particular, rural areas with fast broadband tend to attract more creative class workers. Bai (2016) studied United States counties between 2011 and 2014 and found that while broadband has a positive impact on employment, "ultra-fast" broadband has smaller incremental effects. Lobo et al. (2019) studied the counties within Tennessee and found that unemployment rates are about 0.26 percentage points lower in counties with high speed broadband compared to counties with low speed service. As with Whitacre et al. (2014), this study found that better quality broadband has a disproportionately greater effect in rural areas.

The only study conducted outside the United States was done by Hasbi (2017), analyzing panel data on 36,000 municipalities in France between 2010 and 2015. The author found that deployment of high-speed broadband (> 30 Mbps) increases company relocation and start-up development in the non-agricultural sector. These two effects yield a positive contribution to the reduction of unemployment.

B.6. Broadband speed and consumer surplus

Consumer surplus is defined as the amount that consumers benefit from purchasing a product for a price that is less than the value they assign to it. Broadband consumer surplus, typically assessed against dial up or pricing differences, indicates a high willingness to pay for speed. Most studies of consumer surplus derived from faster speed are based on surveys or focus groups where consumers stipulate what they would be willing to pay for broadband (Savage et al. (2004); Greenstein and McDewitt (2011); Liu et al. (2018)). For example, Greenstein and McDewitt (2009) analyzed survey data of willingness to pay for dial up vs. broadband and concluded that in 2006 the switch from dial-up to broadband access generated between $4.8 billion and $6.7 billion in consumer surplus. Liu et al. (2018) administered two surveys of U.S. consumers to measure households' willingness-to-pay for changes in price, data caps, and speed. They found that the valuation of bandwidth is highly concave. U.S. households are willing to pay about $2.34 per Mbps ($14 total) monthly to increase bandwidth from 4 Mbps to 10 Mbps, $1.57 per Mbps ($24) to increase from 10 to 25 Mbps, and $0.02 per Mbps ($19) for an increase from 100 Mbps to 1000 Mbps.

Studies that rely on pricing differences to estimate consumer surplus include Greenstein and McDewitt (2011), who compared deployment, use of broadband and pricing between 2004 and 2009 for Brazil, U.S., Spain, United Kingdom, Mexico, Canada, and China. They concluded that a decline in broadband real prices[76] generated consumer surplus in 2009 of $10.1 billion in the United States and £ 0.8 billion in the United Kingdom. In 2012, Greenstein and McDewitt (2012) replicated this analysis for thirty OECD countries and concluded that the total consumer surplus from broadband in 2010 in these countries amounted to $156.7 billion.

Finally, other studies on consumer surplus focus on how consumers' data usage reacts to variations in price. For example, Nevo et al. (2015) studied hour-by-hour internet usage for 55,000 U.S. subscribers facing different price schedules. They concluded that consumer surplus for speed is heterogeneous. Consumers will pay between $0 to $5 per month for a 1 Mbps increase in connection speed, with an average of $2.[77] However, and very relevant to our study of 10G, they stipulated that, with the availability of more content and applications, consumers will likely increase their usage, implying greater time savings and a greater willingness to pay for speed.

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[76] The authors' starting point is the unchanged nominal prices for broadband over time; however, since household income grows following inflation, broadband deflated prices and the amount of household income dedicate to its purchasing diminishes.

[77] Heterogeneity in willingness to pay for broadband was also highlighted by Rosston et al. (2010).

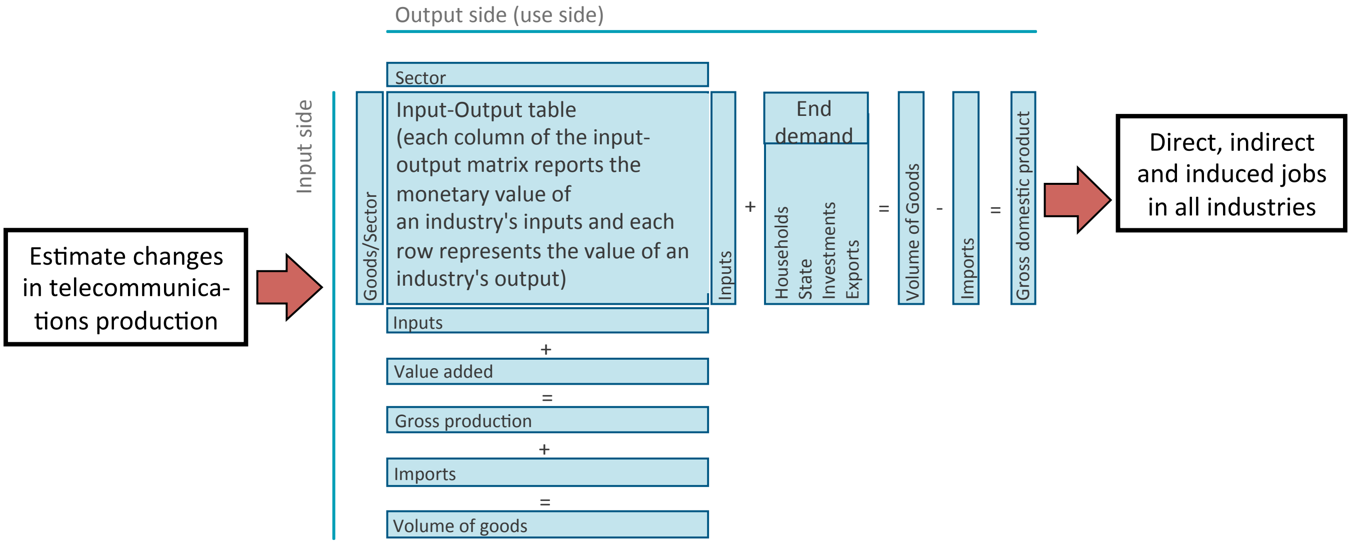
Appendix C: Models Used to Estimate the Economic Impact of 10G

C.1. Estimating the impact of investment in 10G deployment

As described in the review of the literature presented above, the core methodology for estimating the impact of investment in 10G is based on input/output matrices. The structure of an input/output (I/O) table comprises horizontal rows describing how an industry's total output is divided among various production processes and final consumption, and each column denotes the combination of productive resources used within one industry (see figure C-1).

Figure C-1

Structure of an Input-Output Matrix



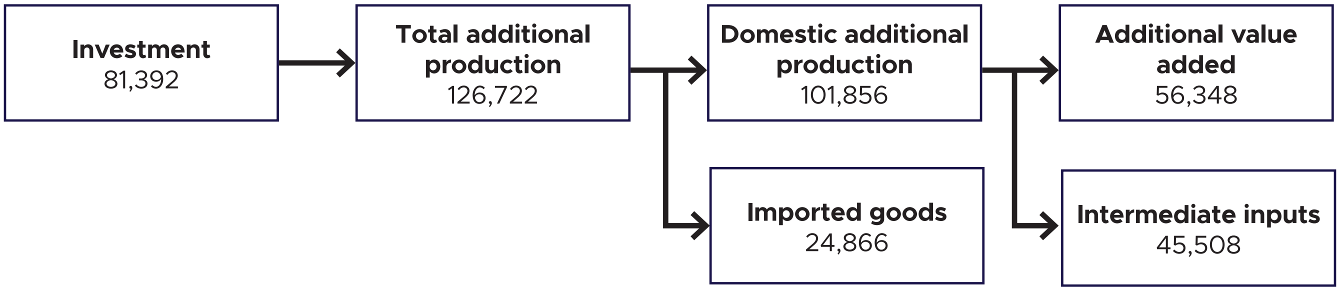
In I/O tables, inputs are used by sectors that produce output (intermediate output), which in turn is sold to another sector for consumption (final output); total output adds intermediate and final outputs. By using labor productivities, one can calculate job creation from these output levels. For purposes of this analysis, I/O tables were developed using the Bureau of Economic Analysis information for 2018.

The output of each I/O table is structured as follows (see figure C-2 on the following page):

Figure C-2

Example of Output of Input / Output Results Table

Direct, indirect and multipliers total		
Value Added	Direct Effect	39174.372 mUSD
	Indirect Effect	171173.752 mUSD
	Total Effect	56348.124 mUSD
	Multiplier	1.44
Employment	Direct Effect	267.211 th employees
	Indirect Effect	108.638 th employees
	Total Effect	375.849 th employees
	Multiplier	1.41
Total Industry Output	Direct Effect	81,392.000 mUSD
	Indirect Effect	45,329.629 mUSD
	Total Effect	126,721.629 mUSD
	Multiplier	1.56



As indicated in Figure C-2, I/O tables can estimate the one-time impact of investment in broadband technology on employment and GDP, differentiating between direct, indirect, and induced effects. In addition, since the tables are based on the interrelationships among sectors and quantify the intermediate goods produced in a country versus those that are imported, the portion of the network investment that is "leaked" to foreign providers can also be estimated. Finally, the tables can also estimate the breakdown of jobs to be created by sector.

The calculation of the investment effects of 10G requires entering in the I/O table the estimated spending required for this migration. Spending needs to be broken down by economic sector (for example, construction and electronic equipment). Data on estimated future investment was compiled from S&P Global Market Intelligence/Kagan.

C.2. Estimating spillovers

In the assessment of 10G economic contribution, spillovers refer to the impact the technology will have beyond the investment needed as it is being deployed. Since more extensive and complete datasets were available at the time of this study, rather than relying on the prior research discussed in Appendix B, we developed new econometric models to estimate the impact of speed on GDP and employment. Once the models were developed, the coefficients of broadband speed were used to calculate the economic impact from the spillovers from 10G

The econometric models were based on historical data panels constructed for 159 countries for a time series between 2008 and 2019. The data comprised 7,314 observations of quarterly data for:

- Average fixed broadband download speed[78] (source: Ookla Speedtest)
- Gross Domestic Product (at current prices $) (source: IMF)[79]
- Population (source: IMF)
- Unemployment rate (source: IMF)
- Fixed broadband adoption (percent of households with fixed broadband with a speed of at least 256 kbps) (source: International Telecommunications Union)
- Controls for country and time periods

The data panels were cut in three samples to calculate coefficients of GDP impact for different speed tiers (download speeds between 1Mbps and 10 Mbps, download speeds between 10 Mbps and 40 Mbps, and download speeds higher than 40 Mbps) and the following model was specified (see exhibit C-1).

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[78] The data on Speedtest/Ookla covers 159 countries including: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Lithuania, Luxemburg, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden, Switzerland, Turkey, and the United States.

[79] The models used GDP at current prices in U.S. dollars since the objective is to measure the impact of GDP in U.S. dollars, without considering a purchasing power parity deflator.

Exhibit C-1

Model for estimating the impact of fixed broadband speed on GDP

$$\begin{aligned} lnGDP_{it} &= \beta_0 + \beta_1 lnGDP_{it-1} + \beta_2 lnDownload\ Speed_{it-4} + \beta_3 lnEmployment_{it} + \beta_4 lnInvestment\ Rate \\ &+ \beta_5 lnFixed\ Broadband\ Adoption_{it} + \delta Country_i + \vartheta Time_t + \mu_{it} \end{aligned}$$

Where the model includes:

- A control for the previous quarter's GDP, to isolate the inertial effect of country growth
- Download speed lagged by four quarters (1 year) to avoid reversed causality effect
- Changes in employment, to isolate the effect on GDP of the evolution of the labor market
- The country's investment rate (% of GDP) to isolate the effect of investment on GDP
- The penetration rate to separate the broadband adoption effect from the speed effect

Regressions were run only for periods and countries with a fixed broadband adoption higher than 1% of households with the following results (see table C-1).

Table C-1

Impact of Fixed Broadband Download Speed on GDP

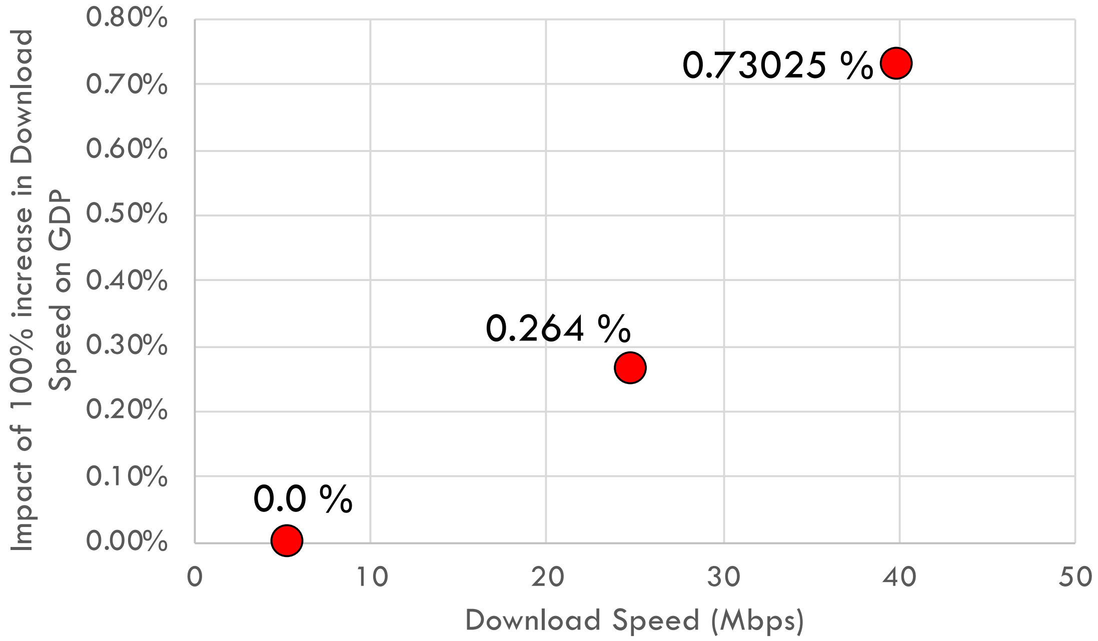
Impact on ln GDP	Download Speed < 10 Mbps	Download Speed 10 Mbps - 40 Mbps	Download Speed higher than 40 Mbps
Ln Download Speed$_{t-4}$	-0.00206 (0.00136)	0.00264 (0.00138) ***	0.00730 (0.00211) ***
Ln Employment$_t$	0.00664 (0.00189) ***	0.00525 (0.00168) ***	0.00458 (0.00165) ***
Ln Investment$_{t-4}$	0.01459 (0.00216) ***	-0.00616 (0.00382)	-0.00085 (0.00481)
Country Fixed Effect	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes
Control for Growth of Previous GDP	Yes	Yes	Yes
Control for Fixed Broadband Adoption	Yes	Yes	Yes
Number of Countries	116	105	49
Observations	2,113	1,792	575
R-Square	0.9516	0.9262	0.9438

***, **, * significant at 1%, 5% and 10% critical value respectively.

As indicated in the coefficients of download speed, the faster download speed, the greater GDP growth impact (see Graphic C-1).

Graphic C-1

Spillover Impact of Download Speed on GDP



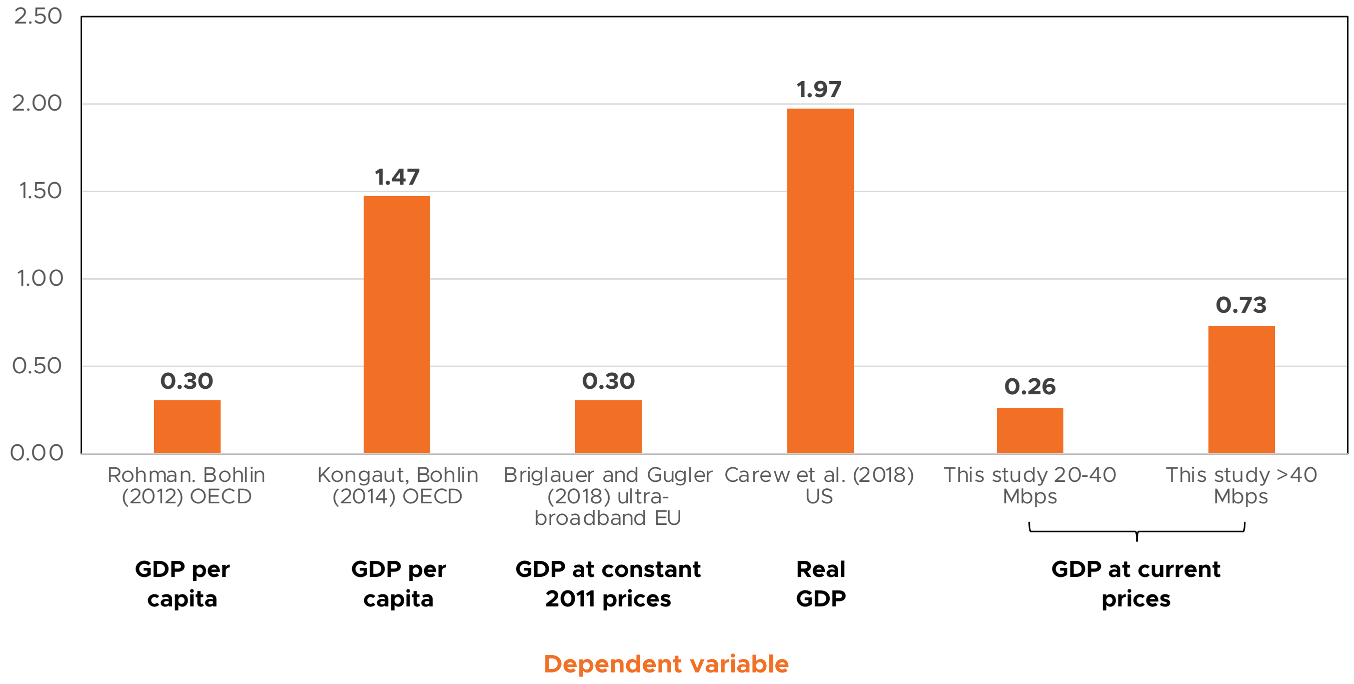
Source: Telecom Advisory Services analysis

According to the results, the impact on GDP of fixed broadband download speeds under 10 Mbps is non-existent, while once the average speed is in a range between 10 and 40 Mbps, the effect on GDP is positive and statistically significant. The effect on GDP is even greater for download speeds in excess of 40 Mbps. The results of this study (see Graphic C-2) are in the range of what was estimated by Briglauer and Gugler (2018) for the EU ultrabroadband impact, while the difference with Carew et. al (2018) is likely because, since broadband adoption is not included in their model as an independent variable, the effect of speed subsumes broadband penetration. On the other hand, the Kongaut and Bohlin (2014) study is somewhat limited due to the time period over which speed data is gathered (up to 2013); furthermore, the fact that speed impact appears to be higher in low income OECD countries (see below) might run against some of the microeconomic research indicating that the contribution of fast broadband is higher when acting as an enabler of digital applications prevalent in advanced economies.

In the case of job impact estimation, additional controls, besides those included in Exhibit C-1, are included in the model. The additional controls are previous population growth, and an education index to isolate the effects of human capital on employment. The following model was specified (see exhibit C-2).

Graphic C-2

Studies measuring the GDP impact on Broadband Speeds (impact of 100% increase in speed on GDP) (%)



Source: Compiled by Telecom Advisory Services

In the case of job impact estimation, additional controls, besides those included in Exhibit C-1, are included in the model. The additional controls are previous population growth, and an education index to isolate the effects of human capital on employment. The following model was specified (see exhibit C-2).

Exhibit C-2

Model for estimating the impact of fixed broadband speed on job creation

Regressions were run for total employment and for service sector employment only for periods and countries with a fixed broadband adoption higher than 1% of households with the following results (see table C-2)

$$\begin{aligned} lnEmployment_{it} &= \beta_0 + \beta_1 lnPopulation_{it-1} + \beta_2 lnDownload\ Speed_{it-4} + \beta_3 lnGDP_{it-1} \\ &+ \beta_4 lnInvestment\ Rate_{it-4} + \beta_5 lnFixed\ Broadband\ Adoption_{it-1} \\ &+ \beta_6 lnEducation\ Index_{it-4} + \delta Country_i + \vartheta Time_t + \mu_{it} \end{aligned}$$

Table C-2

Impact of Fixed Broadband Download Speed on Employment

Impact on In Employment	Employment in all sectors	Employment in the services sector
Ln Download Speed$_{t-4}$	0.00232 (0.00095) **	0.01530 (0.00104) ***
Ln Education Index$_{t-4}$	0.19995 (0.02275) ***	0.32428 (0.02481) ***
Ln Investment$_{t-4}$	0.01024 (0.00218) ***	-0.00090 (0.00238)
Country Fixed Effect	Yes	Yes
Time Fixed Effect	Yes	Yes
Control for previous GDP growth	Yes	Yes
Control for previous FBB adoption growth	Yes	Yes
Control for previous growth of Population	Yes	Yes
Number of countries	120	120
Observations	4,440	4,440
R-Square	0.7006	0.7612

***, **, * significant at 1%, 5% and 10% critical value respectively.

The coefficient of speed impact on overall employment, while positive and statistically significant, is small (0.00232) compared to the impact on the service sector (0.01530), indicating a dual effect of broadband speed. These results are consistent with the findings highlighted in the research literature review. (Hasbi, 2017).

This leads us to conclude that 10G, as an enabler of technology platforms associated with automation and the "Fourth Industrial Revolution", might have an impact on labor force restructuring (shift from manufacturing to the services sector).For example, recent research indicates that 14% of jobs in OECD countries, primarily in manufacturing and agriculture, are likely to be automated, while another 32% will incur significant changes in the way they are conducted as a result of automation (Nedelkoska and Quintini, 2018). In the context of our results, a large portion of the jobs lost to automation in manufacturing will be replaced by jobs in the services sector and faster broadband speeds should be conceived as a general-purpose technology acting as an enabler of this compensating effect.

C.3. Applying econometric models to spillover effects

To use the econometric models to quantify the spillovers, we must first estimate what will be the average fixed broadband download speed in an environment enabled by 10G. For this purpose, we calculate projected peak speeds over time and use the historical relation between peak and average download speed to estimate average speed.

Since spillovers would also materialize because of the ongoing increase in average broadband speed even without 10G, we need to estimate the contribution that can be exclusively attributed to 10G networks. To estimate what the increase in average download speeds will be under 10G, we first assume that, without 10G, the growth in speeds that has occurred so far within the DOCSIS 3.0 and 3.1 technology contexts will extend in the future. Then, we develop a projection of average download speed after the migration to 10G begins. For this purpose, it is assumed that by 2027 average speed will be equivalent to approximately 12.75% of the weighted average peak download speed of 10Gbps after seven years. According to the FCC Report the ratio average to peak speed in the U.S. in June 2018 is 12.75% (94 Mbps/737.5 Mbps).

C.4. Enablement of applications

As alluded to in the review of the literature, the economic impact of speed is influenced by the applications enabled by the network. The econometric models used in the estimation of spillovers are not capable of estimating the value of specific applications and use cases enabled by the technology. Part of the reason of this limitation is that future benefits of 10G are not only derived from faster speed, low latency, and symmetric performance but also from new uses of the technology that are at an early stage of the development life cycle. Our analysis addresses the economic value of 10G focusing on certain applications to provide some micro-economic validation of the macro-estimates generated in the spillover econometric models. Along these lines, these values are subsets of the overall estimates calculated in the spillover section and not additional value created on top of the spillover effects.

Our analysis will focus on assessing the impact of five groups of emerging applications (see figure C-3).

Figure C-3

Emerging Applications Enabled By 10G

		Applications/Use cases	
		Under implementation and deployment	**At an early development stage**
Markets	**Individual consumers**	• Massive multiplayer gaming • Immersive video/8K entertainment	
	Enterprises	• Precision agriculture and food processing • Smart manufacturing • Smart logistics	• Massive Internet of Things • Algorithm-based security systems
	Public services	• eHealth • Smart cities	• Tele-surgery

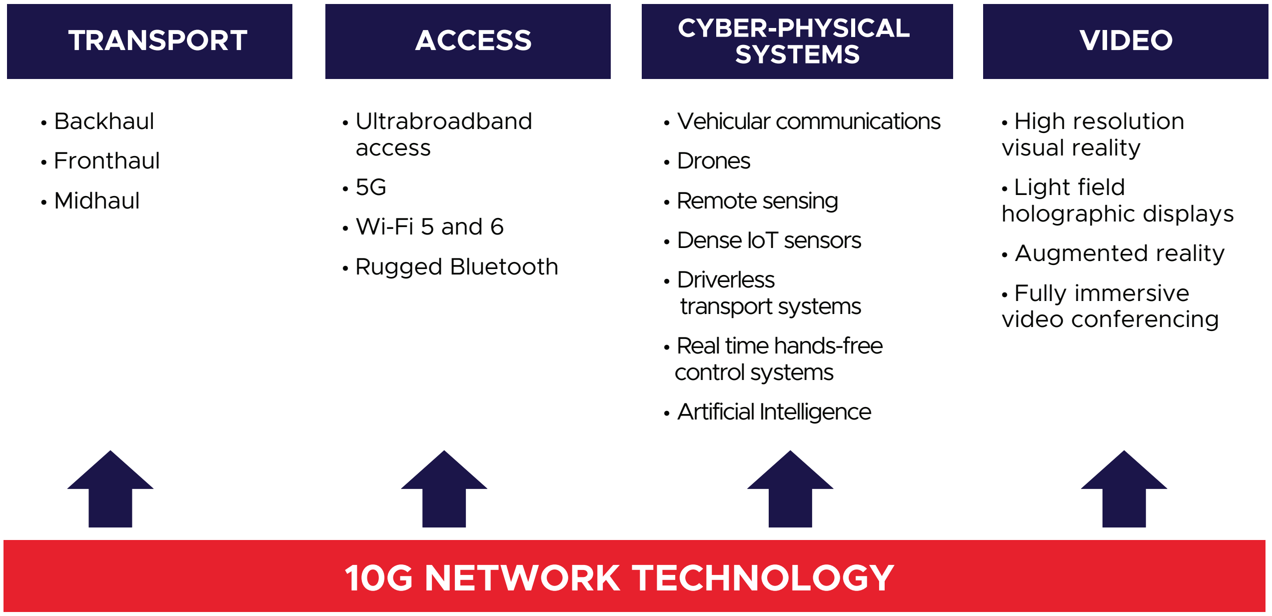
Another analytical challenge in assessing the economic contribution of 10G is that its contribution is achieved in combination with other technologies and platforms. The analytical difficulty of disaggregating the impact of ICT from the facilitative role played by broadband has been previously identified (Foley et al, 2009). This universe of relevant technologies can be grouped into four areas:

- **Access:** technologies that provide the connectivity to end-user devices.
- **Transport:** technologies that provide high performance transport capacity from nodes and points of signal distribution, such as wireless base stations and Wi-Fi hotspots.
- **Cyber-physical systems:** systems built around the integration of computing power, networking, and physical process. Computers and networks monitor and control physical processes, which in turn, generate feedback loops into computers.
- **Video display:** devices capable of displaying video signals and integrating it into the delivery of new information.

Within this typology, 10G technology will play a critical role facilitating the flow of information among devices and display components (see figure C-4).

Figure C-4

Technologies Contributing To New Applications And Business Models



Source: Telecom Advisory Services

Thus, we consider the economic contribution of 10G to emerging applications as an enabler and we do not assess independently from other technologies.

C.5. Estimating consumer surplus

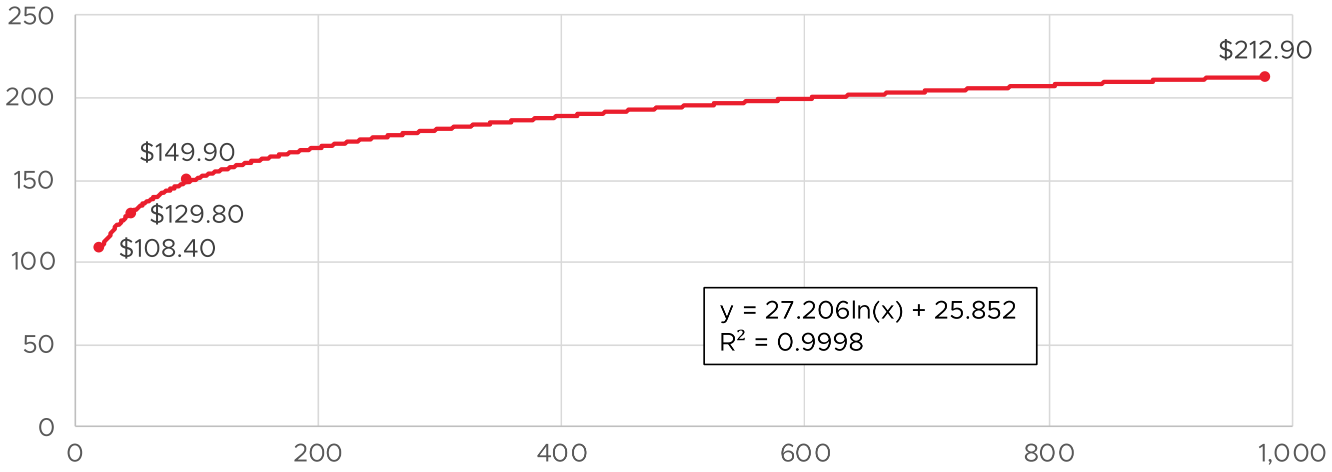
As explained in the review of the literature on broadband generated consumer surplus, most studies rely on changes in consumer behavior as a result of new service availability (Nevo et al., 2016), market research (Savage et al., 2004; Greenstein and McDewitt, 2009; Liu et al, 2018) or changes in pricing in relation to product quality (Greenstein and McDewitt, 2011; Greenstein and McDewitt, 2012). The methodological challenge in this study is to estimate the expected change in consumer surplus resulting from a product not yet generally deployed[80], particularly when considering that the full value of 10G availability will materialize only once new applications are developed.

The analysis conducted for this study relies on the data specifying the relationship between speed and consumer surplus generated by Nevo et al. (2016).[81] This research provides empirical evidence for the United States stating that consumers' willingness to pay (WTP) for improved broadband speed of 1 Mbps ranges from nearly zero to just over $5.00. The range is determined by heterogeneity in WTP, although the average value is $2.02, and the median is $ 2.48. Furthermore, the study indicates that higher speed does indeed generate substantial surplus. However, due to an apparent declining marginal value, speeds of more than 10 times those offered by the typical cable plans imply only an increase of 1.5 times the surplus.

The data provided in the Nevo et al. (2016) study allows the estimation of a log curve depicting the relationship between consumer surplus and speed (see Graphic C-3).

Graphic C-3

Log Curve of Relationship Between Broadband Speed and Consumer Surplus (based on Nevo et al., 2016)



Note: Based on data points of table VII and table VI of Nevo et al., 2016.

Source: Nevo et al.(2016); Telecom Advisory Services analysis

For reference, to calibrate the curve in Graphic C-3, the same analysis was conducted for the work carried out by Liu et al. (2018), where the results were not statistically different.

According to the data of the Graphic C-3, an increase in speed from 92.5 Mbps to 977.9 Mbps (ten times) increases consumer surplus from $149.9 to $212.9 (close to 1.5 times). The equation

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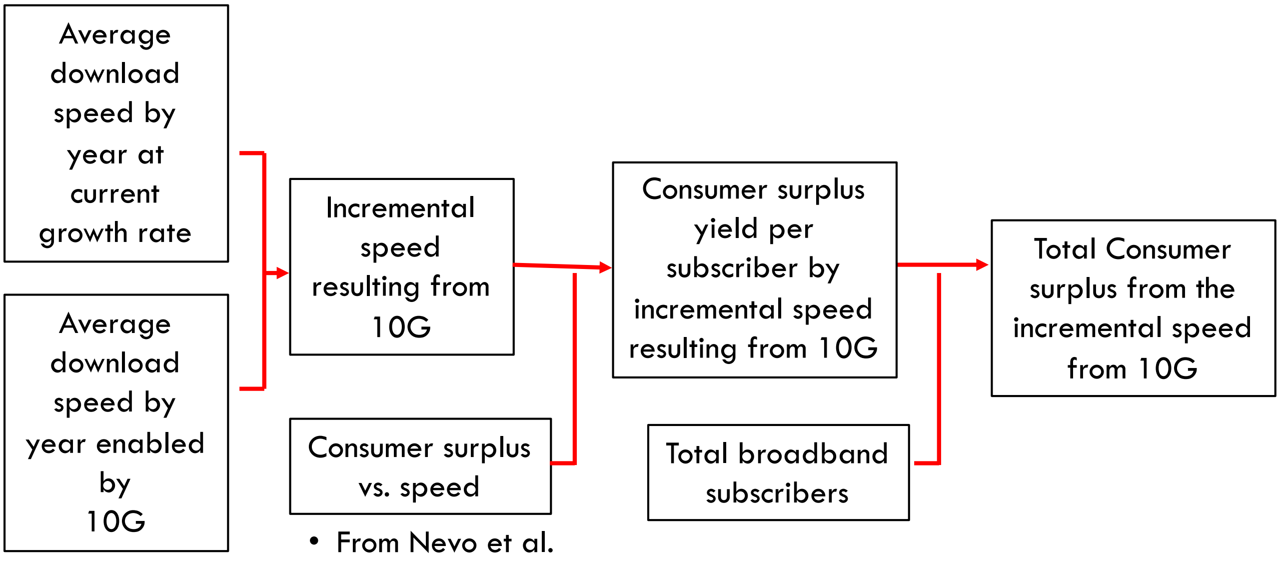
[80] A 10 Gigabit per second product is currently being offered in some limited areas of the United States (for example, service providers offering 10Gbps service include the Electric Power Board of Chattanooga, Tennessee, Fision in Salisbury, North Carolina, and Vtel in Vermont)

[81] Nevo, A., Turner, J., and Williams, J. "Usage-based pricing and demand for residential broadband", Econometrica, vol. 84, No.2 (March), 441-443.

linking speed to consumer surplus from Graphic C-3 was then used to estimate the value to be derived by faster download speeds enabled by 10G. For this purpose, the difference between average download speed enabled by 10G and average download speed if speed increased annually at the current growth rate was multiplied by the coefficient of the log curve as depicted in the graphic above (see figure C-4).

Figure C-4

Estimate of Consumer Surplus as a Function of Speed



Appendix D: Impact of investment in support of 10G migration on GDP and employment

Using data from S&P Global/Kagan, we assume the capital expenditures expected to drive the evolution of cable broadband platforms to the next generation 10G networks in the United States will amount to $81.4 billion over seven years, resulting in a one-time contribution to GDP of $126.7 billion (see table D-1).

Table D-1

United States: Impact of 10G Investment on GDP (in $ billions)

	Seven Years	Annual*
Direct	$81.4	$11.6
Indirect & Induced	$45.3	$6.5
Total	$ 26.7	$ 18.1
Multiplier	1.56	

* Over seven years

Source: Based on I/O table developed with BEA data; Telecom Advisory Services analysis

The $11.6 billion annual direct effect on GDP is focused on the electronics equipment and construction industries since those are two sectors where investment is concentrated. On the other hand, the $6.5 billion annual indirect and induced impact from the investment benefits the industries supplying goods and services to the electronics and construction sectors (metal products, trade, business services, and financial services).

Additionally, the deployment of 10G technology in the United States will translate into 53,700 annual jobs (see table D-2).

Table D-2

United States: Impact of Investment in 10G on Employment

	Total (job years)	Annual jobs *
Direct	267,200	38,200
Indirect & Induced	108,600	15,500
Total	375,800	53,700
Multiplier	1.41	

* Over seven years

Source: Based on I/O table developed with BEA data; Telecom Advisory Services analysis

The 1.41 multiplier is calculated as the sum of direct, indirect and induced jobs divided by direct jobs (defined as a Type II multiplier). As a comparison, Crandall et al. (2003) estimated a multiplier of 2.17 for a broadband investment program in the early 2000s and Katz et al. (2009) calculated a 3.42 multiplier for the investment in the Broadband Technologies Opportunity Program, although this value results from higher induced effects due to the high unemployment rate at the time of the 2008 recession.[82]

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[82] Since induced employment creation is triggered by spending of direct and indirectly created workers, when economies are running at full employment, induced effects are de minimis.

Appendix E: Impact of spillovers from the 10G migration on GDP and employment

The fixed broadband average download speed in the second quarter of 2020 in the United States had reached 138 Mbps. An extrapolation of the last two years growth trend indicates that by year end, the average speed would reach 152 Mbps.

According to operators' announcements, the migration to 10G is likely to start in 2021, with spillovers beginning to take place in that year. Accordingly, average download speed would start increasing at a faster rate than the extrapolation of the historical trend because it would not be limited as much by supply; we assume that it reaches 12.75% of the weighted average peak 10 Gbps by 2027 (see table E-1).

Table E-1
United States: Fixed Broadband Speed (2020-2027)

	2020	2021	2022	2023	2024	2025	2026	2027
Avg. download speed (in Mbps)	152	186	227	277	338	412	503	613
Avg. download speed growth	17.41%	22.00%	22.00%	22.00%	22.00%	22.00%	22.00%	22.00%
Avg. download speed 10G (Mbps)	152	203	271	362	483	644	860	1,147
Avg. download speed growth	17.41%	33.42%	33.42%	33.42%	33.42%	33.42%	33.42%	33.42%

Note: the growth in average download speed in 2020 includes the effect of increase in traffic triggered by COVID-19; The values starting in 2021 were calculated as the average between 2018 and 2020 in order to smooth the impact of COVID-19.

Source: Telecom Advisory Services analysis

Having calculated the two average download speed scenarios (with and without 10G), we move to estimate what the impact of the difference between the two would be on GDP. For this purpose, we bring back the coefficient of the impact of speed on GDP for average speed higher than 40 Mbps that we estimated in the econometric model presented in table C-1. We find that a 1% increase in broadband speed yields 0.0073% increase in GDP and we use this coefficient to calculate the GDP impact of both download speed scenarios. By subtracting the impact of the speed extrapolated from historical growth without 10G from impact with the faster speed, we isolate the GDP impact attributed to the spillovers from the new technology (see table E-2).

Table E-2

United States: 10G Spillover Impact on GDP (2020-2027)

	2020	2021	2022	2023	2024	2025	2026	2027
Speed contribution to GDP (from model)	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%
Impact of historical speed growth on GDP	0.13%	0.16%	0.16%	0.16%	0.16%	0.16%	0.16%	0.16%
Impact of speed growth with 10G on GDP	0.13%	0.24%	0.24%	0.24%	0.24%	0.24%	0.24%	0.24%
Impact on GDP attributed only to 10G	0.00%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%

Source: Telecom Advisory Services analysis

We can now use the values on the last line of table E-2 to estimate the spillover impact of 10G on GDP. The starting point is the GDP of the United States as forecasted by the International Monetary Fund (updated with the 2020 revision that includes the COVID-19 impact) to which the impact of the last line in table E-2 is applied (see table E-3).

Table E-3

United States: 10G Spillover Impact on GDP (2020-2027) (in $ billions)

	2020	2021	2022	2023	2024	2025	2026	2027
Total U.S. GDP	$20,169	$21,117	$21,829	$22,556	$23,308	$24,085	$24,887	$25,716
Impact due to 10G	$0.00	$16.8	$17.6	$18.2	$18.8	$19.4	$20.1	$20.8
Total U.S. GDP (with 10G impact)	$20,169	$21,134	$21,847	$22,574	$23,327	$24,104	$24,907	$25,737

Source: IMF 2020 forecast that includes the COVID-19 impact; Telecom Advisory Services analysis

To sum up, our analysis indicates that the cumulative incremental impact on GDP of fixed broadband speeds enabled by 10G will reach $131.7 billion, evolving from $16.8 billion in 2021 to $20.8 billion in 2027.

We conduct a similar analysis to assess the impact of 10G on employment. Again, the starting point is the difference in download speed scenarios presented in table E-1. In this case, we bring back the coefficient we estimated of the impact of speed on overall employment, as estimated in the econometric model presented in table C-2, which stated that 1% increase in broadband speed yields 0.00232 increase in employment. We use this coefficient to calculate the employment impact of both download speed scenarios. By subtracting historical speed growth without 10G from the faster speed path with 10G, we isolate the spillover effects on employment growth exclusively attributed to the latter (see table E-4).

Table E-4

United States: 10G Spillover Impact on Total Employment (2020-2027)

	2020	2021	2022	2023	2024	2025	2026	2027
Avg. download speed (in Mbps)	152	186	227	277	338	412	503	613
Avg. download speed 10G (Mbps)	152	203	271	362	483	644	860	1,147
Speed contribution to total employment	0.23%	0.23%	0.23%	0.23%	0.23%	0.23%	0.23%	0.23%
Total employment (‘000)	152,309	159,467	160,280	161,097	161,918	162,743	163,573	164,406
Impact attributed only to 10G (‘000)	0.00	42.3	42.5	42.7	42.9	43.1	43.3	43.6
Total employment (with 10G impact) (‘000)	152,309	159,510	160,323	161,140	161,961	162,786	163,616	164,450

Source: For total employment 2019 BLS preliminary release; for 2020 and 2021 change in employment in line with change in GDP; After 2021 we used BLS projection (released Pre-COVID); Telecom Advisory Services analysis

The sum of the next to last line of table E-4 indicates that the cumulative impact of overall spillover effects on employment of fixed broadband speed enabled by 10G will reach 300,200 jobs.

We conduct a similar analysis to assess the impact of 10G on service sector employment. In this case, we bring back the coefficient of speed impact on service sector employment, also from Table C-2, which stated that 1% increase in broadband speed yields 0.0153 increase in service sector jobs. We use this coefficient to calculate the employment impact of both download speed scenarios. By subtracting historical speed growth from the faster speed path with 10G, we isolate the service sector employment growth attributed to the spillovers from 10G networks (see table E-5)

Table E-5

United States: 10G Spillover Impact on Service Sector Employment (2020-2027)

	2020	2021	2022	2023	2024	2025	2026	2027
Avg. download speed (in Mbps)	152	186	227	277	338	412	503	613
Avg. download speed 10G (Mbps)	152	203	271	362	483	644	860	1,147
Speed contribution to service jobs	1.53%	1.53%	1.53%	1.53%	1.53%	1.53%	1.53%	1.53%
Total service employment ('000)	119,600	125,200	125,900	126,600	127,300	128,100	128,800	129,500
Service jobs due to historical speed growth ('000)	0.00	402.5	421.4	423.8	426.2	428.6	431.1	433.6
Service jobs with 10G speed growth ('000)	0.00	611.4	640.1	643.7	647.4	651.1	654.8	658.6
Impact attributed to 10G ('000)	0.00	208.9	218.7	219.9	221.2	222.5	223.7	225.0
Total service employment (with 10G impact) ('000)	119,600	125,409	126,119	126,820	127,521	128,323	129,024	129,725

Source: For service employment 2019 BLS preliminary release; for 2020 and 2021 change in employment in line with change in GDP; After 2021 we used BLS projection (released Pre-COVID); Telecom Advisory Services analysis

The sum of the next to last line of table E-5 indicates that the cumulative impact on service sector employment of fixed broadband speed enabled by 10G will reach 1,540,000 jobs.

As we discussed above, the difference between the total employment growth (300,200) and service sector job creation (1,540,000) suggests that 10G can help mitigate against labor force disruption triggered by automation. As reviewed in the literature, fast broadband speeds have an impact on firm development pertaining to industries in the tertiary sector but no effect in manufacturing (Hasbi, 2017). This leads us to conclude that 10G might have an impact on labor force restructuring in terms of enabling the shift from manufacturing to the services sector.

Recent research on the impact of automation on the labor force indicates that in the United States 10% of jobs are likely to be automated within two to three decades, while an additional 26% will incur significant changes in the way they are conducted due to automation (Autor, 2015; Arntz et al., 2016; Nedelkoska and Quintini, 2018). In this context, a large portion of the jobs lost to automation in the primary and secondary sectors will be replaced by jobs in the services sector; faster broadband speeds should be conceived as a general-purpose technology acting as an enabler of this compensating effect.

Appendix F: Estimates of consumer surplus generated by the migration to 10G

Based on the difference between the extrapolated growth of fixed broadband download speeds with and without 10G, we calculated the monthly consumer surplus per cable broadband subscriber in the United States attributable to 10G (see table F-1).

Table F-1

United States: Monthly Consumer Surplus per Cable Broadband Subscriber (2021-2027)

	2021	2022	2023	2024	2025	2026	2027
Average download speed (in Mbps)	186	227	277	338	412	503	613
Monthly consumer surplus per subscriber based on average download speed without 10G($)	$168.0	$173.4	$178.8	$184.3	$189.7	$195.1	$200.4
Average download speed with 10G (Mbps)	203	271	362	483	644	860	1,147
Monthly consumer surplus per subscriber based on average download speed with 10G ($)	$170.5	$178.3	$186.1	$194.0	$201.8	$209.7	$217.5
Monthly consumer surplus per subscriber attributed to 10G ($)	$2.5	$4.9	$7.3	$9.7	$12.1	$14.6	$17.1

Notes: (2) and (4) Consumer surplus = 27.206*LN(Average download speed)+25.852

Source: Telecom Advisory Services analysis

As indicated in table F-1, monthly consumer surplus per subscriber increases due to the growth in speed attributed to current investment and growth attributed to 10G increases from $2.5 in 2021 (when average download speed reaches 203 Mbps) to $17.1 (when average download speed reaches 1,147 Mbps). This increase in surplus is driven by an improvement in service speed as well the ability to adopt new bandwidth intensive applications, all enabled by 10G.

By converting the monthly consumer surplus estimate to a yearly number and then multiplying the value by the total projected number of cable broadband subscribers, we also can calculate the annual aggregate incremental consumer benefit from 10G (see table F-2).

Table F-2

United States: Total Consumer Surplus Attributed to 10G (2021-2027)

	2021	2022	2023	2024	2025	2026	2027
Annual consumer surplus per subscriber	$29.2	$58.4	$87.6	$116.9	$146.0	$175.3	$204.5
Total cable broadband subscribers (millions)	78.3	80.5	82.7	85.0	87.3	89.7	92.2
Total annual consumer surplus (millions)	$2,300	$4,700	$7,200	$9,900	$12,800	$15,700	$18,800
TOTAL (2021-27)							$ 71,500

Notes: (Line 5 from table F-1)*12; Kagan estimations for 2019-2021. And 2022-2027, was estimated assuming 2020-2021 growth rate; Line 1*Line 2

Source: Telecom Advisory Services analysis

As a result, we estimate that the average annual consumer surplus attributed to 10G between 2012 and 2027 in the United States will reach $ 10.2 billion.

Appendix G: Summary of economic benefits from 10G migration

As discussed in chapter 2 and estimated throughout the study, 10G will yield three major categories of economic effects: 1) a direct, indirect and induced impact on GDP and employment triggered by investment in 10G network migration, 2) the spillovers on GDP and employment resulting from the impact of 10G on consumer expenditures and enterprise productivity, new business model development, and overall business expansion, as evidenced by emerging applications and use cases and 3) consumer surplus.

For the purposes of our analysis, we assume that the impact of investment in 10G starts occurring at the time when the cable industry begins its shift to the deployment of DOCSIS 4.0 technology. This leads to a conservative estimate of the economic benefits, since some of the value of the implementation of DOCSIS 3.1 technology should be attributed to 10G. Spillovers on GDP and employment and increases in consumer surplus begin to materialize as the 10G infrastructure is deployed.

Our analysis shows that the cumulative economic contribution of 10G in the U.S. will evolve from $ 38.2 billion (or 0.17% of GDP) in 2021 to $ 56.6 billion in 2027. These estimates assume that investment for the migration to 10G will be split evenly over seven years (see table G-1).

Table G-1

United States: Total Economic Contribution of 10G (in $ billions)

		2021	2022	2023	2024	2025	2026	2027
Network investment	Direct	$12.2	$12.1	$11.9	$11.6	$11.4	$11.2	$11.0
	Indirect and induced	$6.9	$6.8	$6.7	$6.5	$6.3	$6.1	$6.0
	Total	$19.1	$18.9	$18.5	$18.1	$17.7	$17.3	$17.0
Spillovers		$16.8	$17.6	$18.2	$18.8	$19.4	$20.1	$20.8
Consumer surplus		$2.3	$4.7	$7.3	$9.9	$12.8	$15.7	$18.9
Total		$38.2	$41.1	$44.0	$46.9	$49.9	$53.1	$56.6
Percent of GDP		0.17%	0.17%	0.18%	0.18%	0.19%	0.20%	0.20%

Note: Due to rounding some totals may not correspond with the sum of the separate numbers

Source: Telecom Advisory Services analysis

The impact of 10G on U.S. employment is shown in table G-2.

Table G-2

United States: Total Contribution of 10G to Job Creation

		2021	2022	2023	2024	2025	2026	2027
Network investment	Direct	40,700	40,100	39,200	38,200	37,300	36,300	35,300
	Indirect and induced	16,600	16,400	16,000	15,600	15,100	14,700	14,300
	Total	57,300	56,500	55,200	53,800	52,400	51,000	49,600
Spillovers		42,300	42,500	42,700	42,900	43,100	43,300	43,600
Total		99,600	99,000	97,900	96,700	95,500	94,300	93,200

Source: Telecom Advisory Services analysis

We estimate that the evolution of cable's platform to 10G will generate, from investment and spillovers, an average of 96,600 jobs per year. Of these jobs, 53,700 will be employed either directly or indirectly to help with the migration of current networks to 10G, while spillovers will create an average of 42,900 jobs every year.

While net new job creation may not seem significant, 10G will help ensure that jobs lost in the primary and secondary economies particularly due to automation are offset through new employment in the service sector. We estimate that the technology will create a total of 1,540,000 service sector jobs over a seven-year period (or 220,000 per year).