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The Need for High and Symmetrical Broadband Upload Speed with Low Latency

Current U.S. internet service that typically favors download speed over upload speed is an artifact of a broadcast-focused business model better suited for entertainment than innovation. Asymmetric, low upload speeds with low quality of service, e.g., high latency, are out of date, are already limiting American participation in the 21st century economy, and will materially constrain the development of near-term applications for education, health care and economic growth for millions of Americans.

While incumbent providers are meeting the demand for high upload speed and symmetrical service in affluent areas by building fiber-optic networks in those communities, rural and other areas of modest means remain left behind with antiquated connectivity based on the broadcast model. As China and other countries recognize, symmetric, high-speed internet with low latency for all households is essential to maintain and improve a nation's economic competitiveness. Limited U.S. government funding for rural and other areas of modest means should be dedicated to future-proof technologies, such as fiber-optics, that support high upload speeds, low latency and symmetrical connectivity. These technologies are relatively inexpensive to upgrade to meet growing needs and will provide a platform for decades of innovation and economic growth.

To meet today's minimum needs, a household with two parents working at home with two school-age children needs an upload speed of 8 to 20 Mbps to support four concurrent video calls for remote learning, remote work and telehealth.[1] However, these speeds will not be adequate for long. New applications with increased needs for data and speed are continually being developed and deployed. The IDC estimates that overall data creation will grow at an annual rate of 26% over the next five years.[2] Productivity data, the type that is uploaded by homes and businesses, is forecast to grow even faster, at an annual rate of 40%.[3] At these rates of growth, a need for 20 Mbps today will become a need for 108 Mbps in 2025. Ten, twenty or thirty years from now the need is likely to be exponentially greater, with some future applications requiring upload speeds of 10 Gbps. The market recognizes this current and future need. Americans who have access to high upload speeds generally pay for such speed: the average upload speed in 2020 was 65 Mbps,[4] reflecting the high popularity of fiber-optic service where available. (DSL and cable are generally limited to 10 and 50 Mbps upload speeds, respectively).[5]

Although we cannot know in advance all the applications that will be developed and deployed over the multi-decade life of new broadband infrastructure, a few near-term applications stand out, particularly virtual and augmented reality applications, which are already growing rapidly in the marketplace. Mostly used today for gaming, virtual and augmented reality are increasingly being used for education

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[1] A single high-quality video call requires 2 to 5 Mbps upload speed. eVisit, "What are the basic technical requirements for telehealth?," https://blog.evisit.com/virtual-care-blog/what-are-the-basic-technical-requirements-for-telehealth; Zoom, "System requirements for Windows, macOS, and Linux," https://support.zoom.us/hc/en-us/articles/201362023-System-requirements-for-Windows-macOS-and-Linux; Microsoft, "Prepare your organization's network for Microsoft Teams," https://docs.microsoft.com/en-us/microsoftteams/prepare-network.

[2] International Data Corporation, "IDC's Global DataSphere Forecast Shows Continued Steady Growth in the Creation and Consumption of Data," https://www.idc.com/getdoc.jsp?containerId=prUS46286020

[3] Id.

[4] https://www.speedtest.net/global-index/united-states#fixed

[5] BroadbandNow, "DSL vs Cable vs Fiber: Comparing Internet Options," https://broadbandnow.com/guides/dsl-vs-cable-vs-fiber

and medicine, following the same trajectory of many IT technologies that have moved from niche applications to widespread adoption. These technologies will enable students to, e.g., interactively tour remote museums, participate more effectively in remote seminars, and engage in new forms of learning and education. These technologies are already used for remote counseling and to deliver remote rehabilitation to wounded veterans.[6] In the future, these technologies will be used to enhance telemedicine more generally by providing a more personal interface. Currently available virtual and augmented reality systems require 25 Mbps upload, next generation systems will require 100 Mbps upload, and planned ultra-interactive systems will require 2,000 Mbps upload.[7]

In the not-too-distant future, the tactile internet, which will transmit sensations of touch, will aid aging-in-place, hospital recovery, and other care-intensive telehealth applications through tactile telemedicine. Tactile medicine will also enable remote surgery so that specialists in urban centers can help rural residents. These applications, while not yet commercially deployed, are in active development and the IEEE is already creating technical standards for tactile communications.[8] These applications are expected to require upload speeds of 10 Gbps.[9]

In addition, broadband networks will need to support applications that involve a wireless connection, but that require high-speed and low latency connectivity to the wireless transmitter/receiver, via, e.g., 5G technologies. These applications include unmanned aerial vehicles for precision agriculture, [10] and autonomous vehicles for mobility and package delivery, [11] which are expected to require upload speeds of 120 and 1,000 Mbps, respectively.

Quality of service metrics other than speed, such as latency, are critical to support applications of the future. While video calls can tolerate relatively high, one-way latencies of up to 150 ms, other applications require much lower latency in order to function effectively. Virtual and augmented reality applications require maximum latencies between 5 ms and 20 ms in order to avoid motion sickness, so-called "cybersickness."[12] Autonomous vehicles and unmanned aerial vehicles will require maximum latencies of 5 ms and 10 ms, respectively, in order to operate safely.[13] Tactile applications, such as tactile telemedicine, will require even lower latencies (e.g., below 1 ms) because the human mind perceives touch faster than it perceives sight or sound.[14]

Importantly, these are not merely points of academic or technical debate. Broadband infrastructure has real-world impacts on education, employment, health care, economic competitiveness, and national security. Countries that have universal, cutting edge, symmetric broadband connections with low latency will develop, innovate and deploy advanced applications, gaining most of the economic and strategic benefits. Countries without such connectivity will lag behind. As a result, many countries, such as China, are actively building communications networks that can support symmetric gigabit

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[6] Pedram, S. et al., "Examining the potential of virtual reality to deliver remote rehabilitation." Computers in Human Behavior 105 (2020).

[7] Mangiante, S. et al., "VR is on the Edge: How to Deliver 360 Videos in Mobile Networks." 10.1145/3097895.3097901 (2017).

[8] Sharma, Shree Krishna, et al. "Towards Tactile Internet in Beyond 5G Era: Recent Advances, Current Issues and Future Directions," arXiv:1908.07337 (2019)

[9] Simsek, M,, et al. "5G enabled tactile internet." IEEE J. on Selected Areas in Communications 34.3 (2016): 460 473

[10] 5G!Drones, "D1.1 – Use case specifications and requirements," https://5gdrones.eu/wp-content/uploads/2020/05/D1.1-Use-case-specifications-and-requirements-v1.0.pdf

[11] H. Tataria, "6G Wireless Systems: Vision, Requirements, Challenges, Insights, and Opportunities," arXiv:2008.03213v2 (2021); 5G-PPP, "5G Automotive Vision," https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf.

[12] Mangiante, S. et al., "VR is on the Edge: How to Deliver 360 Videos in Mobile Networks." 10.1145/3097895.3097901 (2017).

[13] 5G-PPP, "5G Automotive Vision," https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf; 5G!Drones, "D1.1 – Use case specifications and requirements," https://5gdrones.eu/wp-content/uploads/2020/05/D1.1-Use-case-specifications-and-requirements-v1.0.pdf

[14] N. Promwongsa *et al*., "A Comprehensive Survey of the Tactile Internet: State-of-the-Art and Research Directions," in *IEEE Communications Surveys & Tutorials*, vol. 23, no. 1, pp. 472-523, First quarter 2021, doi: 10.1109/COMST.2020.3025995

speeds in anticipation of these future applications.[15] In China, 86% of the population has access to the internet over cutting-edge fiber-optic networks.[16] In comparison, only 25% of the U.S. population is so connected, placing U.S. innovation and competitiveness at risk.[17]

Fortunately, future-proof, fiber-optic networks typically have the lowest, long term costs in rural and underserved areas. Fiber-optic networks generally operate for thirty to forty years, with relatively inexpensive electronic upgrades required every ten years to maintain cutting-edge connectivity. In contrast, alternative technologies typically require expensive equipment upgrades every five to ten years to maintain adequate connectivity. Because of this difference in network life and upgrade expense, fiber-optic networks are often the lowest cost connectivity technology, other than in the lowest-density communities. For example, we studied one community with an average density of about 12 homes per mile in which a fiber-optic network was about 40% less expensive than fixed wireless on a thirty-year basis, even though the up-front capital costs for the fiber-optic network were 45% higher than fixed wireless.

America's economic competitiveness and national security require universal, cutting-edge, high-speed, symmetric and low latency broadband. The U.S. can achieve that goal with future-proof technology that has better long term value than alternative technologies that cost less initially but that will be quickly obsolete.

[15] Rethink Technology Research, https://rethinkresearch.biz/articles/chinese-set-to-dominate-1-gbps-broadband/

[16] Cooper, T., "China's Fiber Broadband Internet Approaches Nationwide Coverage; United States Lags Severely Behind," Broadband Now Report, https://broadbandnow.com/report/chinas-fiber-broadband-approaches-nationwide-coverage/ (March 11, 2021).

[17] *Id*.

Broadband Application	Minimum Broadband Requirements		
	Upload Speed (Mbps)	Download Speed (Mbps)	One-way Latency (ms)
Single high-quality Teams,[18] Zoom[19] or eVisit[20] video call for remote learning, telehealth or remote work	1.5 to 5	1.5 to 5	50 to 150
Four concurrent high-quality video calls for remote learning, telehealth, remote work[21]	6 to 20	6 to 20	50 to 150
Current virtual augmented reality[22] for remote learning and rehabilitation	25	25	20
Entry-level virtual/augmented reality[23]	100	100	15
Unmanned aerial vehicle for precision agriculture and other applications[24]	120	120	10
Advanced virtual/augmented reality[25]	400	400	10
Autonomous vehicles[26]	1,000	1,000	5
Ultra-interactive virtual/augmented reality[27]	2,500	2,500	5
Tactile telemedicine[28]	2,000 to 1,000,000	2,000 to 1,000,000	0.5

[18] Microsoft, "Prepare your organization's network for Microsoft Teams," https://docs.microsoft.com/en-us/microsoftteams/prepare-network; Microsoft, "Media Quality and Network Connectivity Performance in Skype for Business Online," https://docs.microsoft.com/en-us/skypeforbusiness/optimizing-your-network/media-quality-and-network-connectivity-performance.

[19] Zoom, "System requirements for Windows, macOS, and Linux," https://support.zoom.us/hc/en-us/articles/201362023-System-requirements-for-Windows-macOS-and-Linux

[20] eVisit, "What are the basic technical requirements for telehealth?," https://blog.evisit.com/virtual-care-blog/what-are-the-basic-technical-requirements-for-telehealth

[21] Estimated by multiplying the requirements for a single video call by a factor of four.

[22] Mangiante, S. et al., "VR is on the Edge: How to Deliver 360 Videos in Mobile Networks." 10.1145/3097895.3097901 (2017).

[23] Id.

[24] 5G!Drones, "D1.1 – Use case specifications and requirements," https://5gdrones.eu/wp-content/uploads/2020/05/D1.1-Use-case-specifications-and-requirements-v1.0.pdf

[25] Mangiante, S. et al., "VR is on the Edge: How to Deliver 360 Videos in Mobile Networks." 10.1145/3097895.3097901 (2017).

[26] H. Tataria, "6G Wireless Systems: Vision, Requirements, Challenges, Insights, and Opportunities," arXiv:2008.03213v2 (2021); 5G-PPP, "5G Automotive Vision," https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf.

[27] Mangiante, S. et al., "VR is on the Edge: How to Deliver 360 Videos in Mobile Networks." 10.1145/3097895.3097901 (2017).

[28] Qi Zhang, Jianhui Liu, and Guodong Zhao, "Towards 5G Enabled Tactile Robotic Telesurgery," arXiv:1803.03586v1; N. Promwongsa *et al.*, "A Comprehensive Survey of the Tactile Internet: State-of-the-Art and Research Directions," in *IEEE Communications Surveys & Tutorials*, vol. 23, no. 1, pp. 472-523, First quarter 2021, doi: 10.1109/COMST.2020.3025995

Broadband Technology	Technology Capability		
	Upload Speed (Mbps)	Download Speed (Mbps)	Latency (ms)
DSL, as deployed (2019)[29]	1.5	13	21 to 61
Fixed Wireless, as deployed (2019)[30]	2	14	20 to 40
Satellite, Geo-synchronous (2017)[31]	3	16	600
TV White Space[32]	1 to 10	10 to 30	10
Cable as deployed (2019)[33]	11	155	16 to 28
Fixed Wireless, new installation (3.5GHz)[34]	10	50	10 to 20
Satellite, LEO (beta)[35]	20	100	20 to 40
Fiber, as deployed (2019)[36]	190	208	5 to 11
DOCSIS 3.1 cable, theoretical[37]	1,000	10,000	5
DOCSIS 4.0 cable, theoretical[38]	6,000	10,000	5
Fiber, new installation (XG-PON2)[39]	10,000	10,000	5

[29] FCC, "10th Measuring Broadband America Fixed Broadband Report," https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-tenth-report (2021)

[30] Preseem, "Fixed Wireless Network Report, 2020 Q3 Fall Edition," https://preseem.com/wp-content/uploads/2020/10/Preseem-Fixed-Wireless-Network-Report-2020-Q3-Fall-Edition.pdf (2020).

[31] FCC, "Eighth Measuring Broadband America Fixed Broadband Report," https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-eighth-report

[32] www.neubeam.com; J. Pressgrove, "'White Space' Internet Could Connect the U.S.'s Isolated Places," https://www.govtech.com/network/white-space-internet-could-connect-the-uss-isolated-places.html; K. Ndlovu, et al., "Network performance analysis of the television white space (TVWS) connectivity for telemedicine: A case for Botswana," 2017 IEEE AFRICON, 2017, pp. 542-547, doi: 10.1109/AFRCON.2017.8095539.

[33] FCC, "10th Measuring Broadband America Fixed Broadband Report," https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-tenth-report (2021). Note that in response to the pandemic, many cable providers have increased both upload and download speed since 2019.

[34] M. Alleven, "Midco sets sights on offering 100/20 Mbps speeds using 3.5 GHz band," https://www.fiercewireless.com/wireless/midco-sets-sights-offering-100-20-speeds-using-3-5-ghz-band; MidCo, "High-Speed Rural Internet," https://www.midco.com/services/internet-services/rural-internet/

[35] Sam Knows, "Space Broadband, the new connectivity frontier," https://samknows.com/blog/the-space-edition

[36] FCC, "10th Measuring Broadband America Fixed Broadband Report," https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-tenth-report (2021)

[37] Cable Labs, "DOCSIS 3.1 Technology," https://www.cablelabs.com/technologies/docsis-3-1

[38] Cable Labs, "DOCSIS 4.0 Technology," https://www.cablelabs.com/technologies/docsis-4-0-technology

[39] Calix, "The right solution for your network, at the right time," https://www.calix.com/solutions/technologies/10g-pon-solutions.html