Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Modernizing Unbundling and Resale	)	WC Docket No. 19-308
Requirements in an Era of Next-Generation	)	
Networks and Services	)	
	)	

COMMENTS OF ELECTRONIC FRONTIER FOUNDATION

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I. Overview

Universal fiber to the home (FTTH) networks are the foundation of 21st century-ready-broadband access. The incumbent local exchange carriers (ILEC) who seek forbearance from the '96 Act's competition provisions have stopped transitioning their networks over to FTTH, while the competitive local exchange carriers (CLEC) that would be harmed by forbearance are actively deploying FTTH. The ILECs are no longer building networks capable of competing and surpassing the cable industry while the CLECs are actively challenging cable markets. And every market where we wish to see 5G high-speed broadband access competition relies on dense fiber networks on the ground that come from FTTH deployments. These facts make forbearance from the competition policies enacted in 1996, which is only supposed to be granted to promote competitive markets, untenable.

It is now long past time for the FCC to reverse the course set in 2005 when the agency concluded that obligations for sharing fiber were unnecessary to promote competition. Since that year, the ILECs have shown us that they will only build to the most lucrative markets and disproportionately favor the upper half of the median income while ignoring both rural and low income neighborhoods throughout the U.S. Such a deployment of FTTH has resulted in not just a digital divide, but a speed chasm among broadband choices. Today a massive number of Americans simply do not have access to the gigabit era of broadband unless it comes from their cable company. If the largest telephone companies that were meant to be the direct competitors to cable are no longer building the infrastructure necessary to challenge cable markets, then we must ask ourselves why that is happening and what policy levers the FCC should pursue to remedy the situation. Ignoring this problem simply allows our international competitors, particularly China, who are aggressively pushing universal FTTH to seize the future of broadband access.

That is not to say that the solution is to simply copy and paste copper-sharing rules towards fiber, but much of the progress we are seeing at the state level and internationally is coming from various fiber sharing arrangements. Some examples include a joint venture between the power utility and fiber provider in Alabama, the multi-city funded construction of an open access fiber network in Utah, and the decision by South Korea to mandate fiber sharing to promote national 5G coverage. Each of these and other versions of sharing access to fiber has promoted more high-speed access to broadband rather than deterred it, calling into question the FCC's central justification that sharing obligations deter investment—particularly given that the ILECs are no longer investing in FTTH.

Therefore, rather than continue pursuing a path of undoing sharing obligations in legacy networks, the FCC should look to modernize its sharing rules in light of these developments. After all, the ILECs already have a direct route to absolve themselves from copper sharing by simply replacing their legacy networks with fiber under the FCC's copper retirement rules. They have just chosen not to do it, despite all of the economically rational reasons to do so given the future-proof nature of FTTH and its vastly superior capability to upgrade past what cable companies can do with DOCSIS. Instead of moving backwards, the FCC should issue a Notice of Inquiry into fiber sharing and how it can be leveraged effectively to achieve universally available, competitive, and affordable 21st century ready broadband access.

II. About EFF

The Electronic Frontier Foundation (EFF) is the leading nonprofit organization defending civil liberties in the digital world. Founded in 1990, EFF champions user privacy, free expression, and innovation through impact litigation, policy analysis, grassroots activism, and technology development. With over 30,000 dues-paying members and well over 1 million followers on social networks, we focus on promoting policies that benefit both creators and users of technology. EFF has been at the forefront of studying the future of broadband access in the high-speed market and has conducted in-depth research and produced both legal and technical publications on the issue. EFF's goal in broadband access is the deployment of universally available, affordable, and competitive high-speed networks. EFF focuses on fiber because it is the only data transmission medium capable of both low latency and speed upgrades for generations to come that far exceed alternative last mile options as well as a necessary component for ubiquitous 5G coverage.

III. The Federal Communications Commission's proposed forbearance is contrary to the public interest and will harm consumers by reducing broadband choice in high-speed access.

To justify forbearance, the Federal Communications Commission (FCC) must show that the regulations are (1) not necessary to ensure that the telecommunications carrier's charges, practices, classifications, or regulations are just, reasonable, and not unjustly or unreasonably discriminatory; (2) not necessary to protect consumers; and (3) consistent with the public interest, including that it will ***promote competitive market conditions***.[1] No existing evidence can show that overall FTTH deployment will benefit from forbearance. Indeed, the ILECs' refusal to deploy FTTH to obtain the regulatory benefits of the FCC's copper retirement rules is the most notable indication that forbearance will not promote FTTH. Meanwhile, CLECs will be hindered by excusing ILECs' from their copper sharing obligations given that CLECs depend on copper sharing to finance their fiber construction. The end result of forbearance will be the FCC reducing overall FTTH deployment and harming high-speed broadband competition, reducing competition in 5G, and reducing our international competitiveness.

A. Fiber is a vastly superior data transmission medium among last mile connections, and the FCC should weight the future proofing and overall global trends to assess whether the market will be made more competitive through forbearance.

EFF's own research of the various last mile options that exist for Americans have led the organization to conclude that fiber and FTTH specifically contain future capacity potential that overshadows the alternatives (research report is attached as Appendix A).[2] It is the only fixed broadband connection that has an economically and technically feasible path towards a multi-gigabit broadband access future well past even the fastest speeds today. Indeed, scientists have

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[1] 47 U.S.C. § 160(c); and FCC forbearance decisions in 2014

[2] Bennett Cyphers, *The Case for Fiber to the Home, Today: Why Fiber is a Superior Medium for 21st Century Broadband*, Electronic Frontier Foundation (Oct 11, 2019), https://www.eff.org/files/2019/10/15/why_fiber_is_a_superior_medium_for_21st_century_broadband.pdf. Also attached as Appendix A.

been able to push 100 terabits per second down a single fiber[3] in laboratory conditions, indicating that real world utilization has ample room for growth. This is not true for 5G wireless broadband, DOCSIS cable systems, or the newest proposed satellite broadband systems. Each of these other systems have concrete barriers that FTTH systems do not contend with at all.[4]

Therefore, the FCC must assess the network technologies deployed in terms of their future potential. The issue is not only about the market today, but about the market tomorrow as demand for bandwidth continues to grow. This will allow the agency to measure whether a broadband access market is trending towards monopolization or competition in the high-speed arena given that eventually today's high speed will become the bare minimum necessary in the future. The FCC's reliance on an outdated definition of broadband access at 25/3 mbps as a type of ceiling for analysis effectively masks the competitive ills that tens of millions of American households face in high-speed competition.[5] A 25/3 mbps broadband standard obfuscates the extent of monopolization (or complete lack) of high-speed broadband options because it allows the government to count legacy technologies and new but capacity limited alternatives to be considered equal rivals. They are not and we should not pretend otherwise.

B. The entry of 5G into broadband will not disrupt cable's dominance in high-speed access because DOCSIS systems already have greater capacity to deliver broadband.

The FCC must not buy into the 5G hype that a revolution in last mile fixed broadband access is coming. Executives and investors in the cable industry have not only indicated they are unworried[6] about 5G broadband as a competitive pressure but they see it as a business opportunity for them to sell capacity.[7] This is because cable systems can already surpass any 5G wireless deployment in terms of high-speed potential by deploying more fiber into their system while simultaneously meeting the capacity needs of 5G towers with their excess capacity. The advantages DOCSIS and its future iterations have over wireless alternatives makes competition at the fastest speeds unrealistic. It is more likely that 5G and cable competition will be about the lower and middle tiers of broadband speeds. Simply as a matter of physics and available spectrum within the wires, only FTTH can have both lower latency and higher speeds than next-generation cable systems. 5G deployment will be dependent on available spectrum and higher speeds (which require using higher frequency bands) are more impacted by environmental conditions that insulated coaxial hybrid/fiber wired systems can avoid.[8]

As the FCC itself has noted in the past, wireless broadband and wireline broadband are complementary services and nothing in the latest developments in wireless technology have indicated a fundamental change. As EFF has noted in previous FCC filings, international markets

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[3] *Id*. at 22
[4] *Id*. at 21
[5] H. Trostle and Christopher Mitchell, *Profiles of Monopoly: Big Cable and Telecom*, Institute for Local Self-Reliance (July 2018), https://ilsr.org/wp-content/uploads/2018/07/profiles-of-monopoly-2018.pdf.
[6] Alex Sherman, *5G broadband is an existential threat to the cable industry, but executives and investors aren't worried*, CNBC (Dec. 1, 2019), https://www.cnbc.com/2019/12/01/5g-broadband-is-a-threat-to-cable-companies-but-execs-arent-worried.html.
[7] Jeff Baumgartner, *Cable '10G' Field Trials on Tap for 2020*, Light Reading (Jan. 6, 2020), https://www.lightreading.com/cable/10g/cable-10g-field-trials-on-tap-for-2020/d/d-id/756561.
[8] Cyphers, *supra* note 2.

that have comparable national high-speed wireless deployment still have consistent growth in their FTTH deployments[9] because users are not substituting one for the other. The FCC must not take a leap of faith that is divorced from both the engineering realities of wireless and trends in already existing markets that have proven the theory of wireless substitution to be wrong.

Lastly, 5G as a last mile broadband product is not producing the revenues both at home and in the advanced international market of South Korea, calling into question how viable it is as a fixed broadband access service. In South Korea, despite extraordinarily rapid growth in 5G subscribers and the upfront cost of laying fiber already being resolved, Internet Service Providers (ISPs) are only able to achieve revenue neutral status with their 5G broadband.[10] This suggests that the future of 5G will not be in the broadband access market, but rather in other, not currently existing markets that will need the unique services 5G can provide that WiFi or LTE cannot. Here at home, Verizon's experimental deployment of 5G as a last mile option and competitor to cable should give the FCC pause before concluding it can disrupt cable's dominance.[11] The fact is, the 5G industry is still figuring out its own future. Notably, the ILECs seeking forbearance as we enter 2020 are only making vague commitments with the public of their 5G goals[12] while expert analysis indicates 5G as a ubiquitously available product remains far into the future.[13]

C. Competition in complementary wireless markets are further enhanced with FTTH deployments and will enhance 5G wireless competition.

Arguably, the biggest barrier to national deployment of 5G wireless broadband is its dependence on national deployment of dense fiber networks. This makes FTTH deployment uniquely important to competition because of the synergies brought on by the convergence between dense fiber wireline deployments and advanced wireless services that the agency has historically supported. One study by the Fibre to the Home Council Europe estimates that highly dense small cell deployments in 5G can have 65% to 74% reduced costs if a preexisting FTTH network is

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[9] EFF response to arguments that wireless broadband can substitute for wireline broadband, GN Docket No. 18-238 (Oct. 12, 2018), https://ecfsapi.fcc.gov/file/101269873074/EFF-%20Wireline%20vs%20Wireless.pdf.

[10] Mike Dano, *Inside the Hunt for New 5G Revenues (Hint: Forget Phones)*, Light Reading (Nov. 19, 2019), https://www.lightreading.com/mobile/5g/inside-the-hunt-for-new-5g-revenues-(hint-forget-phones)/d/d-id/755769.

[11] Jeff Baumgartner, *Verizon Faces 'Steep Climb' to Attain Attractive Return on 5G Home – Analyst*, Light Reading (Mar. 20, 2019), https://www.lightreading.com/mobile/5g/verizon-faces-steep-climb-to-attain-attractive-return-on-5g-home---analyst-/d/d-id/750289.

[12] Mike Dano, *Here's Why It Might Be Time to Worry About mmWave 5G*, Light Reading (Jan. 9, 2020), https://www.lightreading.com/mobile/5g/heres-why-it-might-be-time-to-worry-about-mmwave-5g/a/d-id/756706.

[13] *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017–2022 White Paper*, Cisco (Feb. 18, 2019), Trend 2, https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-738429.html#_Toc953330 (Cisco predicting that 5G will only be available to 10 percent of the US market by 2022); *see also* Berkeley Lovelace Jr., *'There's zero chance that 5G is a ubiquitous technology' by 2021, analyst says*, CNBC (Apr. 23, 2019), https://www.cnbc.com/2019/04/23/analyst-craig-moffett-sees-no-chance-of-5g-becoming-ubiquitous-by-2021.html (Craig Moffet's predicts there is a "zero chance" 5G will be widely available by 2021).

present.[14] This cost savings holds true for both urban and rural markets. This makes promoting FTTH critical given that absence of a dense fiber network conversely means the expense for any single wireless 5G player is increased by 65% to 74% in sunk costs, making many markets economically unattractive for wireless 5G, let alone competition.

The CLECs' contribution towards national coverage of fiber through their efforts to build FTTH further makes forbearance that will stifle their efforts a bad idea. Not only will it reduce direct competition in high-speed access with cable companies, but it will have a downstream impact of reducing competition in complementary wireless markets. CLECs deploying fiber, much like their cable competitors, are not worried about 5G as a competitor and therefore would likely offer their excess capacity to 5G towers. For every market that has a fiber/coaxial hybrid cable provider and a CLEC fiber provider, 5G wireless companies will at least have two high capacity networks to choose from to move data from their towers. This will enhance 5G wireless companies that lack AT&T and Verizon's access to capital and currently existing fiber networks.

Lastly, the FCC has already effectively granted ILECs the equivalent of forbearance under its copper retirement rules and the ILECs have so far been unwilling to accept the deregulatory invitation. Proactively granting them forbearance will not change their lack of FTTH deployment plans. Therefore, the FCC should understand that forbearance that negatively impacts CLECs will mean less overall FTTH deployment from CLECs and as a result less FTTH deployment nationally that will be available to the 5G competitors of the ILECs selling 5G services.

D. The FCC must not rest its competition assessment on availability of 25/3 mbps broadband and update its analytical tools to account for 100/100 mbps, symmetrical gigabit, and beyond.

Broadband consumption has always been on the rise as applications and services continue to evolve. Per Cisco's analysis, North American data consumption will reach 90 exabytes per month by 2022.[15] This persistent growth in consumption means that consumers will continue to seek broadband products that quickly grant access to ever larger amounts of data. When the FCC adopted the 25/3 standard in 2015,[16] monthly data consumption was less than half of what it is projected to reach in the near future. This consistent growth makes the continued reliance on 25/3 mbps as a standard to assess competition in broadband access a bad metric. Furthermore, advancements in broadband technology, particularly in fiber technology, have not grown linearly, but by orders of magnitude.

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[14] Raf Meersman, *5G and FTTH: The Value of Convergence*, FTTH Conference (Mar. 13, 2019), https://www.ftthcouncil.eu/documents/COM-190313-FibreFor5G-ConvergenceStudy-Presentation-RafMeersman%20-%20v4%20-%20publish.pdf.

[15] *Cisco Visual Networking Index: Forecast and Trends, 2017–2022 White Paper*, Cisco (Feb. 27, 2019), https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html.

[16] Micah Singleton, *The FCC has changed the definition of broadband*, The Verge (Jan. 29, 2015), https://www.theverge.com/2015/1/29/7932653/fcc-changed-definition-broadband-25mbps.

Year	North America IP Based Traffic in Exabytes Per Month
2012	14.4
2018	43
2022	90

Source: Cisco Visual Predictions 2012-2017 and 2017 - 2022

The early advantages cable companies had with DOCSIS explains our current predicament in high-speed access and why FTTH is our solution. In 2007, Comcast's Senior Vice President of New-Media Development openly acknowledged his industry's structural advantage over the telephone industry.[17] As he noted, the entire cable industry would be able to incrementally upgrade to DOCSIS 3.0 (an international telecommunications standard for high-bandwidth data transfer over a coaxial cable TV system) for a "couple billion dollars," while Verizon would have to invest $18 billion to cover just 14 percent of the country with fiber optics.[18] The discrepancy in cost is due to the fact that telephone companies have to completely replace their copper infrastructure with fiber optics in order to surpass cable systems using DOCSIS. Verizon later discontinued its fiber optic deployment of FiOS in 2010 with a total of $23 billion invested in connecting homes.[19] Cable companies' structural advantage has continued with the gigabit rollout of DOCSIS 3.1, which again relies on less inexpensive incremental upgrades.

Given the persistent growth in data consumption needs of American consumers, cable's dominance in the high-speed market (above the 25/3 standard) in the absence of wide deployment of FTTH is entirely predictable. DOCSIS systems will continue to be able to upgrade on an incremental basis by pushing fiber further throughout their systems. In fact, future iterations of DOCSIS appear to allow cable to achieve symmetrical gigabit speeds (albeit not with the same low latency properties) that compare with fiber networks.[20] But even with all of this upgrade potential, EFF's research has found that cable companies will eventually fall far short of the newest FTTH advancements.[21]

This speed race is completely ignored by a 25/3 mbps analysis of competition. Under such a low standard, legacy technologies and other new yet capacity-constrained options could look like viable alternatives to cable. But given that cable has been able to incrementally upgrade into gigabit speeds, it is beyond doubt that as consumer needs grow into the gigabit era, they will have either a cable monopoly or no choice at all. In light of these trends, the FCC should update its 25/3 standard to a more dynamic analysis that attempts to capture the consistent growth in consumption and asks whether the broadband options available in the market can stay ahead of

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[17] Todd Spangler, *Advantage: DOCSIS 3.0*, MULTICHANNEL NEWS (May 11, 2007), https://www.multichannel.com/news/advantage-docsis-30-270766.
[18] *Id*.
[19] Roger Cheng, Verizon to End Rollout of FiOS, WALL STREET JOURNAL, Mar. 30, 2010, available at https://www.wsj.com/articles/SB10001424052702303410404575151773432729614
[20] Cyphers, *supra* note 2 at 15.
[21] *Id*.

consumption needs. This will allow its competition analysis to look at the market that exists today and also to effectively measure potential reduction in competition as applications and services advance.

IV. The FCC should revisit its 2005 decision to not apply sharing obligations to fiber in light of the failure of ILECs to completely transition their networks to fiber and willingness to cede the market to cable.

A. Rationales that justified the gradual retreat from the competition policies of the 1996 Act have not panned out as high-income markets are favored over lower-income and rural markets.

In 2005, the FCC predicted that not pursuing fiber sharing obligations would ensure "the deployment on a reasonable and timely basis of advanced capability to ***all*** Americans."[22] In the 15 years since, as other advanced nations achieved universal fiber deployment or are poised to achieve it soon, what has happened to the U.S. market is both an urban and rural divide as well as an income divide. According to the FCC's Communications Marketplace Report,[23] homes on the bottom half of the income scale, in rural markets, or both, disproportionately lack high-speed broadband competition. In essence, a lack of access to high-speed broadband is a proxy for lacking access to FTTH given that cable companies have systemically upgraded their systems into gigabit speeds.[24]

Fig. D-10

Average Percentage of Population with Multiple Provider Options for 250 Mbps/25 Mbps by Census Block Group Demographic Variable (As of December 31, 2017)

	Zero	One	Two	More Than Two
Population Density				
First Quartile (Lowest Pop. Density)	61.3%	30.0%	7.5%	1.2%
Second Quartile	37.2%	40.4%	16.2%	6.2%
Third Quartile	29.3%	44.1%	17.7%	8.9%
Fourth Quartile (Highest Pop. Density)	22.4%	36.4%	18.7%	22.6%
Median Household Income($2016)				
First Quartile (Lowest Median Household Income)	45.1%	37.7%	11.3%	5.8%
Second Quartile	44.1%	37.4%	12.5%	6.0%
Third Quartile	37.3%	38.4%	15.4%	8.9%
Fourth Quartile (Highest Median Household Income)	23.5%	37.5%	21.0%	18.0%

[22] 2005 Wireline Broadband Order at ¶ 3, n.8; 47 U.S.C. § 706

[23] Communications Marketplace Report, et. al., GN Docket No. 18-231, et. al. (2018), https://docs.fcc.gov/public/attachments/FCC-18-181A1.pdf

[24] *America is Now a Gigabit Nation*, NCTA (Jan. 18, 2019), https://www.ncta.com/whats-new/america-is-now-a-gigabit-nation.

This outcome must force us to re-evaluate our original assumptions about the market. In light of that need, EFF researchers in conjunction with the Samuelson-Glushko Technology Law & Policy Clinic analyzed the regulatory history behind the FCC's rationale to not require fiber sharing in 2005 (attached as Appendix B). It is our conclusion that agency predictions have not panned out.[25] First, the FCC believed that market incentives alone would incentivize sharing by cable operators in the absence of a mandate on ILECs.[26] Second, the FCC concluded that broadband competition from satellite, wireless, and broadband over power line[27] would join the direct competition between DSL and cable. Yet today it is pretty clear that none of these alternatives has kept pace with cable's advancements in high-speed access except for FTTH (which has surpassed cable).

Last, the common refrain that began in 2005 and persists today—that sharing obligations diminish incentives to invest and deploy new broadband infrastructure—do not match up with reality. In 2020, the two major ILECs no longer have investment plans to transition their national deployment of copper to FTTH, while their smaller competitors, still dependent on legacy sharing obligations, are modernizing their networks with FTTH. This is despite the near total deregulation ILECs have enjoyed from the Restoring Internet Freedom Order,[28] despite billions in new revenues being freed up from the reduction in corporate taxes,[29] and despite the FCC's copper retirement rules absolving them of sharing obligations if they transitioned over to fiber. At some point we have to assume Lucy is going to pull the football and chart a new course.

B. New sharing approaches are proving effective in deploying FTTH and the FCC should investigate how these new approaches can be part of a federal strategy towards universal fiber access and high-speed competition.

EFF is not saying that the FCC should simply copy and paste its copper sharing rules over to fiber. Rather, the agency should look at what is happening under various fiber sharing arrangements and see what lessons can be learned and applied in federal policy. Access to rights-of-way infrastructure has already been shown to be a major part of the deployment question, while the absence of such rights can stall even the world's largest and powerful corporations.[30]

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[25] Elliott Browning, *Managing Last-Mile Monopolists: Reevaluating Sharing Obligations for the Modern U.S. Wireline Broadband Market*, Electronic Frontier Foundation (Mar. 22, 2019), https://tlpc.colorado.edu/wp-content/uploads/2019/05/2019.05.22-TLPC-EFF-Broadband-Sharing-White-Paper-Final.pdf.

[26] 2005 Wireline Broadband Order at ¶ 64

[27] Id. at ¶ 50

[28] See Restoring Internet Freedom Order, WC Docket No. 17-108, Declaratory Ruling, Report and Order, and Order, at 52.

[29] Tax Cuts and Jobs Act of 2017, Pub. L. No. 115-97, 131 Stat. 2054; See also Ryan Knutson & Austen Hufford, *Verizon to Pay Down Debt, Given Employees Stock Awards with Tax Windfall*, Wall Street Journal (Jan. 23, 2018), available at https://www.wsj.com/articles/verizon-dials-up-wireless-revenue-growth-1516714601 (reporting an extra $ 4 billion of cash on hand for Verizon); *see also* Reuters & Fortune Editors, *AT&T Is the Latest Company to Report a Tax Reform Windfall*, Fortune, Feb. 1, 2018, available at http://fortune.com/2018/02/01/att-earnings-tax-reform (reporting an extra $3 billion of cash on hand from Congress cutting corporate taxes)

[30] Jon Brodkin, *Why AT&T Says it can Deny Google Fiber Access to its Poles in Austin*, Ars Technica, (Dec. 16, 2013), available at https://arstechnica.com/tech-policy/2013/12/why-att-says-it-can-deny-google-fiber-access-to-itspoles-in-austin.

Access to fiber capacity can be viewed through the same lens as poles and attachment rights; obtaining access to capacity can allow for more private and public entry.
Open access fiber can be viewed as an example of pursuing fiber on shared premises and as an infrastructure effort. Utah is proving to be a leader in this space: more and more households are connected to an expanding open-access fiber network run by local cities called Utopia, where residents enjoy 11 private options for gigabit service.[31] This type of approach to broadband infrastructure, where the government builds the wires and shares its capacity to broadband providers, holds tremendous promise. One study predicts a structurally separated network deployment could connect rural homes to fiber without standard subsidies and through long term low-interest financing.[32]

In Alabama, the state legislature passed a law clarifying that electric utilities could leverage their easements and private rights-of-way to enable telecommunications services over their fiber assets.[33] As a result, Mississippi-based C Spire and Alabama Power will jointly invest and share fiber infrastructure to mutually support the needs of both electricity and telecommunications. Homes in Birmingham, Shelby County, and other parts of the state will now obtain FTTH from C Spire. But such partnership would not have happened in the absence of policy from the state government to promote this type of infrastructure sharing.

In the EU, open-access fiber has made tremendous progress in furthering the national policy goals of the EU's gigabit society. These new types of infrastructure efforts that aggregate broadband providers to share over the same fiber lines have proven successful in various markets.[34] But the open access fiber industry's entry into the EU market was brought about from changes in the European Electronic Communications Code and has allowed new high-capacity entrants to join in the effort to deploy national FTTH.[35]

C. The United States lags behind other advanced economies in fiber to the home.

The end of Verizon's deployment of FIOS[36] years ago, Google's entry into and exit from the broadband market with Google Fiber,[37] and AT&T's discontinuation of its FTTH deployment now that the DirecTV mandate has been lifted,[38] all show that no large national corporation in

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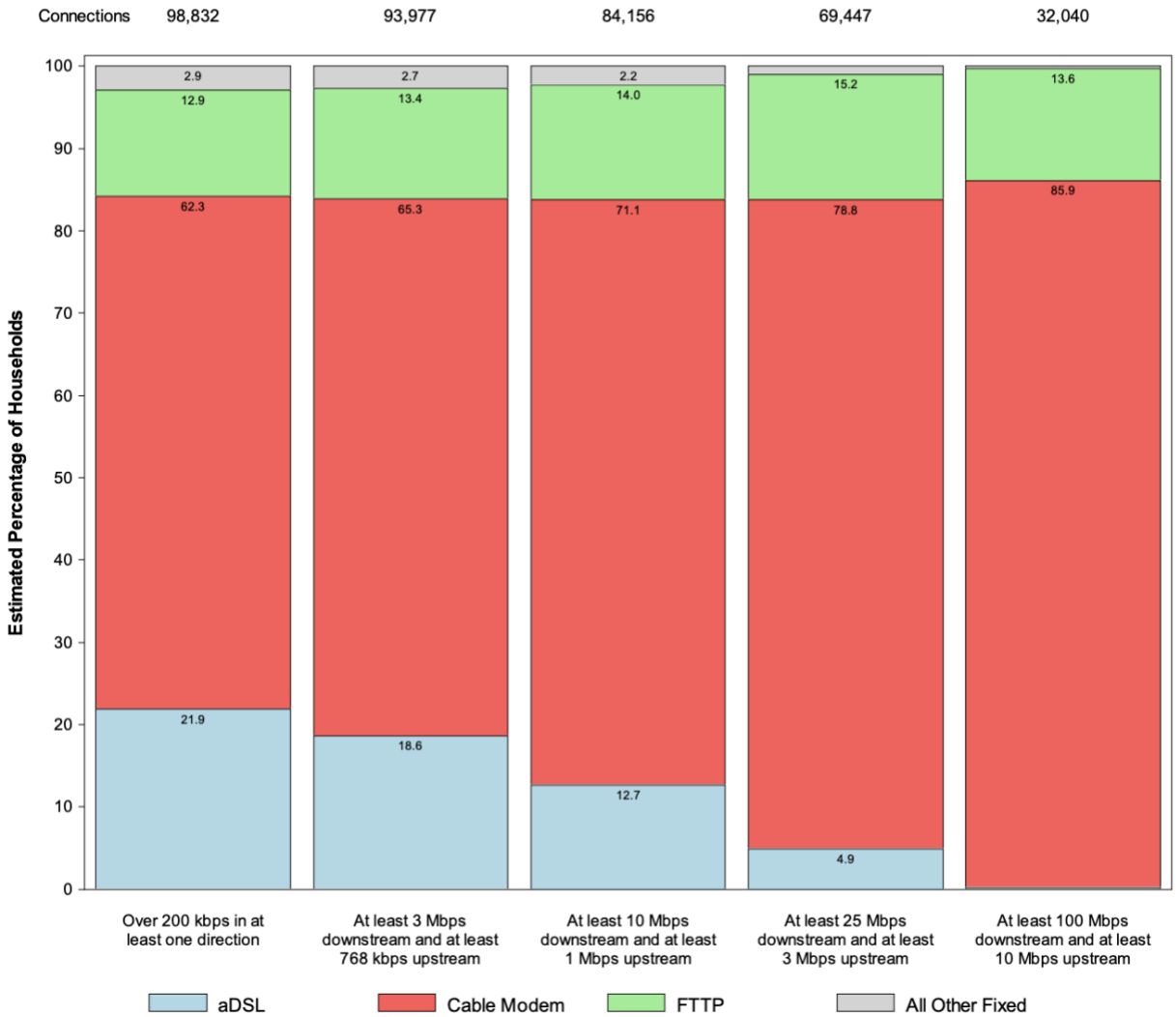
[31] Utopia Fiber, Residential Pricing, https://www.utopiafiber.com/residential-pricing (last visited February 4, 2020).
[32] Benoit Felten & Thomas Langer, *Structurally Independent Broadband Infrastructure can Solve Perceived FTTH Coverage Issues*, DIFFRACTION ANALYSIS (Jun. 13, 2016), https://www.diffractionanalysis.com/services/white-papers/2016/06/structural-remedies-solve-rural-broadband-issue.
[33] H.B. 400, 2019 Leg., Reg. Sess. (Al.), https://legiscan.com/AL/bill/HB400/2019.
[34] Ilsa Godlovitch & Tseveen Gantumur, The Role of Wholesale Only Models in Future Networks and Applications, WIK-CONSULT, Mar. 23, 2018, available at https://www.stokab.se/Documents/Nyheter%20bilagor/The%20role%20of%20wholesale%20only_WIK.pdf
[35] *Europe's wholesale-only and open access operators form new alliance to accelerate the rollout of fiber networks*, REYKJAVIK FIBRE NETWORK (last visited Feb. 3, 2019), http://www.reykjavikfibrenetwork.is/news/europes-wholesale-only-and-open-access-operators-form-new-alliance-accelerate-rollout-fiber.
[36] Cheng, *supra* note 19.
[37] Brian Fung, Why Google Fiber Stopped Its Plans to Expand to More Cities, WASHINGTON POST, Oct. 26, 2016, available at https://www.sacbee.com/news/nation-world/national/article110655177.html.
[38] Jon Brodkin, *AT&T cuts another 1,800 jobs as it finishes fiber-Internet buildout*, ARS TECHNICA (June 17, 2019), https://arstechnica.com/tech-policy/2019/06/att-cuts-another-1800-jobs-as-it-finishes-fiber-internet-buildout.

the U.S. market intends to wire every American home and business in their territory directly with fiber optics in the same way CLECs do today. In the absence of a federal plan promoting fiber deployment, the lonely efforts of small private ISPs and local governments have resulted in a generally uncompetitive market that is woefully unprepared to keep pace with our international competitors, most notably China. Per the FCC's data, a discrete minority of U.S. users have access to FTTH while a supermajority is reliant on cable, which as our research has pointed out will not keep pace with advancements in fiber.[39]

Figure 27
Residential Fixed Connections by Technology as of December 31, 2017
(Shares of selected technologies for selected speeds, connections in thousands)

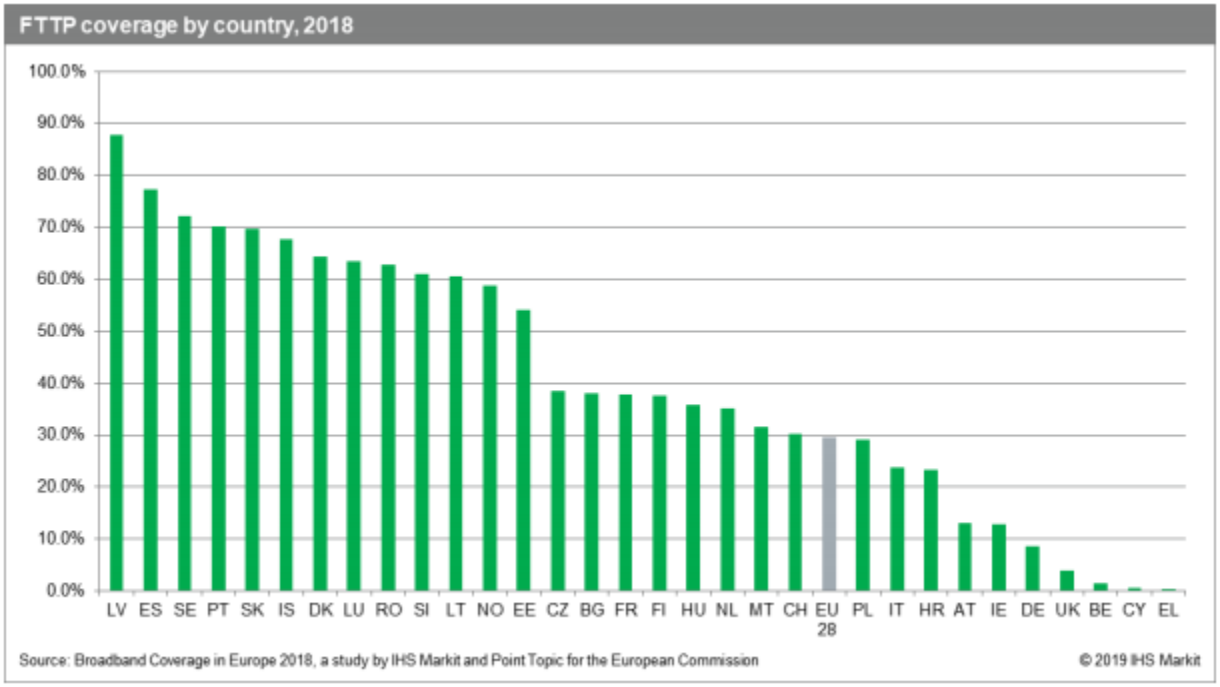


Source: Internet Access Services as of 12/31/17

Today's EU data indicates that their FTTH deployment, on average, is superior to the U.S. market's overall deployment. A majority of the EU nations have greater FTTH coverage than the United States and continue to rise. Slovakia has now joined Portugal, Latvia, Lithuania, and

[39] Cyphers, *supra* note 2.

Spain in achieving 70 percent FTTH coverage. Another six EU members have reached 60 percent FTTH coverage and more are making progress towards universal deployment.



As we noted in our previous filing on the US Telecom petition, only a discrete minority of EU nations now lag behind the United States on FTTH deployment, forcing them to conduct an active rethinking of their telecom policy. For example, Ireland's fiber growth has expanded their fiber deployment at a meteoric 419.6% from 2016-2017 as a result of wholesale-only initiatives.[40] But rather than rehash the EU story in comparison to the United States, or the clear advantages South Korea has demonstrated with its universal fiber network,[41] the fundamental challenge towards American leadership in technology and innovation is coming from China.

A recently published report by BroadbandNow[42] has assessed that China's fiber infrastructure program is currently building fiber connections nine times faster than the United States as of 2013. The country's "Belt and Road Initiative," which has been its global development infrastructure strategy, has allowed China to run laps around the U.S. telecom market not just on

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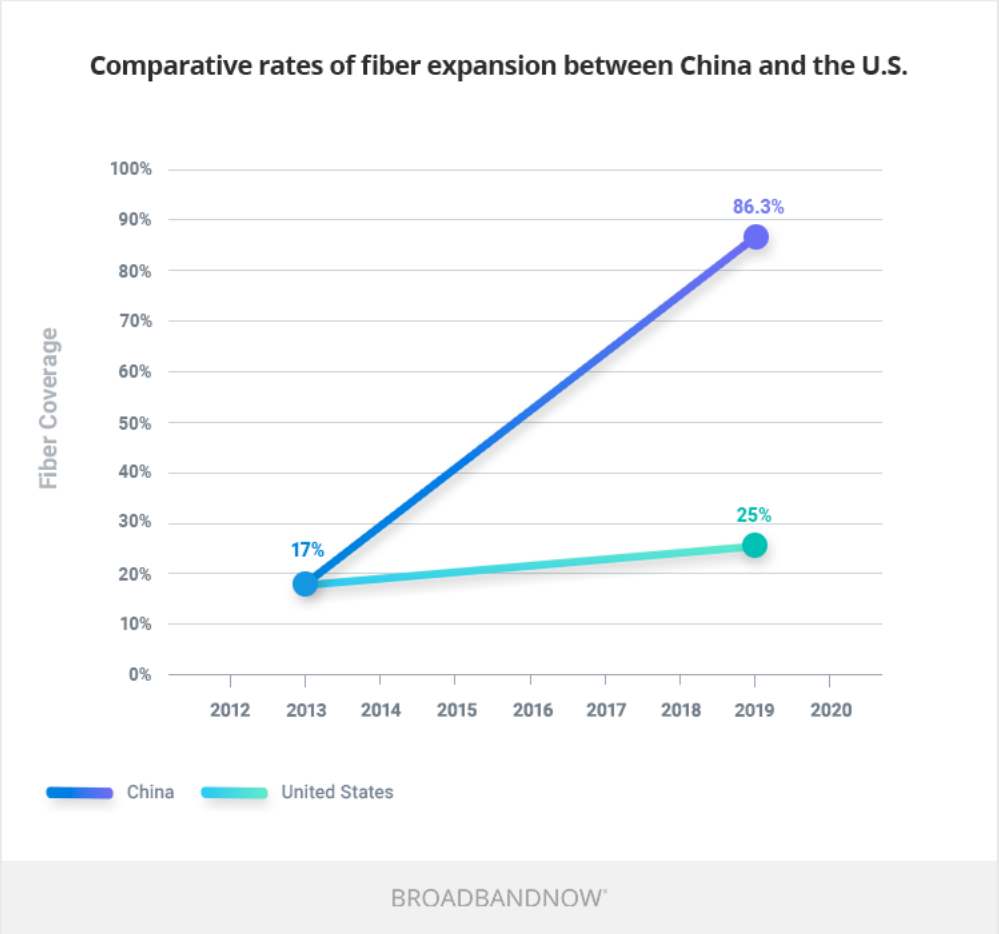
[40] ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, Penetration and Data Usage (Growth of fibre subscriptions Dec. 2017), available at http://www.oecd.org/sti/broadband/1.11-FibreGrowth-2017-12.xls; *see also* Ilsa Godlovitch, Bernd Sorries, & Tseveen Gantumur, A Tale of Five Cities: The Implications of Broadband Business Models on Choice, Price and Quality, WIK-CONSULT, Jun. 2, 2017, available at https://www.stokab.se/Documents/Nyheter%20bilagor/A%20tale%20of%20five%20cities.pdf.

[41] Erwan Lucas, In South Korea, the Race is on for Olympics 5G Next Year, PHYS.ORG, Feb. 28, 2017, available at https://phys.org/news/2017-02-south-korea-olympics-5g-year.html.

[42] Tyler Cooper, *China's Fiber Broadband Internet Approaches Nationwide Coverage; United States Lags Several Behind*, BROADBANDNOW (Dec. 3, 2019), https://broadbandnow.com/report/chinas-fiber-broadband-approaches-nationwide-coverage.

FTTH but on 5G as well.[43] This is due to the convergence between FTTH and 5G that Chinese telecommunications companies intend to leverage. China Telecom has openly stated their plan to have both a universal fiber network with 5G deployment riding on top of the wires.[44] While the United States can't mirror the Chinese approach to fiber infrastructure, we should not be complacent as China approaches universal fiber acccess in a few years. Nor should we conclude that the U.S. approach can't be reformed in order to vastly outperform China and other international markets.



But the stakes are very high as each year passes because dominance in the multi-gigabit era of broadband will carry major ramifications. Future innovations in applications and services that rely on multi-gigabit instantaneous transmission of data will find their home in countries where those networks are universally deployed. Given that cable networks cannot match the future potential of FTTH, given that national high-speed 5G broadband depends on universally

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[43] Susan Crawford, *China Will Likely Corner the 5G Market – and the US Has No Plan*, Wired (Feb. 20, 2019), *available at* https://www.wired.com/story/china-will-likely-corner-5g-market-us-no-plan.

[44] Alan J. Weissberger, *China Telecom to Accelerate 5G Deployment; 100% Fiber Network Coverage; Gigabit Fiber Broadband Deployment*, IEEE COMMUNICATIONS SOCIETY, (Mar. 19, 2019), *available at* https://techblog.comsoc.org/2019/03/19/china-telecom-to-accelerate-5g-deployment-100-fiber-network-coverage-gigabit-fiber-broadband-deployment.

available dense fiber networks throughout the nation, and given that the ILECs are not transitioning their networks to fiber, the FCC should not proceed on this NPRM, but rather should refocus its efforts on this critical question of international competitiveness on fiber deployment with a Notice of Inquiry.

VI. The FCC should abandon this proceeding and investigate how to achieve universal fiber deployment and determine what private and public barriers prevent progress.

The ILECs have shown they will not bridge the digital divide by deploying new next generation technologies throughout America. Freeing them from competition policy will not promote their investment in or the deployment of advanced network infrastructure in currently underserved and unserved areas. But it will hinder the financial capability of the CLECs that still rely on copper sharing agreements. While the FCC has narrowed the forbearance to urban markets, the fundamental facts on the ground challenge the entire premise of forbearance. So long as CLECs remain committed to closing the digital divide and the speed chasm that exists between cable and non-fiber alternatives, the FCC should stick with the approach outlined in its copper retirement rules where ILECs can free themselves by deploying their own fiber.

EFF reiterates its call for a Notice of Inquiry into the new competition policies that are taking root around the world as well as new business models that are reducing the cost of deployment and expanding FTTH. The focus needs to be on dense fiber networks because it holds future proof potential that no other alternatives can provide. Dozens of countries have caught on to this fact and are adopting a wide range of new approaches. If several nations are able to connect all of their citizens to a universal fiber network, we should not be surprised that innovation in applications and services happen overseas rather than here. Now is the time to rethink current US policies that impact deployment, competition, universality, and affordability.

APPENDIX A

EFF White Paper Comparing Future Capacity Differences of Fiber to the Home, 5G, and Cable Systems

The Case for Fiber to the Home, Today

WHY FIBER IS A SUPERIOR MEDIUM FOR 21ST CENTURY BROADBAND

ELECTRONIC FRONTIER FOUNDATION

Author: Bennett Cyphers

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The Case for Fiber to the Home, Today

WHY FIBER IS A SUPERIOR MEDIUM FOR 21ST CENTURY BROADBAND

BENNETT CYPHERS
Staff Technologist

OCTOBER 11, 2019

Table of Contents

Executive Summary	5
Glossary	6
Technical Background	10
DOCSIS 3.1 and the Future of Coax	15
5G and the Future of Wireless	18
Fiber Today and in the 21st Century	21

Executive Summary

The debate over the best infrastructure to deliver fixed last-mile broadband service in the 21st century is settled, and fiber is the undisputed winner. Fiber-to-the-home deployments are a better option for consumers today, and they are the only option that will allow expansive, efficient upgrades to America's networks for a generation.

This is not to say that no broadband technology will ever surpass fiber-optics, but we know the limitations of existing technologies in use today. Currently, the alternatives to fiber face headwinds that fiber does not, including limited bandwidth, attenuation, noise, upstream/downstream asymmetry, and latency. While other means of delivering high-speed broadband are not too far behind fiber right now, the properties of each technology will allow fiber deployments to scale up quickly and easily while copper and wireless broadband networks will struggle to keep up. If we install fiber-to-the-home connections today, we'll be able to upgrade the transmitters at each end without touching the underlying cables, yielding massive performance increases at low cost for decades to come. Fiber will enable the next generation of applications that depend on high-throughput, low-latency, high-reliability connections. There is an identifiable "speed chasm" between fiber and everything else that is only going to grow more pronounced in time.

This whitepaper gives a brief technical background and explains key concepts for understanding internet services such as bandwidth, latency, channel capacity, and noise. Understanding these concepts is essential in order to assess and compare broadband networks. This whitepaper then evaluates three different classes of last-mile broadband connections—coaxial cable, wireless, and fiber—from a technical perspective. It argues that through this lens, fiber is indisputably the best option for consumers today. New wireless technologies, like mmWave 5G, will supplement rather than compete with fiber-to-the-home technology. And aging wireline technologies like DOCSIS are already being incrementally replaced by fiber.

This paper focuses on the "last mile" of broadband connections because a vast majority of the internet infrastructure before the last mile has already transitioned to fiber. Lawmakers and regulators in positions of determining infrastructure policy must understand the realities of networking technologies in order to properly assess the capability of networks to absorb greater user demand.

This paper does not explore policy mechanisms to address the fiber deficit currently facing the United States market. EFF intends to publish such material at a future date. The purpose of this paper is to educate policymakers as to the technological differences between different broadband networks and as to the future proof nature of fiber networks. With the advent of cloud computing, virtual reality, gaming, telehealth, remote services, and high capacity services we have not yet imagined yet, policymakers must grapple with updating the Internet's infrastructure for the 21st century so that the American people are not left behind.

Glossary

4G - The fourth generation of cellular network technology. 4G was standardized in 2008 by the International Telecommunication Union (ITU) as "IMT-Advanced," and is specified to support speeds up to 1 Gb/s down. However, real-world systems have more commonly achieved a maximum of a few hundred megabits, and an average of a few tens of megabits.

5G - The fifth generation of cellular network technology. 5G is still in the process of being standardized by the ITU as "IMT-2020." 5G will use low- and mid-band frequencies below 6GHz for mid- and long-distance communication, as well as millimeter wave frequencies above 24GHz for short-range, high bandwidth communication. 5G promises to support high-throughput communication up to 10Gb/s as well as "last-hop" latencies as low as 1-4ms.

Absorption - A type of attenuation that occurs when signal-carrying photons are absorbed by other matter. Wireless signals may be absorbed by walls, foliage, or the air; beams of light in a fiber-optic cable are absorbed by tiny imperfections in the fiber's glass core. When signal-carrying photons are absorbed by environmental obstructions, the signal becomes weaker.

Amplifier - In coaxial cable deployments, a device which amplifies information-carrying signals. Amplifiers are installed along coaxial cable running between a headend and customer terminals in order to boost signal power. Amplifiers can add noise to the system as well and decrease the signal-to-noise ratio.

Amplitude - A measure of the power of an electromagnetic wave. Waveforms generated with more power will have greater amplitudes; this makes signal-bearing waves easier to detect relative to background noise.

Attenuation - Loss of signal power over distance. Attenuation is a factor in all methods of signal propagation. Wireless signals attenuate according to the inverse-square law in free space. Electrical signals in coaxial cables attenuate primarily due to electric impedance. Guided beams of light in fiber-optic cables attenuate primarily due to absorption.

Bandwidth - The range of frequencies available in a given channel. Bandwidth is defined as the difference between the maximum frequency available in a channel and the minimum frequency available.

Base station - In cellular networking, an installation that generates and receives wireless signals in order to provide wireless service to cellular phones and other mobile devices. Also known as a "cell site" or "cell tower."

Bits per second (B/s) - Measure of information throughput. A bit is a single value, 1 or 0. Modern broadband channels can transmit many millions (megabits or Mb) or billions (gigabits or Gb) of bits per second.

Cable headend - A facility for processing television and internet signals from a service provider's regional network and transmitting them over the "last mile" from the larger network to customers' buildings.

Cellular network - A network in which the last-mile link is wireless. Cellular networks use cell sites, or base stations, to broadcast wireless signals "over the air" and provide internet service over a wide area. Cell sites usually communicate with cellular consumer devices, like phones, using radio-frequency signals. Cellular network standards are generally referred to by "generation;" the newest generation to be implemented is the fifth, or 5G.

Channel - A logical connection over which information-carrying signals may be transmitted. A channel comprises a transmitter, a receiver, and the medium over which signal travels between those two. Examples of channels are the connection between a WiFi transmitter and a laptop computer, as well as the connection between a cable headend and a customer's modem.

Coaxial cable - A copper cable consisting of a central conducting wire and an outer conducting tube separated by an insulating sheath. The central wire carries current in one direction and the conducting sheath carries it in the other direction. Most coaxial cables can carry radio frequencies up to around 3 GHz over relatively long distances, and are designed to minimize electrical interference.

Crosstalk interference - Interference that occurs when an electrical signal in a medium interacts with another signal from outside the medium. For example, in unshielded twisted pair wiring, signal form one pair can interact with signal in a nearby wire, adding noise and diminishing the channel's information capacity.

DOCSIS - Short for Data Over Cable Service Interface Specification. DOCSIS is the international standard for carrying internet signals in last-mile networks over coaxial cable. The most recent version of DOCSIS is 3.1.

Electromagnetic spectrum - Commonly referred to as spectrum, it refers to the full range of frequencies that can characterize electromagnetic waves. Portions of spectrum are often referred to as "bands" and described by their middle frequency; for example, the "5 GHz band" might refer to the section of spectrum between 4.95 and 5.05 GHz. Different bands are used for transmitting different kinds of signals, both in guided media (like cables) and "over the air" as unguided waves.

Electromagnetic wave - The oscillation of an electromagnetic field. Electromagnetic "waves" are the representation of electromagnetic radiation in classical theory. Electromagnetic waves always propagate at the speed of light. Waves are measured by their amplitude (power) and frequency (speed of oscillation).

Fiber-optic cable - A transparent thread made of high quality glass utilized for fiber optic communications. Fiber-optic cables operate as waveguides for beams of light. A beam of light shined down one end of a fiber-optic cable will reflect off the insides of the cable and be completely contained within the glass core. "Single-mode" fibers are used for links longer than a few meters. These cables are extremely thin, around 9 micrometers, and only allow light to travel in one path or "mode" through the fiber in order to minimize noise.

Forward error correction - Method for encoding information in a signal with some redundancy so that the signal is robust to noise. Forward error correction uses error-correcting encoding to send information such that, if small portions of the signal are transmitted incorrectly, the receiving end of the channel can recognize and correct the errors.

Frequency - A measure of the speed of oscillation of an electromagnetic waveform. Frequency is usually measured in oscillations per second, or Hertz. For example, a radio station operating at 88.9 Megahertz (MHz) has electrons oscillating on its antennae at 88,900,000 cycles per second. Frequency is inversely proportional to wavelength, meaning the higher the frequency, the shorter the wavelength—and vice versa.

Hertz (Hz) - A unit for measuring frequency, equal to one oscillation per second.

Interleaving - Transmission technique which makes forward error correction more effective. Errors in DOCSIS systems tend to occur in bursts. Forward error correction is better at dealing with errors that are spread out over time, so operators can "interleave," or mix up, symbols before they are sent. This increases the effectiveness of error correction at the expense of more latency.

Internet backbone - High-capacity portion of the internet where large amounts of data are exchanged between different regional networks and different internet service providers. Links in the internet backbone are typically extremely low latency and high throughput, and may span oceans or continents.

Inverse-square law - Physical law governing the rate at which wireless signal power attenuates in a vacuum. For every doubling in distance from a signal's source, the power of the signal is reduced by a factor of 4 (75%).

Jitter - Deviation from expected timing in a series of packets. Jitter is caused by sudden, random spikes in latency. In broadband systems, it may be caused by dropped packets, sudden delays due to congestion on shared networks, or delays in upstream traffic due to bandwidth allocation. Jitter can negatively impact time-sensitive applications like video chat or online gaming.

Last mile - The portion of the internet which connects service providers' shared infrastructure to end users, such as homes or businesses. In a DOCSIS cable network, the last mile is the connection between the cable headend and the customer's building. In a cellular wireless network, the last mile is the wireless connection between a base station and a mobile device. Sometimes also called the "first mile."

Latency - The time it takes for a signal to be transmitted over a channel. This includes encoding time, travel time, and decoding time.

Millimeter wave - Refers to signals between 30GHz and 300GHz, designated by the ITU as "Extremely High Frequency (EHF)" signals. 30GHz waves have a wavelength of approximately 1 millimeter.

Modem - Short for "modulator-demodulator." A consumer device for receiving and transmitting internet signals over a last-mile wireline connection. Modems are usually sold by internet service providers and used to connect customers to the wider network.

Noise - Any unwanted or unintended modifications to a signal that occur during transmission. Noise can come from a variety of factors, including crosstalk (interference with other signals), ambient radiation, and errors in transmitters or receivers.

Optical line terminal (OLT) - The headend of a fiber-optic Passive Optical Network. A single OLT may serve internet to several dozen optical network terminals (ONTs). Signals from the OLT are directed to individual ONTs by passive optical splitters (lenses) that duplicate and redirect optical signals.

Optical network terminal (ONT) - The consumer end of the last mile connection in a Passive Optical Network. An ONT receives downstream signals generated by its OLT, interpret the packets meant for it, and responds with its own upstream signals on the shared fiber optic cable.

Passive optical network (PON) - Network architecture for last-mile internet over fiber optic cable. A single optical line terminal (OLT) drives signals to several optical network terminals (ONTs). The OLT sends a single stream of downstream traffic that is seen by all ONTs. Each ONT reads the content of only those packets that are addressed to it; packets can be encrypted to prevent eavesdropping. ONTs respond to the OLT by taking turns, known as "time-division multiplexing."

Scattering - Related to absorption; scattering occurs when photons are reflected, or absorbed and re-emitted, by matter. Scattering is one of the chief causes of attenuation and noise in wireless signals, especially when they pass through obstructions like buildings and foliage.

Shannon limit - The absolute upper bound on the amount of information a channel can carry, in bits per second. The Shannon limit is a function of the bandwidth of a channel and its signal-to-noise ratio.

Signal - Any time-varying wave or function that carries information. Electromagnetic waves can transmit signals using amplitude modulation (AM), frequency modulation (FM), binary pulsing, or other means.

Signal-to-noise ratio (SNR) - The ratio between the power of information-carrying signal and the average power of the noise in a channel. Along with bandwidth, the SNR determines the maximum theoretical information capacity of a channel.

Symbol - The smallest coherent unit of a signal. Every signal can be thought of as a sequence of symbols. Each symbol takes on one out of a possible set of values. In the simplest case, a symbol is a bit: either a 1 or a 0. Symbols may be represented as high or low voltage values, as pulses of light, or as different shapes of electromagnetic waveform.

Throughput - The rate of information that a channel can carry, usually measured in bits per second.

Wavelength - A measure of the distance between peaks in an electromagnetic wave. Inversely proportional to frequency. Higher-frequency waveforms have shorter wavelengths.

Technical Background

All information is transmitted via *signals*. Telegraphs, radio, land-line telephones, the spacecraft Voyager 1, and 5G-enabled phones all rely on signals transmitted by some kind of *electromagnetic wave*. Signals can either be analog, as with AM radio or traditional phone service, or digital, like the signals used to carry data over the internet. A digital signal is a sequence of information-carrying symbols, like letters in a string of text.

Signals are carried over *channels*. A channel is a connection that can carry a signal from one place to another. Different channels are useful for different purposes, and there are tradeoffs involved with choosing to use one kind of channel over another. Land-line telephone signals are transmitted by electricity over copper wires, which are cheap and reliable. Analog radio is transmitted "through the air" by radio waves, which can carry simple signals in all directions over long distances. And the backbone of the internet uses guided light waves in fiber-optic cables to transmit huge amounts of information for hundreds of miles, but building and installing these cables can be expensive. In all of the aforementioned channels, specially-formed electromagnetic waves are used to carry the signal.

Bandwidth and noise

Electromagnetic waves are described by their *amplitude* (power) and *frequency*. The frequency of a waveform is measured in Hertz (Hz), or oscillations per second. Different channels can carry different frequencies of EM waves. For example, old-school analog phone lines were designed to carry frequencies from 300 to 4,000 Hz, approximately the range audible to the human ear. The range of frequencies a channel can carry is called its

bandwidth. The bandwidth is calculated simply by subtracting the minimum frequency a channel can carry from the maximum. A channel spanning 0 to 1,000 Hz has 1,000 Hz of available bandwidth, and a channel spanning 100,000 to 101,000 Hz has the same. Bandwidth helps determine how much information a channel can transmit: more bandwidth means more information capacity.

Noise is a general term for all the random, chaotic, and meaningless disruptions that information-carrying signals in a channel might suffer. Electromagnetic noise is everywhere; radio waves are constantly being pumped into the air by cell towers, police radios, power lines, and the sun. These sources of radiation can interfere with individual signals traveling from one device to another through the air, and are part of the reason wireless signals can't travel over infinite distances. In shielded media like coaxial cables and fiber optics, imperfections in shielding or connections can allow noise to "leak" in; signal transmitters and receivers can also add noise by themselves. The *signal-to-noise ratio* (*SNR*) in a channel is the ratio of the power of the signal to the power of the noise.

All signals degrade over distance; this is referred to as *attenuation*. Wireless signals, like radio waves, lose power according to the inverse-square law: that is, if you travel twice as far away from the source, the signal will be at least four times as weak. Wireless signals also attenuate due to interactions with the environment, including *absorption* and *scattering*. Just as a beam of light can be blocked by a wall in its way, wireless signals can be disrupted by buildings, trees, and people. Wireless signals at higher frequencies degrade much more quickly than lower-frequency signals. As soon as a wireless signal's power falls below that of the average background radiation, it becomes impossible to decipher, so high-bandwidth wireless signals generally can't travel very far.

In wires, signals aren't subject to the inverse-square law, so signal power attenuates more gradually. However, signals in traditional twisted-pair copper wires become noisy over distance due to *crosstalk interference* and other factors. Coaxial cables suffer from less noise, but still aren't perfect. Modern fiber optic cables are even better, and have exceptionally low noise. In fiber optic communication systems, most noise comes from imperfections in transmitters and receivers.[1] Still, light beams in fibers attenuate over distance due to interactions with small imperfections in the glass. Signals can travel much further in some channels than in others, but the SNR always increases with distance.

Channel capacity and the Shannon limit

Given a fixed amount of bandwidth and a constant signal-to-noise ratio, there is a theoretical limit to the amount of information throughput a channel can carry. This limit is captured by the Shannon-Hartley theorem, often referred to as the *Shannon limit*. The Shannon limit expresses the maximum information *capacity*, C, of a channel in bits per second. C is a function of *B*, the bandwidth, *S*, the power of the signal, and *N*, the average

[1] A. Demir, "*Noise Analysis for Optical Fiber Communication Systems,*" Institute of Electrical and Electronics Engineers, *available at* https://ieeexplore.ieee.org/abstract/document/1257814.

power of the noise. The relationship *S/N* is often referred to as the *signal-to-noise ratio*, or *SNR*. The exact equation is shown below.

$$C = B \log_2 \left(1 + \frac{S}{N} \right)$$

The Shannon-Hartley theorem, describing the theoretical limit to the information capacity of a channel as a function of bandwidth (B), signal power (S) and average noise power (N).

You don't need to understand the math behind the theorem to get the basics: more bandwidth means more capacity, as does a better signal-to-noise ratio. If bandwidth and signal power of a channel are fixed, more noise means less capacity. The Shannon limit is important to understand because it means we can take the physical properties of a medium, like copper wire or fiber optics, and figure out how much capacity we might someday squeeze out of it—even if we can't do it yet.

Generally, the longer the distance a signal has to travel, the weaker the signal power becomes due to attenuation. This reduces the SNR and, according to Shannon's theorem, the total information the signal can carry. Therefore, it's not possible to talk about the capacity of a channel without knowing how far a signal has to go. The channel capacity of 10 yards of cable might be 10 Gb/s, but the capacity of 10 miles of the same cable might only be 5 Mb/s.

To recap: the *bandwidth* and *signal-to-noise ratio (SNR)* of a channel determine the maximum rate of data it can carry. The longer a link needs to be, the worse the channel's SNR will become. Most channels can carry high-capacity signals for short distances, but few can support the same capacity over many miles.

Latency and jitter

Channel capacity is only half the story. The Shannon limit describes how many bits per second a channel can carry, but it says nothing about how fast a bit actually gets from point A to point B. *Latency* is the time it takes for a message to make the trip from one end of a channel to the other. *Jitter* describes variations in latency; it occurs when portions of a signal arrive out of sync from their expected schedule. Think of a video call over the internet. Latency is responsible for the constant small delay between you speaking and the other person registering your voice, while jitter is responsible for glitches, freezes, and other distortions in the stream.

The ultimate lower bound on latency is determined by the speed of light: no signal can travel faster than light in a vacuum. The speed of light limits how fast signals can be transmitted across oceans and continents, but in last-mile connections (the subject of this whitepaper), latency is almost always dominated by the time it takes to process a signal at each end of a channel. For example, the latency between a phone and a 4G LTE

tower a mile away is approximately 9 milliseconds;[2] however, the radio waves that carry the signal can travel that distance in around 5 *microseconds* (0.005 ms). That means over 99.9% of the latency is incurred by the transmitting and receiving devices.

In low-bandwidth and error-prone channels, messages need to be encoded with layers of error-correcting codes, and signal encoding/decoding can take some time. On the other hand, channels with lots of bandwidth and low error rates can be generated and processed with little latency. Error rates in modern fiber-optic channels are typically very low, and signals can be transmitted and received with minimal delays for processing and error correction.

Jitter occurs when packets sent over a channel are delayed or dropped. Jitter is experienced as spikes in latency: instead of *all* packets being delayed by a fixed amount, *some* packets are delayed, while others arrive on time. For example, even with error correction, some parts of a signal may be dropped entirely, which can cause higher-level protocols like TCP/IP to pause and retransmit old packets. This results in an uneven or "choppy" connection. Latency can be constant and predictable, but jitter is always random. Channels that are subject to jitter may be fine for tasks like downloading large files or streaming video, but will cause noticeable issues with applications like video chat or online gaming.

From channels to networks

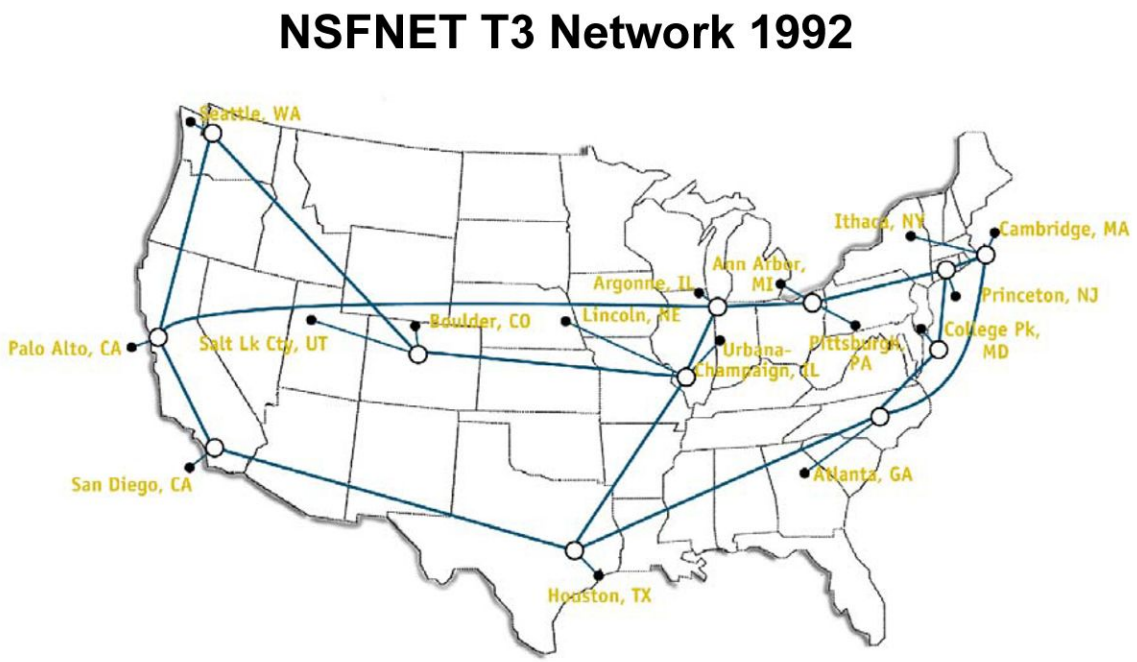
Modern, high-speed network links comprise many different parts, with different technologies used to transmit data for different stages of the journey. Data networks, like the internet, use a hierarchical "tree" structure: high-capacity links at the "trunk" carry data from many people across long distances, while lower-capacity links in the "branches" carry a few connections to smaller regions. Eventually, the branching links are subdivided into "leaves" that each link to a single network participant, like a computer or mobile phone.

Let's consider an example. When you connect to Google using a laptop on your home's WiFi network, the data first travels from your computer to your WiFi router via radio waves in the 2.4 GHz or 5 GHz bands. Next, it travels over ethernet, which probably uses short (<100m) copper wires to carry the data from your router to your modem. If you have cable internet, the signal then travels over a coaxial cable from your house to a small "cabinet" or "node," a box on the curb that serves a few dozen or few hundred people in your neighborhood. From there, it travels along with your neighbors' traffic through a fiber to a "cable headend," the local service center where your cable company operates. The connection from your home to your local cable headend is known as the "last mile" connection.

From there, data from you and all the other customers in your neighborhood travels along one or more higher-capacity connections, using fiber-optic cables, until it reaches

[2] Wireless One, *LTE Latency Today 9 ms. Down to 2 ms ~2019*, March 17, 2018, *available at* http://wirelessone.news/10-r/1007-lte-latency-today-9-ms-down-to-2-ms-2019

the "backbone" network connection for your region. The backbone carries thousands of connections from one regional subnetwork to another, which could be across the country or across the world. Backbone networks nearly always use high-capacity fiber optic cables, which are, by far, the most effective way to carry high-bandwidth signals over long distances. The backbone connection will carry your data (along with data from thousands of others) to the regional subnetwork where the nearest Google server is located, where it will be routed back down through the "branches" of that network to the "leaf," a server in a datacenter that will process and respond to your request.



A diagram showing the "backbone" of the early Internet. Today, the backbone has many more connections.

With the technical background explained, this whitepaper will now turn to the "last mile" connections that link local subnetworks to individual internet subscribers. While "middle mile" and backbone connections have been systematically converted to fiber-optic cable over the past three decades, last mile connections still use a diverse set of technologies: DSL, DOCSIS, 4G (and soon, 5G) wireless, and fiber-to-the-home. This paper gives a brief overview of the dominant last-mile technologies in use today. It argues that while there are advances to be made in DOCSIS and wireless internet technology, they are not in a position to surpass fiber. In fact, future advancements in other technologies will rely on fiber. Fiber-to-the-home is the best option for reliable, high-throughput, and future-proof last mile connections today.

DOCSIS 3.1 and the Future of Coax

Coaxial cable, or "coax" (pronounced co-*axe*), is the standard conduit for cable TV. It is made up of a core copper wire and an outer copper tube separated by an insulating sheath. The design of coaxial cable makes it much more resistant to "crosstalk" and other noisy interference than traditional twisted-pair copper wiring. Coax can carry much higher-bandwidth signals with less interference than other copper cables, which is why it is preferred to twisted-pair cables for broadband internet.

Although coax has much better resistance to noise than copper alternatives, some noise is still present due to reflections and radio-frequency interference.[3] In addition, each coaxial cable has a "cutoff frequency" above which signals become muddled and hard to recover.[4] Most commercial cables are rated to carry up to a few GHz of bandwidth.[5] High-powered signals cause more noise, and cables are usually rated for a maximum signal power. Coax also experiences signal attenuation (weakening over distance) due to electrical impedance, and higher-frequency signals suffer from more attenuation.

All of that means trying to send a high-frequency signal over a long distance is a tough proposition. The signal power drops off drastically over distance, but the power at the transmitter can only be raised to a certain point before it starts adding too much noise. As a result, high-throughput signals can only be carried over shorter cables or using *amplifiers* installed along the cable.

The standard used by cable companies to deliver internet service over coax is called DOCSIS (Data Over Cable System Interface Specification). DOCSIS signals are served from a "cable headend," a station that generates signals and transmits them along cables to subscriber homes. On the other side, modulator-demodulators, or "modems," allow cable customers to interpret the signals produced by the headend and generate their own digital signals in return. A single cable headend can serve customers up to a few miles away. Older DOCSIS setups sent signals strictly over coax, but modern headends usually drive signals down fiber optic lines to smaller "nodes," each of which uses coax to serve just a few subscribers. In each node, the signal from the fiber is "split" and sent down coax for the final few meters to subscriber homes. These kinds of deployments are known as "hybrid fiber-cable" (HFC) networks.

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[3] Radio-frequency interference is usually the greatest source of noise in coaxial cables. Though the design of coax cancels out most noise, electrical resistance in the outer shield can induce noise and holes in the shield allow high-frequency signals to "leak" through. *See* Howard Johnson & Martin Graham, High-Speed Signal Propagation: Advanced Black Magic (Prentice Hall, 2003).

[4] Above a cable's cutoff frequency, waves begin to propagate in different "modes" and at different speeds, causing interference and making it much harder to recover a useful signal. Cables with smaller diameters have higher cutoff frequencies, but also have much worse power handling capabilities. See Peter McNeil, How High is a Coaxial Cables Max Frequency?" *See* Peter McNeil, *How High is a Coaxial Cable Max Frequency?*, Pasternack Blog (Oct. 11, 2018) *available* at https://blog.pasternack.com/coaxial-cable/how-high-is-a-coaxial-cables-max-frequency.

[5] Helukabel, *Cable specifications overview*, *available* at http://biakom.com/pdf/RG-coaxial_cables_Helukabel.pdf.

The latest version of the standard is DOCSIS 3.1.[6] DOCSIS 3.1 was first deployed in early 2016. By 2019, much of the U.S.'s cable infrastructure had been upgraded from DOCSIS 3.0.[7] DOCSIS 3.1 uses 1.2 GHz of bandwidth and, in theory, it can support 10 Gb/s download speeds and 1Gb/s upload speeds over a single cable. While these numbers represent the *theoretical* throughputs available to individual subscribers, they do not reflect the reality of DOCSIS performance on the ground. The 10Gb/s maximum is the amount of data that can be sent down a single cable; most deployments use one cable to reach multiple houses, so the total capacity is shared between dozens or hundreds of customers. Furthermore, the maximum speeds can only be reached with "deep fiber" HFC setups, where most of the last mile is fiber and a relatively short length of high-quality coax connects the node to subscribers. Although Comcast finished deploying DOCSIS 3.1 in October 2018,[8] independent tests from around that time show that it offered average real-world speeds around 100Mb/s down and 15Mb/s up.[9]

The first major drawback of DOCSIS 3.1 is the tremendous discrepancy between upload and download speeds. In the recent past, internet users have demanded much more data capacity for downloads than they have for uploads. Activities like browsing the web and watching videos pull lots of data down from servers without sending much back, so DOCSIS has evolved to prioritize downstream throughput. Most DOCSIS deployments allocate less than 85 MHz of the 1.2 GHz of available bandwidth for upstream service. The 3.1 standard only supports using up to 200 MHz of bandwidth, about ⅙ of the total, for upstream traffic.[10] But usage patterns are changing, and operators expect to see major growth in demand for upstream throughput over the next few years.[11] Cable operators will have to upgrade their systems sooner rather than later if they want to keep up with the requirements of modern applications and demand driven by fiber-to-the-home competitors. And the upgrades will involve laying lots of new fiber.[12]

DOCSIS 3.1 deployments also suffer from issues related to latency and jitter. There is a good deal of variation in the quality and conditions of cable networks. Older cable may have higher noise rates or significant attenuation, especially when carrying high-frequency signals that it was not originally intended to handle. To deliver consistent throughputs in the face of these discrepancies, DOCSIS employs sophisticated

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[6] CableLabs, *DOCSIS 3.1 Technology*, *available at* https://www.cablelabs.com/technologies/docsis-3-1.

[7] Press Release, Comcast, Comcast to Introduce World's First DOCSIS 3.1-Powered Gigabit Internet Service in Atlanta, Chicago, Detroit, Miami, and Nashville (Feb. 2, 2016); *See also* Tech News Today, *Cable Companies Can Save Money Now That DOCSIS 3.1 Upgrade is Mostly Done* (Jun. 15, 2019), *available at* https://latesttechnewsblog.com/2019/06/15/cable-companies-can-save-money-now-that-docsis-3-1-upgrade-is-mostly-done.

[8] Daniel Frankel, *Comcast Reaches the Finish Line on DOCSIS 3.1 Deployment*, Multichannel News (Oct. 18, 2018), *available at* https://www.multichannel.com/news/comcast-reaches-the-finish-line-on-docsis-3-1-deployment.

[9] Speedtest, *United States Fixed Broadband Speedtest Data Q2-Q3 2018*, *available at* https://www.speedtest.net/reports/united-states/2018/#fixed.

[10] John Ulm, *Making Room for D3.1 & FDX*, in SCTE & ISBE Journal of Network Operations, 4, 1, 2018, *available at* https://www.scte.org/SCTEDocs/Journals/SCTE-ISBE%20Network%20Operations%20Journal%20N4V1.pdf.

[11] Ayham Al-Banna, Tom Cloonan, and Jeff Howe, *Network Migration Strategies for the Era of DAA, DOCSIS 3.1, and New Kid on the Block… Full Duplex DOCSIS!*, SCTE-ISBE and NCTA, 2017. *Available at* https://www.nctatechnicalpapers.com/Paper/2017/2017-network-migration-strategies/download.

[12] See *supra* 10, table 2 on page 19. (The only viable options for significantly improving upstream capacity involve going "fiber deep" or transitioning to fiber-to-the-home entirely.)

encoding schemes[13] which offer better robustness at the expense of up to 3.5ms of extra latency.[14] For example, "interleaving" involves scrambling portions of a signal before sending it over the wire, allowing forward error correction to more effectively deal with bursts of noise. This scrambling and unscrambling means that symbols cannot be processed in real time, and interleaving can add milliseconds of latency to the system.[15] Headend operators can choose how to configure their networks: simpler encoding schemes add less guaranteed latency but are worse at correcting for noise, which leads to more dropped packets and jitter. More complex encoding schemes add milliseconds of latency, but deliver more consistent throughput. Furthermore, "media acquisition" protocols in DOCSIS 3.1—which are used to grant individual modems access to upstream traffic on shared cables—add an additional 2-8 ms of latency to the system.[16]

The next generation of DOCSIS technologies includes a proposal for "Low Latency DOCSIS" (LLD).[17] LLD would primarily improve latency for certain applications, like video chat or online games, by prioritizing some types of traffic over others at the modem level. While this doesn't improve average latency, it does offload latency to applications (like downloads or streaming video) where it doesn't matter as much. LLD will also improve on the media acquisition protocols currently used in DOCSIS 3.1. This change will improve average latency, but it won't address the delays caused by encoding and decoding traffic. As DOCSIS advances and transmission technologies improve, they will remain subject to tradeoffs: better throughput will only be possible with more complex encoding schemes and over shorter coax cables.

Planned future versions of DOCSIS will support "full duplex" speeds of 10Gb/s for both uploads and downloads, and may use up to 3 GHz of spectrum down the road.[18] The next version of DOCSIS, know as 4.0, is still in early stages of development and will not be standardized until the mid or late 2020's. In the long term, coax may be able to deliver speeds up to 25 or even 50 Gb/s, but the technology will run up against the Shannon limit sooner rather than later.

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[13] John Downey, *Understanding DOCSIS Data Throughput and How to Increase it*, *available at* http://piedmontscte.org/resources/DOCSIS_Throughput.doc

[14] In DOCSIS 3.1, the simple Reed-Solomon error correction encoding used for versions 1.0 to 3.0 was replaced with a concatenated Bose, Ray-Chaudhuri, Hocquenghem (BCH) and Low Density Parity Check (LDPC) encoding. This scheme allows operators to push data throughput closer to the Shannon limit at the expense of computational complexity; *See* Brady S. Volpe & Mike Collins, *It's All About the FEC: Like a Box of Chocolates*, Broadband Library (May 26, 2018), available at https://broadbandlibrary.com/fec.

[15] Errors in DOCSIS systems tend to occur in bursts. Error-correcting encodings are better at dealing with errors that are spread out over time, so operators can "interleave," or mix up, symbols before they are sent. This increases the effectiveness of error correcting codes at the expense of more latency. See Cisco, *Understanding Data Throughput in a DOCSIS World*, *available at* https://www.cisco.com/c/en/us/support/docs/broadband-cable/data-over-cable-service-interface-specifications-docsis/19220-data-thruput-docsis-world-19220.html.

[16] *See* Sundaresan White & B. Briscoe, *Low Latency DOCSIS: Technical Overview*, (Feb. 2019), *available at* https://tools.ietf.org/id/draft-white-tsvwg-lld-00.html#LLD-white-paper.

[17] *Id.*

[18] Alan Breznick, *Here Comes DOCSIS 4.0*, LightReading (May 22, 2018), *available at* https://www.lightreading.com/cable/docsis/here-comes-docsis-40/d/d-id/743285 (Researchers have begun experimenting with using frequencies up to 3GHz for what will become DOCSIS 4.0, with the goal of having a full specification by the mid to late 2020s. Based on previous standard rollouts, we might expect to see widespread deployment of DOCSIS 4.0 3 to 5 years after that).

One big draw of DOCSIS is that cable companies can use existing infrastructure to continue delivering high-speed broadband. However, in order to serve cable customers with gigabit speeds and beyond, any remaining all-coax networks will need to be replaced with HFC networks and fiber nodes in HFC networks will have to be moved even closer to subscriber homes.[19] Cable operators will need to increase their node counts by a factor of 10 or 20,[20] and the "last mile" will become closer to a "last meter." In addition, it's unclear whether the aging coax already in the ground will be able to support extended frequencies up to 3 GHz.[21] Old coax may need to be decommissioned and replaced in order to take full advantage of DOCSIS 4.0.

To summarize: high-bandwidth broadband over coax is possible, but we are approaching the limits of what the technology can do. Current-generation DOCSIS technology suffers from relatively high latencies and huge discrepancies between upstream and downstream throughputs. Next-gen improvements to cable internet can mitigate these issues, but will require decommissioning miles of old coax and running fiber closer to subscriber homes. And while future versions of the technology will improve on the relatively high latencies of DOCSIS 3.1, high-throughput DOCSIS will continue to be subject to more latency than pure fiber.

5G and the Future of Wireless

Wireless broadband solves a fundamentally different problem than wireline technologies like cable and fiber. Wireline technologies deliver service to a fixed point, like a home or business. Wireless delivers data service to mobile devices through the air, and it's the only way to offer flexible broadband service to large public areas. For the past two decades, wireless and wireline broadband technologies have coexisted harmoniously in the internet ecosystem. However, some industry representatives have suggested that the fifth generation of cellular broadband, known as 5G, will be able to compete directly with wireline broadband options or replace it altogether.[22] This section will describe how wireless broadband works, and examine how it compares to wireline technologies as a last-mile link. It will argue that for the vast majority of users, wireline internet will remain the better option for fixed-point broadband.

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[19] Many providers have already begun reaching closer to homes with fiber to support the DOCSIS 3.1 rollout. In addition, proposed technologies like full duplex DOCSIS will require providers to upgrade their amplifiers or reach close enough with fiber to remove them altogether. Brian Santo, *Cable Nodes Becoming a Chokepoint*, LightReading (Dec. 5, 2016), *available at* https://www.lightreading.com/cable/ccap-next-gen-nets/cable-nodes-becoming-a-choke-point/d/d-id/728754; *See also* Daniel Frankle, *Cox Set to Take Fiber to the Node, Deploy DOCSIS 3.1*, FierceVideo (May 23, 2016), *available at* https://www.fiercevideo.com/cable/cox-set-to-take-fiber-to-node-deploy-docsis-3-1

[20] See *supra* 10

[21] Philip Dampler, *Cable's DOCSIS 4.0 - Symmetrical Broadband Coming*, Stop The Cap! (Jun. 25, 2019), *available at* https://stopthecap.com/2019/06/25/cables-docsis-4-0-symmetrical-broadband-coming.

[22] See https://www.lifewire.com/5g-internet-wifi-4156280 and https://knowledge.wharton.upenn.edu/article/the-push-for-5g/

Wireless broadband systems are significantly different from cable and other wireline systems. For one, wireless broadband doesn't need to be deployed to each customer; each wireless base station serves whoever happens to be in its vicinity. In addition, wireless signals degrade in power over distance much more quickly than wired signals. While a single cable headend can serve customers for many miles in every direction, cellular base stations in populated areas are typically placed no more than a mile apart.[23]

Wireless internet deployments are also subject to constraints that wired systems are not. Low-frequency wireless signals, like AM/FM radio and broadcast TV, are able to pass through trees, buildings, and miles of open air without a problem. Higher-frequency bands have more bandwidth and generally carry more information. However, higher-frequency signals are also more susceptible to absorption and scattering, which limits how far they can be transmitted. While 2.4 GHz WiFi can pass through brick walls in a house, 5GHz WiFi has more trouble, and is often unable to reach across multiple rooms. The next generation of WiFi technology, known as WiGig, utilizes frequency bands as high as 60GHz.[24] At that frequency, signals are almost completely disrupted by walls and furniture, so 60GHz routers will work best for nearby, line-of-sight communication.

The current generation of cellular internet technologies is known as "4G" (for "4th generation"). 4G operates on frequencies between the 700 MHz and 2.6 GHz bands, which can serve devices up to a few hundred meters away in urban areas and up to a few miles away in rural areas. Technically, 4G systems are supposed to be capable of serving 1 Gb/s download speeds to low-mobility devices (like phones in the hands of pedestrians).[25] However, in the real world, most carriers offer speeds from 10 to 50 Mb/s down and 3 to 20 Mb/s up.[26] Tests of 4G networks in the US have measured latencies around 50ms, with the "air latency" link between the tower and the device accounting for a significant portion of that.[27]

5G promises improvements over 4G in both throughput and latency. For long-distance links, 5G will use the same spectrum currently used by 4G, between 700 MHz and 4 GHz. Improvements to antennas and encoding technology will allow carriers to make better

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[23] Bernard Prkić, *Understanding Small-Cell Wireless Backhaul*, ElectronicDesign (Apr. 3, 2014), *available at* https://www.electronicdesign.com/communications/understanding-small-cell-wireless-backhaul (In suburban areas, cell sites are typically installed 1-2 miles apart, while in urban areas, they may only be ¼ mile apart due to population density and to overcome interference caused by buildings).

[24] Wi-Fi Alliance, *Wi-Fi Certified WiGig: Multi-gigabit, Low Latency Connectivity*, *available at* https://www.wi-fi.org/discover-wi-fi/wi-fi-certified-wigig.

[25] International Telecommunications Union, *Requirements related to technical performance for IMT-Advanced radio interface(s)*, (2008), *available at* http://www.itu.int/pub/R-REP-M.2134-2008/en.

[26] 2019 tests found that Verizon, the fastest U.S. carrier, provides average speeds of 53 Mb/s down and 17.5 Mb/s up; Cricket, the slowest tested network, achieves 6.8 Mb/s down and 5.8 Mb/s up. See Tom's Guide, "Fastest Wireless Network 2019: It's Not Even Close." *See* Tom's Guide, *Fastest Wireless Network 2019: It's Not Even Close*, *available at* https://www.tomsguide.com/us/best-mobile-network,review-2942.html.

[27] *See supra* 2. Also Mehdi Daoudi, *There's No Avoiding Network Latency on 4G*, Catchpoint (Jan 15, 2014), *available at* https://blog.catchpoint.com/2014/01/15/theres-no-avoiding-network-latency-on-4g (A 2014 test found average pings on 4g networks to be around 55ms, compared to an average of 22ms on wireline broadband).

use of the same spectrum.[28] In terms of throughput, long-distance 5G may not be a massive step forward: tests of sub-6GHz 5G deployments have found it to be capable of a few hundred Mb/s in the best case, only slightly better than the most advanced 4G LTE systems.[29]

In addition to re-using 4G spectrum, 5G will support "millimeter wave (mmWave)" frequencies at 26 GHz and above. Higher frequency channels are attractive because they offer more usable bandwidth, and can therefore support higher maximum throughputs. Using mmWave spectrum, 5G transmitters will be able to provide much better transfer speeds, maxing out between 1 and 10 Gb/s under optimal conditions. But since mmWave signals are so much higher frequency than traditional cellular signals, they suffer much greater absorption and scattering. Millimeter wave signals cannot pass through most walls, thick foliage, or even inclement weather without encountering significant interference. They also lose power much faster, even in clear conditions, than sub-6GHz signals.[30] That means mmWave won't work well for outdoor-to-indoor communication. Early adopters of mmWave in US cities have reported needing to do the "5G shuffle"—physically dancing around 5G transmitters—in order to take advantage of gigabit speeds.[31] As a result, mmWave transmitters will work more like WiFi, providing service to small, open areas, rather than drop-in replacements for 4G.

5G also promises to improve on the latency of 4G. While providers have promised air latencies between 1 and 4 ms, these numbers will only be available with mmWave spectrum.[32] Real-world tests have found that the sub-6GHz 5G equipment being shipped today has air latencies between 9 and 12 ms, which is comparable to advanced 4G technology.[33]

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[28] One example of an improvement is "massive MIMO (Multiple Input Multiple Output)" technology. MIMO allows base stations to use multiple antennas to transmit over a greater portion of the available spectrum at once. *See* Qualcomm, *How 5G Massive MIMO Transforms Your Mobile Experiences*, OnQ Blog (Jun. 20, 2019), *available at* https://www.qualcomm.com/news/onq/2019/06/20/how-5g-massive-mimo-transforms-your-mobile-experiences.

[29] In a CNet experiment from July 2019, the best sub-6GHz deployment was from SK telecom in Seoul, which achieved peak download speeds of 618 Mb/s. In the US, the top tested deployment was in Dallas, where the Sprint 5G network achieved 484 Mb/s. *See* Jessica Dolcourt, *We Ran 5G Speed Tests on Verizon, AT&T, EE, and more: Here's What We Found*, CNet (Jul. 3, 2019), *available at* https://www.cnet.com/features/we-ran-5g-speed-tests-on-verizon-at-t-ee-and-more-heres-what-we-found.

[30] See FCC Office of Engineering and Technology, *Millimeter Wave Propagation: Spectrum Management Implications* (1997), *available at* https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet70/oet70a.pdf.

[31] TechRadar journalists tested Verizon's 5G deployment in Chicago in May 2019. They were able to achieve super-gigabit download speeds by physically moving around the mmWave transmitter. *See* Matt Swider, *5G Speed Test: 1.4 Gbps in Chicago, but Only if You Do the '5G Shuffle,'* Techrader (May 19, 2019), *available at* https://www.techradar.com/news/5g-speed-test.

[32] Ronan McLaughlin, *5G Low Latency Requirement,* Broadband Library (May, 25, 2019), *avaialble at* https://broadbandlibrary.com/5g-low-latency-requirements.

[33] Jon Brodkin, *AT&T's 5G Trials Produce Gigabit Speeds and 9ms Latency*, ArsTechnica (Apr. 11, 2018), *available at* https://arstechnica.com/information-technology/2018/04/atts-5g-trials-produce-gigabit-speeds-and-9ms-latency (An AT&T test of mmWave 5G in Waco, Texas found "latency rates of 9-12 ms." This likely refers to the air latency between the device and the tower, which matches up with Verizon's 5G deployments

What about 6G and beyond? As time goes on, cell providers will likely find ways to squeeze more throughput out of the usable long-range frequencies below 6GHz. However, the bandwidth available at these frequencies is limited, and background noise will always be present. Cellular providers will soon run into the Shannon limit for wireless channels. Furthermore, as applications for mobile devices advance, they will likely demand higher sustained data rates than before, which will put greater strain on mobile networks. Since each cell tower has to serve all devices in an area using the same limited bandwidth, as more devices clamor for more data, the average available throughput will suffer. More base stations can be built to accommodate some of the increased demand, but the stations will still need to share a limited amount of spectrum. Speeds for everyone are likely to improve, but not as much as the lab-tested scenarios would suggest.

To summarize, 5G is a big step forward, but it is not a panacea. Millimeter-wave 5G will use more bandwidth to serve fewer devices in a smaller area, so it should be able to deliver true gigabit speeds. It should be able to deliver last-hop latencies that are comparable to, or even better than, fiber-to-the-home. However, mmWave deployments will require running fiber-optic cables to individual buildings in order to be useful.[34] In other words, the most exciting parts of 5G will supplement, rather than replace, fiber-to-the-home.

Fiber Today and in the 21st Century

Fiber-optic cables are long, extremely thin, and carefully crafted strands of glass that can "guide" beams of light from one end to the other. Fiber optics can carry light over hundreds of miles without allowing the light to scatter or disperse. Although the mode of transmission is different in fiber than in coax, the principle is the same: both fiber-optic and coaxial cables guide electromagnetic waves and protect them from interference in transit.

Fiber carries much higher-frequency signals than coax does. DOCSIS 3.1 uses frequencies up to 1.2 gigahertz, but common fiber-optic cables carry light in the infrared spectrum between 200 and 350 *terahertz*.[35] A typical fiber-optic cable has around 10,000 times more usable bandwidth than a typical coaxial cable. Furthermore, fiber-optic cables are

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elsewhere); Wireless One, *Latency 30 ms at Verizon 5G* (Apr. 04, 2019), *available at* http://wirelessone.news/10-r/1368-5g-latency-30-ms-at-verizon (Real-world latency from device to server remains around 30ms).

[34] Gemalto, *Introducing 5G Networks - Characteristics and Usages*, *available at* https://www.gemalto.com/brochures-site/download-site/Documents/tel-5G-networks-QandA.pdf (Both the bandwidth and latency improvements that 5G promises assume fiber-optic links directly to base stations).

[35] Fiber optic cables carry light wavelengths between 850 and 1620 nm. Not all wavelength bands are viable due to absorption, and different protocols use different bands; PON protocols use wavelengths between 1400 and 1610 nm for transmission. *See* Alice Gui, *From O to L: The Evolution of Optical Wavelength Bands*, Cable Solutions (Oct. 13, 2015), *available at* http://www.cables-solutions.com/from-o-to-l-the-evolution-of-optical-wavelength-bands.html.

much less susceptible to interference and noise than coax or wireless channels. Beams of light do not interfere with other electromagnetic waves in the same way that radio-frequency signals do, so fiber isn't vulnerable to crosstalk or radio-frequency leakage like coax is. The main limiting factor for fiber is attenuation, or power lost over distance. Even modern fiber isn't perfectly transparent. Over the course of long distances, light is absorbed by tiny imperfections in the glass, causing the beam to become dimmer. Therefore, fiber cables spanning extremely long distances (like oceans) must have repeaters installed to periodically boost the signal.

Today, fiber is often used to carry Internet signals through every part of the network *except* the last mile. We've already discussed how fiber carries data around the internet backbone, how it brings broadband from cable headends to curbside "nodes" in hybrid fiber-cable DOCSIS deployments, and how fiber will connect to base stations in 5G networks. When fiber-optic cables are used to deliver service directly to a subscriber's residence, it's known as "fiber-to-the-home" (FTTH). The most common FTTH architecture is the Passive Optical Network (PON), a design in which signal is driven down a single fiber and "split" using a series of passive lenses to serve individual subscribers. There are competing standards for last-mile fiber deployments, including the ITU-T's NG-PON2[36] and the IEEE's 10G-EPON,[37] but most of them use the same basic PON architecture.

We are nowhere near able to take advantage of fiber's full potential for last-mile connections. The huge amount of bandwidth available through fiber, and the minimal noise added during transmission, mean that the Shannon limit to fiber-optic channels tends to be extraordinarily high. In a lab setting, researchers have been able to achieve data rates upwards of 100 Tb/s over many kilometers in a single, standard fiber,[38] and it's likely that we'll see further improvements in the years to come. But transmitters and receivers capable of more than 1 Tb/s are still quite expensive. For now, they are only used in enterprise settings and the internet backbone.

A typical fiber-to-the-home deployment today has symmetrical upload and download speeds around 1 Gb/s, though currently adopted PON standards support symmetrical speeds up to 10Gb/s.[39] As technology continues to develop, better transmitters will become cheaper and more efficient, and providers will be able to upgrade existing fiber deployments without any changes to the fiber itself. Once fiber is laid, its capacity can be upgraded by orders of magnitude just by changing the transmitters at each end. Fiber-optic cables are typically designed for a lifetime of at least 25 years, though they

[36] Gigabit-capable Passive Optical Network (GPON) is the common name for the G.984 standard by the ITU-T, introduced in 2003. It has since been superseded by G.987, aka XG-PON, and by G.989, aka NG-PON2. *See* International Telecommunications Union, *40-Gigabit-capable passive optical networks (NG-PON2): General requirements*, *available at* https://www.itu.int/rec/T-REC-G.989.1-201303-I.
[37] Ethernet Passive Optical Network (EPON) was first standardized by the IEEE in 2004; updated versions of the standard that support 10 Gb/s, known as 10G-EPON, and beyond have since been standardized. See IEEE P802.3av Task Force, *10Gb/s Ethernet Passive Optical Network*, *available at* http://www.ieee802.org/3/av.
[38] Jeff Hecht, *Ultrafast Fibre Optics Set New Speed Record*, NewScientist (Apr. 19, 2011), *available at* https://www.newscientist.com/article/mg21028095-500-ultrafast-fibre-optics-set-new-speed-record.
[39] Both the ITU-T's NG-PON2 standard and the IEEE's 10G-EPON standard support symmetrical connections of 10 Gb/s or better, *supra* notes 36 and 37.

can, and frequently do, last much longer.[40] And as long as the cables themselves remain sound, FTTH connections are all but future-proof.

The fact that many PON architectures have fully symmetrical data speeds gives them a significant advantage over DOCSIS. As we discussed previously, DOCSIS 3.1 uses a small portion of spectrum for upstream traffic, and only allows for 1 Gb/s of upload throughput to be shared between all customers in a service group.[41] Meanwhile, NG-PON2 allocates 4 different channels of 10Gb/s each for upstream data, yielding 40Gb/s of total upstream throughput to be shared among the customers on a network terminal.[42] Latency is another area where fiber has a major advantage. In DOCSIS 3.1, upstream bandwidth allocation adds 2-8 ms of latency.[43] FTTH protocols need to address the upstream allocation problem too, but the excessive upstream bandwidth available in fiber-optic systems makes it easier to deal with. Testing has shown that dynamic bandwidth allocation in PON systems adds less than a millisecond of latency.[44]

Furthermore, as described above, coax is more susceptible to noise than fiber, especially when carrying high-frequency signals. To overcome that noise, DOCSIS transmitters need to use ever-more complex error-correcting encoding schemes. Encoding and decoding symbols takes time at each end of the cable, and it limits how quickly data can travel. On the other hand, signals driven over fiber contain very little noise. GPON and other fiber protocols transmit data with less overhead for error correction.[45] As a result, total last-mile latency in GPON FTTH channels can be specified below 1.5 ms, even for links up to 20km.[46] In addition, because fiber-optic channels experience fewer dropped packets than coax channels do, they suffer from less jitter. Fiber provides a smoother, more real-time internet experience than any competing wireline technologies. This makes fiber the best choice for applications where responsiveness is critical, like voice-over-IP, video chat, remote-controlled robotics, and virtual reality.

In short, fiber is the superior medium for carrying fixed broadband by almost every metric: available bandwidth, SNR, theoretical capacity, real-world throughput, latency, and jitter. Furthermore, fiber cables can be installed now and upgraded for decades to come, while most existing coax infrastructure will likely need to be replaced within the

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[40] David Stockton, *4 Factors That Influence How Long Your Fiber Network Will Last*, PPC Blog, *available at* https://www.ppc-online.com/blog/4-factors-that-influence-how-long-your-fiber-network-will-last (Cracks and other flaws in fiber optics, introduced during manufacturing or deployment, are exacerbated over time and can lead to failure after several years. For correctly installed tier-1 fibers, the probability of a given km of fiber failing on its own within 20-40 years is approximately 1 in 100,000. However, the most common cause of failure is construction or "dig-ups" that occur after the fiber has been laid. In lieu of these kinds of failures, fiber-optic deployments can last for many decades).

[41] See *supra* 6

[42] See *supra* 36

[43] See *supra* 16 for information about upstream allocation latency in DOCSIS.

[44] Pavel Sikora et al., *Efficiency Tests of DBA Algorithms in XG-PON*, MDPI Electronics 2019, 8, 762; *available at* https://www.mdpi.com/2079-9292/8/7/762/pdf.

[45] GPON systems have configurable error correction, and some systems may not require error-correcting encoding at all. *See* Calix Resource Center, *available at* https://www.calix.com/content/calix/en/site-prod/library-html/systems-products/b-series/system-operation/b6-user-docs/release8-0/ug/index.htm?toc45430275.htm?52773.htm.

[46] International Telecommunications Union, *Gigabit-capable passive optical networks (GPON): General characteristics*, available at https://www.itu.int/rec/T-REC-G.984.1.

next few years in order to keep up with consumer demand. While 5G is a promising upgrade over 4G, long-range wireless broadband cannot outperform fiber as a last-mile link to homes and businesses. In highly populated areas, mmWave 5G will be a supplement to, not a replacement for, fiber-to-the-home. In rural areas, attempting to install enough fiber to enough base stations to provide full mmWave coverage makes less sense than to simply run wireline service to each home.[47] And to top it off, future upgrades to both DOCSIS and wireless broadband will require laying many miles of new fiber. As a result, civic planners looking ahead should invest in last-mile fiber infrastructure today. Fiber-to-the-home is the best option to serve most Americans with high-speed, low-latency broadband now, and it will remain so for the foreseeable future.

[47] Jon Brodkin, *Millimeter-wave 5G will never scale beyond dense urban areas, T-Mobile says*, ArsTechnica (Apr. 22, 2019), *available at* https://arstechnica.com/information-technology/2019/04/millimeter-wave-5g-will-never-scale-beyond-dense-urban-areas-t-mobile-says/

APPENDIX B

Samuelson-Glushko Technology Law & Policy Clinic White Paper Examining the History and Competitive Effects of Sharing Obligations in the Provision of Last-Mile Connectivity (Prepared for EFF)

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Managing Last-Mile Monopolists: Reevaluating Sharing Obligations for the Modern U.S. Wireline Broadband Market

Authored for the Electronic Frontier Foundation (EFF)

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Table of Contents

Introduction **1**

Discussion **2**

I. Wireline Broadband Competition in the United States 2

A. The Market for Fiber Deployment 2

B. Broadband Mapping 5

II. Stagnation in the Local Exchange and the 1996 Act 5

A. Early Degradation of Competition in the Local Exchange (1894–1984) 6

B. Breaking Down the Baby Bells: Competitive Boom or Bust? (1984–1996) 8

C. The Local Competition Provisions (1996) 9

D. Implementation of Sharing Obligations (1996–2005) 11

III. The FCC Rejects Sharing Obligations for Wireline Broadband 12

A. Legal and Regulatory History (1966–2005) 13

B. The FCC's Misguided Rationale (2005) 14

Introduction

The United States has become complacent in its connectivity. Over 24 million Americans do not have access to minimally-acceptable broadband speeds, and the vast majority of high-speed markets are controlled by local cable monopolies. Other developed nations have deployed future-proof, nationwide fiber networks as the United States has pursued a path of deregulation and seen wireline competition and deployment stagnate. This trend will not only widen the digital divide between Americans of different geographic areas and races, but it will also encumber the country's economic progress as peer nations speed ahead. Both the individual and collective prosperity of Americans depends on access to continually improving broadband services. Yet, if the long-term goals of the United States are so dependent on advanced wireline connectivity, then why have competition and deployment stalled?

The answer to this question is best explained by looking to history. The dominant position of modern incumbent wireline broadband providers—namely, local cable monopolies—closely mirrors the market power held by local exchange monopolies of the past. Absent government intervention, incumbent providers of a telecommunications network are able to exploit their atypical, natural monopoly position—insulated by network effects and economies of scale—to preclude competitive entry.

This anti-competitive dynamic in the local telephone market was so problematic that Congress enacted sweeping structural changes to the industry in the Telecommunications Act of 1996 ("the 1996 Act"), which centered around sharing obligations for incumbents. However, in 2005, while the broadband market was in its formative years, the Federal Communications Commission (FCC) reconsidered these sharing obligations in the context of wireline broadband internet access service (BIAS). Rather than look to history as a guide, the FCC optimistically, but naively, speculated about the competitive development of the broadband market and chose instead a path of deregulation.

With an eye towards remedying the stagnation in the broadband market and encouraging the widespread deployment of fiber, the following paper will examine the history and competitive effects of sharing obligations in the provision of last-mile connectivity. Part I will evaluate the current market for high-speed broadband in the United States with a specific focus on the deficiency in fiber deployment. Part II will review the development of competition—or lack thereof—in the local exchange from the invention of the telephone to the ultimate passage of the 1996 Act. Finally, Part III will reconsider the FCC's 2005 decision to not extend sharing obligations to wireline BIAS providers in light of the modern broadband market.

Discussion

I. Wireline Broadband Competition in the United States

The wireline broadband market in the United States has stagnated. Despite a backdrop of recent deregulation ostensibly designed to facilitate infrastructure investment, the reality remains that consumers have few, if any, choices for high-speed internet. Local cable monopolies provide 94 percent of all broadband subscriptions exceeding 100 Mbps—at least to those lucky enough to be connected.[1] Over 80 percent of rural census blocks are denied even the option to purchase such speeds, and 53 percent of all census blocks have no provider offering speeds above a meager 50 Mbps.[2] Even more starkly, under an antiquated understanding of what constitutes "high-speed," defined by the FCC as 25 Mbps download and 3 Mbps upload (25 Mbps/3 Mbps), over 24 million Americans still lack any choice of provider at all.[3]

The poor state of wireline broadband deployment becomes even more apparent when the United States is benchmarked against other developed nations—particularly those that have focused on the deployment of fiber networks. Where the United States has struggled to connect a fraction of its citizens to legacy, asymmetrical 25 Mbps/3 Mbps speeds, peer nations like Sweden, Japan, South Korea, and Singapore can offer symmetrical speeds at or exceeding 100 Mbps over fiber networks to the vast majority of their populations.[4]

Moreover, these next-generation fiber networks are functionally future-proof; they can be upgraded without the costly and intrusive process of digging them up from the ground.[5] As it currently stands, however, the latest government data projects that only 11 million of the total 126 million homes in the United States have fiber connections, and there is scant industry discussion about large-scale fiber-to-the-home (FTTH) deployment.[6] The following sections will examine the factors contributing to the United States' lackluster performance in fiber deployment.

A. The Market for Fiber Deployment

Under current regulatory and market conditions, the likelihood of widespread fiber deployment in the United States is low.[7] Despite the demonstrable benefits of a nationwide

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[1] Susan Crawford, *Fiber: The Coming Tech Revolution—And Why America Might Miss It*, Yale University Press, 38 (2018) (hereinafter "*Fiber*").

[2] *Id.* at 38-39.

[3] *In the Matter of Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion*, GN Docket No. 17-199, 2018 Broadband Deployment Report, 33 FCC Rcd. 1660, ¶ 50 (2018).

[4] *Fiber* at 9.

[5] *Id.* (describing how the information-carrying capacity of a fiber network "can be almost infinitely upgraded without digging up the cable, merely by swapping out the electronics that encode and power the pulses of light that travel within its walls.").

[6] *Id.*

[7] *The Potential for Ubiquitous, Open Fiber-To-The-Premises in San Francisco*, CTC Technology & Energy, Fiber for San Francisco Initiative at 49 (Oct. 2017) (finding that a purely private FTTH deployment strategy will not meet the

fiber network, incumbent broadband providers have no competitive impetus to deploy and the absence of sharing requirements precludes new competitors from meaningfully entering the market—though not for their lack of trying. Thus, the narrative of fiber deployment in the United States follows two tracks.[8] The first involves limited spurts of fiber deployment by major corporations—namely, Verizon and Google—curbed early by pressure from Wall Street investors given the projects' capital-intensive nature.[9] The second involves disruptive competitors—the competitive local exchange carriers (CLECs)—relying on legacy sharing obligations to gain sufficient funding to deploy fiber networks of their own.[10] These narratives will be examined in turn.

Major Providers Lack Incentives. Verizon's well-intentioned, but short-lived attempt at widespread fiber deployment is illustrative of the market forces constraining major providers. In 2005, following the deregulation of the wireline broadband industry by the FCC, Verizon launched an ambitious plan to expand its customer base and service offerings by deploying FTTH.[11] To undertake this high-cost venture, Verizon secured a number of state-regulated rate increases and redirected funds mandated for improvements to the public switched telephone network (PSTN).[12] Despite both state and federal regulatory concessions, investors nevertheless believed the project was too capital-intensive and cut it short.[13] The immediate financial interest of shareholders outweighed any countervailing long-term interest in developing a FTTH network.[14]

In today's market, the same fear of shareholder reprisal exists. No major broadband provider—whether its network is composed of copper or coaxial cables—is willing to undertake the sizeable financial investment to upgrade to fiber while its effective monopoly over last-mile connectivity remains unchallenged.[15] In fact, by parsing the geographic and service markets amongst competing providers, local cable monopolies are now able to merely increase the price on their existing service to generate additional revenue.[16]

Moreover, even innovative competitors from outside the traditional telecommunications industry struggle to justify fiber deployment to investors. For instance, Google launched its

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goals of "open access and direct fiber connectivity to every home and business" in San Francisco, a densely-populated, affluent city).

[8] Jon Brodkin, *AT&T Gets DirecTV Merger Approval, Must Deploy Fiber to 12.5M Customers*, Ars Technica (July 24, 2015), https://arstechnica.com/information-technology/2015/07/att-gets-directv-merger-approval-must-deploy-fiber-to-12-5m-customers/. Note that the described two-track narrative intentionally omits AT&T's recent fiber deployment, as it was required as a condition of its merger with DirecTV.

[9] *Fiber* at 56.

[10] *See* Electronic Frontier Foundation Comments Regarding U.S. Telecom Petition for Forbearance, WC Docket 18-141 at 3 (Aug. 6, 2018) (hereinafter "EFF Comments").

[11] *Fiber* at 52.

[12] Bruce Kushnick, *The Great Verizon FiOS Ripoff*, HuffPost (Dec. 6, 2017), https://www.huffpost.com/entry/the-great-verizon-fios-ripoff_n_1529287.

[13] *Fiber* at 52.

[14] *Id.*

[15] *Id.* at 38.

[16] *Id.* at 54.

own fiber initiative in 2010 in an attempt to disrupt the broadband industry.[17] To provide for timely and efficient deployment, Google negotiated agreements with municipalities to ensure special access to utility poles.[18] However, incumbent providers—specifically, AT&T and Comcast—filed lawsuits to quash their new competitor, claiming that Google's agreements violated federal rules.[19] These fights proved to be a costly distraction for Google during what was already a cost-intensive venture.[20] The result: Google announced it was "pausing" its fiber deployment in 2016.[21]

Legacy Sharing Obligations. Aside from short-lived efforts by large corporations, the most prominent player in fiber deployment is the CLEC. Thanks to legacy unbundling requirements from the 1996 Act, CLECs may lease capacity on the facilities of incumbent local exchange carriers (ILECs).[22] This allows CLECs—without the prohibitive expensive of building their own network—to sell digital subscriber line (DSL) service over existing facilities to generate revenue and develop a customer base. Not only does this immediately inject competition—price, customer service, or otherwise—into the local broadband market, but it also allows CLECs to generate sufficient revenue to deploy FTTH networks of their own. Moreover, as CLECs increasingly deploy better, more advanced fiber networks, their incumbent peers are forced to take competitive action. Either the incumbent responds by building out a competing fiber network capable of offering the same speeds, or it risks losing customers to the superior fiber offering.

Incumbents cannot stand this competitive pressure. Their immense frustration with sharing obligations is perhaps best evidenced by the recent regulatory action of the trade group, USTelecom – The Broadband Association. This coalition of natural monopolists petitioned the FCC to forebear from the 1996 Act's local competition provisions requiring unbundled access to the transmission component of an incumbent's wireline facilities.[23] To justify such an argument in light of woefully inadequate broadband connectivity and competition, USTelecom sought to avoid the issue by directing attention towards voice subscriptions. In response, consumer advocates called attention to this misdirection, suggesting instead the FCC focus on "the far greater number of broadband subscribers and potential future CLEC customers" that forbearance would affect.[24]

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[17] Brian Fung, *Why Google Fiber Stopped Its Plans to Expand to More Cities*, Washington Post (Oct. 26, 2016), https://www.sacbee.com/news/nation-world/national/article110655177.html.

[18] *Id.*

[19] *Id.*

[20] Blair Levin & Larry Downes, *Why Google Fiber Is High-Speed Internet's Most Successful Failure*, Harvard Business Review (Sept. 7, 2018), https://hbr.org/2018/09/why-google-fiber-is-high-speed-internets-most-successful-failure.

[21] *Id.*

[22] *See* 45 U.S.C. § 251(c)(3); 45 U.S.C. § 252(d)(1).

[23] *See* Petition of USTelecom for Forbearance Pursuant to 47 U.S.C. § 160(c) to Accelerate Investment in Broadband and Next-Generation Networks, WC Docket 18-141 (May 4, 2018).

[24] EFF Comments at 3.

B. Broadband Mapping

These problems surrounding fiber deployment—as well as broadband competition more generally—have persisted in part due to fundamental flaws in the FCC's broadband mapping process. As currently conducted, the FCC requires facilities-based broadband providers to self-report their broadband coverage and speeds via Form 477 twice per year.[25] Despite the fact that providers are incentivized to over-report speeds and under-report coverage failures, the FCC does not audit the veracity of the data.[26] Moreover—and perhaps most crucially to any competitive analysis—the FCC refuses to make the pricing data provided available to the public.[27] Further critiques include the published information being outdated by as many as 18-months by the time it reaches policy conversations,[28] and that it lack any specification about the type of facility (*e.g.*, copper, cable, or fiber) over which the service is provided.[29] Since regulators are left unable to meaningfully assess the scope of the problem—or are perhaps able to rely on faulty data to suggest there is ample competition in the broadband market—little progress is made.

Moreover, in September 2018, the Government Accountability Office (GAO) published a report critical of the FCC's broadband maps, calling attention to the downstream consequences of its reporting deficiencies.[30] Specifically, the GAO's independent study had shown that the FCC has consistently overstated the availability of broadband on tribal lands.[31] It went on to document how this systematic over-reporting leads to less targeted funding to actually provision broadband service to these underserved areas, directly connecting the FCC's reporting failures to consumer harm in a historically marginalized population.[32]

II. Stagnation in the Local Exchange and the 1996 Act

The narrative of stagnant competition in a wireline telecommunications market is not a new one. For over a century, consumers were deprived of the benefits of meaningful competition in the provision of telephone service while AT&T leveraged its geographic monopolies and close relationship with federal regulators to protect its market dominance.[33] Only through targeted legislative action was Congress able to curb anti-competitive practices in the local exchange.[34] By imposing sharing obligations on incumbent providers, the 1996

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[25] Karl Bode, *How Bad Maps are Ruining American Broadband*, The Verge (Sept. 24, 2018), https://www.theverge.com/2018/9/24/17882842/us-internet-broadband-map-isp-fcc-wireless-competition (hereinafter "Bode, *Bad Maps*").

[26] *Id.*

[27] *Fiber* at 46.

[28] Bode, *Bad Maps*.

[29] *Fiber* at 46.

[30] *Broadband Internet: FCC's Data Overstate Access on Tribal Lands*, Government Accountability Office, Report to Congressional Requesters, GAO-18-630 (Sept. 2018).

[31] *Id.*

[32] *Id.*

[33] *See* infra Part II.A.

[34] *See* infra Part II.C.

Act immediately injected competition into a market long characterized by local monopolies.[35] The following will examine the history and development of competition in the local exchange, focusing on the competitive imperative of sharing obligations in wireline telecommunications markets.

A. Early Degradation of Competition in the Local Exchange (1894–1984)

From the earliest days of its nearly 150-year history, the Bell System[36] did not shy away from anti-competitive, anti-consumer practices in pursuit of long-term structural dominance. In 1894, promptly after Alexander Graham Bell's original patents expired, AT&T began cementing its monopolistic market position by refusing to interconnect its network with that of its competitors, despite the mutually beneficial nature of such an arrangement.[37] Accordingly, in the absence of interconnection agreements, inefficient competition arose in the form of duplicate telephone networks in major cities—one to talk with AT&T customers and another to talk with non-AT&T customers.[38] However, by the turn of the century, AT&T recognized the folly of this redundant competition and began to take action against it—not by implementing the competition-inducing interconnection measures but instead by establishing exclusive arrangements with once-competitors to reduce or eliminate head-to-head competition in the local exchange.[39]

While the refusal to interconnect hindered competition in these nascent telecommunications markets, AT&T's control over crucial long-distance patents and its proprietary customer premises equipment also played a role in precluding competition. In the context of long-distance markets, AT&T leveraged its patents to establish dominance nationwide and then refused interconnection to potential local competitors.[40] By preventing rivals from meaningfully offering both local and long-distance services, AT&T was able to offer a superior product to consumers—albeit almost certainly at a higher price—and greatly outpace any other telecommunications firm in building out its network.[41] While the Department of Justice (DOJ) ultimately mandated interconnection in an antitrust consent decree with AT&T in 1914 to address this exclusionary behavior in the long-distance market, the regulatory intervention came too late to mitigate the lasting structural harm.[42]

From 1913 until the late-1960s, AT&T maintained dominance in the customer premises equipment market under the guise of network safety by forbidding and aggressively litigating

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[35] *See* infra Part II.D.

[36] Note the "Bell System" includes AT&T (which provisioned local and long-distance services), Western Electric (which provided customer premises equipment), and Bell Telephone Laboratories (which conducted research and development on behalf of the Bell System). For the purpose of simplicity, the shorthand "AT&T" is used to refer to the collective Bell System prior to its break-up in 1984.

[37] Jerry Kang & Alan Butler, *Communications Law and Policy*, 262 (6th ed. 2018) (hereinafter "*Communications Law*").

[38] *Id.*

[39] *Id.*

[40] *Id.* at 263.

[41] *Id.*

[42] *Id.*

against the connection of "foreign devices" to the PSTN.[43] Regardless whether the proposed attachment provided significant utility to consumers or was entirely innocuous with regard to the network's security, AT&T fought to ensure that only Bell devices were allowed connection to the PSTN.[44] The quintessential example of this anti-competitive litigation involved AT&T's refusal to allow the "Hush-A-Phone," a cup-like device mounted on the Bell phone's mouthpiece to reduce the risk of being overheard, from being used in conjunction with its customer premises equipment.[45] "The FCC absurdly agreed with AT&T's submission that the use of such 'foreign devices' threatened the integrity of the telephone system, even though the practical effect of the device was equivalent to covering the receiver with one's hand."[46]

By the early 1970s, AT&T's scope and influence was staggering; not only had AT&T become the nation's sole provider of long-distance services, but it also controlled roughly 80 percent of the local exchange market.[47] In response to this apparent market failure and to address the concerns of new competitors, like MCI Telecommunications, the FCC gradually took steps to introduce competition into the long-distance market—first allowing more competition in private line services and later allowing for open competition with AT&T.[48] However, this regulatory intervention was not without a prolonged—albeit unsuccessful—legal challenge from AT&T.[49] The company's response to this legal defeat was to systematically and aggressively lower its prices in the long-distance markets now also served by newfound competitors, recouping the lost revenue by hiking up its prices in markets where it still maintained a monopoly.[50]

The DOJ took action to curb this flagrant anti-competitive behavior. In response to AT&T's predatory cross subsidization scheme, its discriminatory provision of access to the local exchange for long-distance competitors (referred to as "operational discrimination"), and its overly-restrictive customer premises equipment practices, the DOJ filed an antitrust action against AT&T in 1974.[51] The resulting Modified Final Judgement—implemented almost a decade after the lawsuit was filed—took aim at AT&T's anti-competitive conduct through a rarely invoked structural remedy: divestiture.[52] Regulators, conceding that the local exchange exhibited natural monopoly characteristics, sought to eliminate the bottleneck of control AT&T maintained at the local exchange by splitting the company into discrete

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[43] *Id.*

[44] Jonathan E. Nuechterlein & Philip J. Weiser, *Digital Crossroads: American Telecommunications Policy in the Internet Age*, 58 (2d ed. 2007) (hereinafter "*Digital Crossroads*").

[45] *See* Hush-A-Phone v. United States, 238 F.2d 266 (D.C. Cir. 1956).

[46] *Digital Crossroads* at 58.

[47] *Communications Law* at 263.

[48] *Id.* at 264.

[49] *See* MCI Telecommunications Corp. v. FCC, 561 F.2d 365 (D.C. Cir. 1977).

[50] *Communications Law* at 264.

[51] *Id.*

[52] *Id.*

entities—dividing control over the local exchange and long-distance markets.[53] The resulting companies included AT&T Long Lines, which provisioned long-distance services and was explicitly prohibited from entering the local exchange market, and seven Regional Bell Operating Companies (or "Baby Bells"), which provisioned local exchange service within defined regions and were explicitly prohibited from entering the long-distance market.[54]

B. Breaking Down the Baby Bells: Competitive Boom or Bust? (1984–1996)

While the break-up of AT&T temporarily alleviated concerns around predatory pricing and operational discrimination, the structural remedy failed to meaningfully introduce competition in the local exchange.[55] Indeed, the Modified Final Judgement explicitly approved of seven regional monopolies in the local exchange without a feasible mechanism for subsequently increasing competition.[56] As such, the threat of predatory cross subsidization where AT&T controlled vertically adjacent markets no longer existed, but the bottleneck in the local exchange nevertheless remained. Since the newly-formed Baby Bells had both an inherent ability and natural incentive to block competition, they did just that by provisioning access to their local exchanges in a technically-inferior manner and charging rates that exceeded cost.[57]

Competition with the Baby Bells arose, then, as a means to bypass the local exchange entirely. Competitive access providers (CAPs) were a new entity that competed in the provision of competitive access services, but not in the local exchange market itself.[58] Crucially, this type of competition was only able to exist because of the high-volume of business customers between major cities. By building high-capacity fiber "rings" underneath major cities to bypass the Baby Bell's local exchange, CAPs were thus able to enjoy economies of scale while only serving a small, but lucrative portion of the customer base in any given city.[59]

Although CAPs could bypass the local exchange in certain limited contexts, doing so often proved prohibitively expensive and interconnection was almost always more efficient. Thus, policy debates over local access competition centered around the terms on which CAPs could demand interconnection to the Baby Bell's local exchange when it was infeasible for them to build out their own last-mile network.[60] In response to this debate and in an incremental step towards local exchange competition, the FCC issued its *Expanded*

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[53] Glen O. Robinson, *The Titanic Remembered: AT&T and the Changing World of Telecommunications*, 5 Yale J. Reg. 517, 531-32 (1988).

[54] *Id.*

[55] *Digital Crossroads* at 63.

[56] John Pinheiro, *AT&T Divestiture & the Telecommunications Market*, 2 Berkeley Tech. L.J. 303, 316 (1987).

[57] *Digital Crossroads* at 65.

[58] Note the distinction between competition in *local access* markets compared to competition in *local exchange* markets. Local access competition exists when CAPs *bypass* some or all of the local exchange and serve high-volume business customers by connecting them directly to long-distance carriers. Conversely, local exchange competition exists when an individual user has a meaningful alternative to the incumbent local exchange carrier in placing local calls over the local exchange.

[59] *Digital Crossroads* at 65.

[60] *Id.* at 66.

Interconnection Orders in the early 1990s to allow CAPs to co-locate their own interconnection equipment in specially designated areas in the incumbent's local exchange.[61]

As debates over local exchange competition progressed, regulators by the mid-1990s began experimenting with policies designed to increase competition in the local *exchange* markets—not just local *access* markets. For instance, in New York and California, regulators implemented regulatory regimes where new entrants were allowed to "interconnect with the incumbent's network and lease capacity on its facilities at low wholesale rates to provide competing local exchange services."[62] This type of wholesale leasing arrangement formed the basis for the 1996 Act's subsequent introduction of unbundled network elements (UNEs).[63] Moreover, it is important to note that CAPs, which had previous experience in deploying and administering similar networks (*e.g.*, fiber "rings" around major cities), were among the first to enter these new markets.[64]

While the competitive effect of these early regulations was moderate—largely due to their limited applicability and scope—they nevertheless played a major role in informing the drafters of the 1996 Act. Their influence is best evidenced by the "local competition provisions" of Sections 251 and 252, which mirrored—albeit on a much larger scale—many of the attempted regulatory interventions.[65]

C. The Local Competition Provisions (1996)

The 1996 Act, the most comprehensive reform of federal telecommunications policy since the New Deal, was designed in essence to increase competition in the local exchange.[66] Regulators recognized that the fundamental economic characteristics of the wireline telecommunications industry—namely, network effects and economies of scale—in the absence of government intervention had incentivized and even rewarded anti-competitive behavior.[67] As a result, Congress granted new entrants expansive rights to interconnect their networks with those of the incumbents and to lease unbundled capacity on an incumbent's network, both at regulated rates.[68] The specific local competition provisions which enabled

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[61] *See Expanded Interconnection with local Telephone Company Facilities, Amendment of Part 69 Allocation of General Support Facility Cost*, Report, Order, and Notice of Proposed Rulemaking, 7 FCC Rcd. 7369 (1992); *Expanded Interconnection with Local Telephone Company Facilities, Amendment of Part 36 of the Commission's Rules and Establishment of a Joint Board*, Report, Order, and Notice of Proposed Rulemaking, 8 FCC Rcd. 7374 (1993).

[62] *Digital Crossroads* at 67.

[63] *Id.*

[64] *Id.* Note the similarity of CAPs in the mid-1990s to the current market position of CLECs, which have analogous prior experience in deploying and administering DSL services. As such, CLECs are similarly well-positioned to spur competition through shared access agreements with wireline BIAS providers.

[65] *Id.* at 68.

[66] *Id.* at 69.

[67] *Id.* at 75. Network effects exist where the value of a network (*e.g.*, a telephone system or a social media platform) increases with each additional user of the network. Economies of scale refer to reduced costs per unit that arise from increased total output of a product (*e.g.*, once a firm has built out a telephone system to a sufficient scale, the cost of providing service to each additional user will be substantially lower than for a firm which has a less-developed network or is a non-facilities-based competitor).

[68] *Id.*

these structural changes—interconnection, unbundled network elements, rate regulation, and resale—will be examined in turn.[69]

Interconnection. Designed specifically to mitigate network effects, Sections 251(c)(2) and 251(c)(6) allow new competitors to demand interconnection with the incumbent's network "at any technically feasible point," not just a location of the incumbent's choosing.[70] Moreover, these provisions grant new entrants the right to co-locate their own equipment at the incumbent's facilities.[71] As a practical matter, these provisions allowed "any competitor [to] rent space in an incumbent's central office; place its equipment there to interconnect with the incumbent's network; and purchase various related services, such as power and air conditioning, from the incumbent."[72] Moreover, Section 252(d)(1) allowed regulators to limit the rate a new competitor had to pay an incumbent for interconnection and housing the equipment.[73]

Unbundled Network Elements. In an effort to minimize the barrier to entry of economies of scale, Sections 251(c)(3) and 252(d)(1) granted new entrants a right to obtain "access to [the incumbent's] network elements on an unbundled basis;" that is, to lease capacity on the incumbent's network facilities at regulated cost-based rates.[74] "In this context, to say that network elements are available on 'an unbundled basis' is simply to say that the competitor may, if it wishes, lease them individually at separate rates or in combinations of its choosing."[75] While leasing is used as the shorthand for gaining access to UNEs, it is important to note this does not necessarily mean the competitor has access to the discrete physical facility. "Often, the competitor receives only *capacity* on such a facility, along with its 'features, functions, and capabilities.' For example, when a competitor leases 'dedicated transport' from an incumbent, it does not normally lease an entire fiber-optic strand; instead, it leases a fixed increment of capacity on that strand."[76]

Relatedly, Section 251(d)(2) directs the FCC to limit the network elements subject to unbundling under Section 251(c)(3) by "consider[ing], at a minimum, whether . . . the failure to provide access to such network elements would impair the ability of the telecommunications carrier seeking access to provide the services that it seeks to offer."[77] This is known as the impairment standard, which in practice tells the FCC to identify, at some level of generality, the elements that a competitor truly needs to compete.[78]

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[69] To minimize the use of acronyms, the following will refer to competitive local exchange carriers (CLECs) as new entrants or competitors and will refer to incumbent local exchange carriers (ILECs) as the incumbent.
[70] 45 U.S.C. § 251(c)(2).
[71] 45 U.S.C. § 251(c)(6).
[72] *Digital Crossroads* at 79.
[73] 45 U.S.C. § 251(d)(1).
[74] 45 U.S.C. § 251(c)(3); 45 U.S.C. § 252(d)(1).
[75] *Digital Crossroads* at 81.
[76] *Id.*
[77] 45 U.S.C. § 251(d)(2).
[78] *Digital Crossroads* at 81-82.

Rate Regulation. Pricing for UNEs is based on "total element long-run incremental cost," or TELRIC.[79] This pricing standard uses a forward-looking approach based on what it would cost a hypothetical "most-efficient" provider to build out today—not based on the network's design or what it actually cost the incumbent.[80] Although the FCC establishes the pricing methodology, specific disputes between incumbents and new competitors are resolved before individual state public utility commissions (PUCs).[81]

Despite an immediate legal challenge claiming the pricing scheme was unfair to incumbents,[82] interviews with members of the CLEC industry conducted during the course of preparing this paper reflect the opposite. In fact, although the cost to a hypothetical "most-efficient" provider should presumably decrease over time, one CLEC representative reported that an incumbent provider successfully petitioned the Oregon PUC to raise rates, attributing the price increase to the outsized legal and economic resources of the incumbents. Seven years after introducing TELRIC pricing, the FCC itself conceded its formulation was problematic; it expressed concern that "the excessively hypothetical nature of the TELRIC inquiry" had led to the creation of a "black box" from which a variety of rates could emerge.[83]

Resale. Another mechanism to mitigate economies of scale is contained in Section 251(c)(4), which permits a new entrant to sign up large numbers of local service customers by reselling an incumbent's "retail" services under its own brand name. In this manner, the new competitor can build brand recognition, develop a customer base, and then—when the economies of scale are great enough—serve its customers over facilities of its own. "To make resale a more plausible entry strategy, Congress entitled competitors to obtain, for resale, an incumbent's 'retail' services at retail rates *minus* the retail-specific costs (of marketing, billing, etc.) that the incumbent will 'avoid' by virtue of no longer providing retail service to the customers at issue."[84] Moreover, Section 252(d)(3) provides the framework for pricing these arrangements, referred to as "the avoided-cost discount."[85] As applied based on a 2000 Court of Appeals decision, however, the avoided-cost discount has proven insufficient to make resale viably generate competition.[86]

D. Implementation of Sharing Obligations (1996–2005)

Following the passage of the 1996 Act, there was significant debate around the respective roles of the FCC and state regulators in implementing the local competition

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[79] *Id.* at 83.

[80] *Id.*

[81] *Id* at 84.

[82] *See* Verizon Communications Inc. v. FCC, 535 U.S. 467 (2002).

[83] *Review of the Commission's Rules Regarding the Pricing of Unbundled Network Elements and the Resale of Service by Incumbent Local Exchange Carriers*, WC Docket No. 03-173, Notice of Proposed Rulemaking, 18 FCC Rcd. 20,265, ¶¶ 6-7 (2003).

[84] *Digital Crossroads* at 85.

[85] *Id.*

[86] *Id.*

provisions.[87] Ultimately, "the FCC establishes the basic rules governing the local competition matters, and state PUCs apply those rules in resolving specific carrier to carrier disputes."[88] The resolution of such disputes are governed by the procedural provisions of Section 252.[89]

Disputes between ILECs and CLECs typically stem from disagreement over interconnection agreements, which specify the key terms governing the shared access arrangement.[90] There are two possible paths these negotiations can follow. First, the two providers might resolve all relevant issues without regulatory intervention.[91] In that event, they file with the state PUC, which will approve the agreement so long as it does not harm third parties or otherwise threaten the public interest.[92]

Alternatively, the negotiations between the two parties will break down, either because "the parties disagree about what each side owes under the governing law or the other believes that it can achieve a more favorable outcome by taking the matter to litigation."[93] When this occurs, the state PUC arbitrates the disputed issues pursuant to the procedures articulated in Section 252 and the relevant provisions of the 1996 Act.[94] Either side may appeal the state PUC's order by filing in the relevant federal district court.[95]

Moreover, Section 252(i) requires a carrier to "make available any interconnection, service, or network element provided under an agreement approved under this section to which it is a party to any other requesting telecommunications carrier upon the same terms and conditions as those provided in the agreement."[96] Originally, the FCC interpreted this provision as allowing CLECs to pick-and-choose which provisions from incumbent's existing interconnection agreements were most advantageous to themselves.[97] Incumbents argued that this right of CLECs discouraged private negotiations as a meaningful alternative to arbitration.[98] As such, in 2004 the FCC eliminated the pick-and-choose rule in favor of an all-or-nothing rule, which requires a competitor "seeking to avail itself of terms in an interconnection agreement to adopt the agreement in its entirety," which the FCC believed would encourage better agreements through negotiation.[99]

III. The FCC Rejects Sharing Obligations for Wireline Broadband

Shortly after the implementation of sharing obligations in the local exchange, the FCC confronted a similar structural problem in the emerging wireline broadband industry. In

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[87] *Id.* at 86.
[88] *Id.*
[89] 45 U.S.C. § 252(i).
[90] *Digital Crossroads* at 86.
[91] *Id.*
[92] *Id.*
[93] *Id.* at 87.
[94] *Id.*
[95] *Id.*
[96] 45 U.S.C. § 252(i).
[97] *Digital Crossroads* at 87.
[98] *Id.*
[99] *Id.*

2005, the FCC was tasked with deciding whether the sharing obligations of the 1996 Act should carry forward and apply to wireline BIAS providers.[100] It recognized that the decision necessarily relied, in large part, on its "predictive judgment regarding a rapidly changing, dynamic industry," that did not have a single, clear-cut answer.[101]

However, the FCC's "predictive judgement" failed to recognize that the "dynamic" wireline broadband industry exhibited the same natural monopoly characteristics as the local exchange market of the past. As a result, federal regulators rejected sharing obligations for wireline BIAS providers, believing instead that competition would increase in a deregulated market and that a market-based incentive would lead to sharing in the absence of a mandate.[102] Moreover, the FCC concluded that any imposition of sharing requirements "would impede the development and deployment of innovative wireline broadband Internet access technologies and services."[103]

With the benefit of hindsight and an updated understanding of the future of broadband, it is evident that the FCC's concerns around sharing obligations in 2005 were overblown. In today's wireline market, the absence of sharing requirements—not their imposition—can function to impede deployment of advanced broadband technologies.[104] CLECs rely on legacy unbundling obligations from the 1996 Act to lease capacity on existing facilities to offer DSL service and then use this revenue to fund fiber deployment.[105] This creates competitive pressure for other providers to offer competing advanced services, resulting in increased fiber deployment and improved choices for consumers.[106]

Without similar sharing requirements for wireline BIAS providers, incumbent providers will reap the rewards their natural monopoly position affords with no incentive to improve networks beyond their current capacity, all while economies of scale prevent competitors from deploying a competing facilities-based network. The following will explore the legal and regulatory history leading up to the *2005 Wireline Broadband Order* and contextualize the FCC's justifications in light of modern telecommunications markets and the current state of fiber deployment.

A. Legal and Regulatory History (1966–2005)

From the late 1960s onward, as both telephone and cable providers began offering data services—each providing the same connection to the internet but operating under distinct regulatory regimes—the FCC was faced with the difficult task of delineating and governing the rapidly evolving landscape of internet network technology. The challenge of this undertaking is perhaps best evidenced by the length and complexity of the regulatory

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[100] *Appropriate Framework for Broadband Access to the Internet over Wireline Facilities,* CC Docket No. 02-33, Report and Order, 20 FCC Rcd. 14853, ¶ 41 (2005) (hereinafter "*2005 Wireline Broadband Order*").

[101] *Id.* at ¶ 78.

[102] *Id.* at ¶ 64.

[103] *Id.* at ¶ 65.

[104] *See* EFF Comments at 3.

[105] *See* infra Part I.A.

[106] *Id.*

history; the FCC wrestled with industry groups and consumer advocates over classifications for nearly 40 years in a series of proceedings known as the *Computer Inquiries*.[107]

This culminated in early 2002, as telephone and cable providers began pressuring the FCC in an attempt to insulate themselves from sharing obligations and other provisions of the 1996 Act. Specifically, they sought to ensure that wireline BIAS was classified as an "information service," rather than a "telecommunications service," so that providers would fall under a more lenient regulatory regime without common carriage obligations.[108]

The FCC originally agreed, but a coalition of small providers—composed largely of CLECs—brought suit, arguing instead that the sharing requirements were necessary for the competitive health of local BIAS markets. The well-known case, titled *NCTA v. Brand X*, ultimately rose to the Supreme Court. Writing for a 6-3 majority, Justice Thomas held that the definitions of "information service" and "telecommunications service" within the 1996 Act were ambiguous and that the Court should defer to the judgement of the FCC regarding the interpretation of the terms.[109] Consequently, the FCC issued the *2005 Wireline Broadband Order* to articulate definitively—at least until a change in administration—that the classification for wireline BIAS was as an "information service."[110]

Another explanation for the FCC's deregulatory decision was the extent to which the telecommunications industry held the deployment of fiber networks over the heads of federal regulators to pressure for deregulation.[111] For instance, in June 2004, Ed Whitacre, the chairman of Southwestern Bell Company, the predecessor to today's AT&T, told the *Los Angeles Times* that his company planned to invest $6 billion in fiber-related upgrades once the regulatory environment became "more rational."[112] Professor Susan Crawford describes this as one of many "Lucy-with-the-football" moments of telecommunications history.[113] Though the political stunt resulted in the industry's desired rollback, it never resulted in the consumers' desired deployment of fiber.[114]

B. The FCC's Misguided Rationale (2005)

In classifying wireline BIAS as an "information service," the FCC based its decision on its mandate to encourage "the deployment on a reasonable and timely basis of advanced telecommunications capability to all Americans."[115] It weighed the competitive benefits of sharing obligations against the infrastructure investment harms pursuant to this obligation

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[107] *2005 Wireline Broadband Order* at ¶ 21.

[108] *Inquiry Concerning High-Speed Access to the Internet Over Cable and Other Facilities*, GN Docket No. 00-185, Declaratory Ruling and Notice of Proposed Rulemaking, 17 FCC Rcd. 4798, ¶ 42-47 (2002).

[109] *See* National Cable & Telecommunications Ass'n v. Brand X Internet Services, 545 U.S. 967 (2005).

[110] *2005 Wireline Broadband Order* at ¶ 8-9. Note also that "[w]ireline broadband Internet access service, for purposes of this proceeding, is a service that uses existing or future wireline facilities of the telephone network to provide subscribers with Internet access capabilities."

[111] *Fiber* at 51.

[112] *Id.*

[113] *Id.*

[114] *Id.*

[115] *2005 Wireline Broadband Order* at ¶ 3, n.8; 47 U.S.C. § 706.

and decided deregulation would be the best means to accomplish this end.[116] However, the FCC's assessment of the broadband market fell short in a number of key ways—namely, through erroneous predictions about the development of market incentives, inter- and intramodal competition, infrastructure investment, and market penetration. The following will evaluate these shortcomings in turn.

Market Incentives for Sharing. One justification for the FCC's deregulatory classification was that incumbent wireline BIAS providers would have market-based incentives to share in the absence of a mandate.[117] The rationale was primarily economic: "[t]he record makes clear that [cable operators] have a business interest in maximizing the traffic on their networks, as this enables them to spread fixed costs over a greater number of revenue-generating customers."[118]

Though this claim reads as economically plausible, the FCC could only identify two unsatisfying pieces of evidence to show this actually happened in practice: a statement from Comcast's 10-K Annual Report that "a number of cable operators" had engaged in wholesale agreements and the behavior of Time Warner following a consent decree with the Federal Trade Commission (FTC).[119] The former needs more corroboration, as it alone is insufficient to support the FCC's claim of widespread wholesale access in the absence of a mandate. The latter should be disregarded entirely, as it is the result of a legally-enforceable consent decree, not market forces. Perhaps the struggle to produce evidence is itself strong evidence that market forces will not lead incumbents to open up their networks to competitors in the absence of a legal requirement.

In its market analysis, the FCC acknowledged the difficulty of making a "meaningful assessment of the market for wholesale access to the transmission component of broadband Internet access service."[120] This assessment was particularly difficult because facilities-based wireline providers were at the time the only BIAS provider compelled by regulation to have a wholesale offering.[121] Moreover, the FCC even acknowledged that "in many areas, the incumbent LEC is currently the only wholesale provider of this transmission component," but nevertheless did not view this as dispositive on the issue of market competition in wholesale transmission.[122] The FCC never went so far as to affirmatively state that incumbents would necessarily share in the absence of a mandate, but instead chose the inverse: the FCC could not "state unequivocally that incumbent LECs would not otherwise provide wholesale access, absent this compulsion."[123]

This assurance did not assuage the concerns of CLECs, whose entire industry hinged on the FCC's weak contention that incumbents would not unequivocally not offer a

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[116] *2005 Wireline Broadband Order* at ¶ 43.
[117] *Id.* at ¶ 64.
[118] *Id.*
[119] *Id.* at ¶ 64, n.186.
[120] *Id.* at ¶ 63.
[121] *Id.*
[122] *Id.*
[123] *Id.*

wholesale transmission component.[124] In fact, many commenters urged the FCC to expand its market analysis to look not just at the availability of broadband for consumers, but also to consider the wholesale access market, which they viewed as imminently weakening or disappearing entirely in the wake of this classification.[125] Despite conceding in the same section that only one wholesale provider exists in many areas, the FCC cited "[v]igorous competition between different platform providers [which] already exists in many areas and is spreading to additional areas" as sufficient to provide consumers with the benefits of meaningful choice.[126] A quick examination of the market for wholesale broadband access today reveals that the FCC's predictions did not come to fruition; only a limited number of government-owned municipal networks have allowed for wholesale access.[127]

Moreover, almost in passing, the FCC brushed aside concerns that absent a sharing requirement, incumbents would charge monopoly prices in areas without another facilities-based competitor. Relying on the testimony of the incumbents, the FCC concluded that "service providers tend to set prices on a national or regional basis regardless of whether there are multiple broadband providers serving local markets."[128] However, such a claim cannot be meaningfully verified because the FCC refuses to publicize the Form 477 pricing data it collects from providers.[129]

Increased Intra- and Intermodal Competition. Another underlying premise of the FCC's deregulatory decision was a prediction that both intra- and intermodal competition in the provision of broadband services would proliferate.[130] The FCC hypothesized that competition in the broadband market—then definitively led by DSL and cable modem providers, which were both rapidly expanding—would boom as innovative technologies emerged and consumer demand for broadband continued to swell.[131] It pointed to "other existing and developing platforms, such as satellite and wireless, and even broadband over power line in certain locations" as indicative that BIAS would not be in a perpetual state of head-to-head competition between DSL and cable modem providers. Moreover, the FCC suggested that the "competitive pressure" from "other forms of broadband Internet access, whether satellite, fixed or mobile wireless, or a yet-to-be-realized alternative, will further stimulate deployment of broadband infrastructure, including more advanced infrastructure such as fiber-to-the-home."[132]

However, the FCC's prediction about the development of competition in the broadband market failed to anticipate the dominant position cable providers would occupy absent sharing requirements—particularly in the market for speeds above 100 Mbps. In fact,

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[124] *Id.* at ¶ 62.

[125] *Id.*

[126] *Id.*

[127] *Municipal FTTH Networks*, Institute for Local Self-Reliance, Community Networks (Mar. 19, 2019), https://muninetworks.org/content/municipal-ftth-networks.

[128] *Id.*

[129] *See* supra Part I.B.

[130] *2005 Wireline Broadband Order* at ¶ 50.

[131] *Id.*

[132] *Id.* at ¶ 57-58.

94 percent of all broadband subscriptions exceeding 100 Mbps are provided by local cable monopolies.[133] Moreover, "if you are one of the 100 million Americans living in the most densely populated 37,000 square miles in the continental United States, it is very likely your only choice for internet access over 25 Mbps is your local cable monopoly."[134]

Infrastructure Investment. A frequent refrain of the telecommunications industry—one that the FCC found highly persuasive in the *2005 Wireline Broadband Order*—is that any modicum of regulation or oversight will cause infrastructure investment to come to a grinding halt. Specifically, the FCC noted that sharing obligations "can have a significant impact on the ability of wireline platform providers to develop and deploy innovative broadband capabilities that respond to market demands."[135] Industry commenters made clear in the proceeding—as well as in messaging and public statements—that the additional costs of a sharing obligation diminished their incentive and ability to invest in and deploy new broadband infrastructure.[136]

Limited Market Penetration. Lastly, the FCC suggested that the wireline BIAS market was not ripe for regulation in its decision to deregulate.[137] While noting the recent growth in both cable modem and DSL markets, the FCC placed substantial weight on the fact that market penetration for the technologies was still far below the size of the potential market.[138] "The 20 percent cumulative penetration rate for broadband services stands in marked contrast to other, more mature markets the FCC has examined and regulated to varying degrees."[139]

To any observer of telecommunications history, the claim that the FCC should wait until the market is sufficiently "mature" should be striking. The history of telecommunications competition has been a series of post hoc fixes to incumbents exploiting their natural monopoly position at the expense of consumers. Waiting to impose sharing obligations will only let these monopolists further cement their market dominance, while providing no competitive impetus to lower prices or drive technological innovation.

Examining the broadband market today makes the fallacy of this argument even more apparent. The level of penetration has reached a point that now major cable providers like Comcast and Spectrum, dividing the geographic and service markets amongst one another, achieve growth primarily by raising prices for existing customers as opposed to serving new ones.[140] Regulators should not have—and should not now—stand idly by as last-mile monopolists continually hike up prices for the same legacy service.

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[133] *Fiber* at 38.
[134] *Id.* at 53.
[135] *2005 Wireline Broadband Order* at ¶ 44.
[136] *Id.*; *Fiber* at 53.
[137] *2005 Wireline Broadband Order* at ¶ 55.
[138] *Id.*
[139] *Id.*
[140] *Fiber* at 54.