Bringing Everyone Up to Speed

Analysis of Costs to Upgrade and Maintain
WAN and Internet Access Connections for all K-12 Public Schools

Presented by

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Introduction

Since 1998, the Federal Communications Commission's E-rate program has helped schools and libraries acquire telecommunications services and basic Internet connectivity. However, as new technologies offering powerful digital learning opportunities are made available to students, teachers and library patrons, schools and libraries require much higher speed, more ubiquitous and more robust connectivity. Basic connectivity is simply insufficient to support the technologies needed to prepare America's students for postsecondary success.

In its July E-rate Modernization Order,[1] the Commission recognized the need to upgrade the broadband infrastructure in America's schools and libraries and established clear connectivity targets that, if met, will allow every teacher and student to take advantage of the promise of digital learning. Specifically, the Commission established the following long-term connectivity targets for K-12 schools[2]

- Internet access connectivity of 1 Gbps per 1,000 students and staff in schools;
- WAN connectivity capable of scaling to 10 Gbps per school

Meeting these goals requires the Commission to take additional steps to modernize the E-rate program. As Chairman Wheeler outlined in his remarks at the LEAD Commission Ed Tech Summit on September 29, 2014, "we must still address the challenge of improving the broadband infrastructure *to* the building for many schools and libraries, particularly in rural America."[3] This, he noted, will involve both ensuring that every school has access to the broadband infrastructure it needs by closing the rural fiber gap, and dramatically improving the affordability of broadband by delivering on the Commission's "statutory responsibility to assure that the E-RATE is the lowest rate"[4]

In the E-rate 2.0 Order, the Commission included a Further Notice of Proposed Rulemaking ("FNPRM") asking for comment on the level of E-rate resources required to ensure that all schools and libraries could meet the Commission's connectivity targets. The attached model provides a tool for estimating the cost of upgrading K-12 public schools to the Commission's Internet access and WAN connectivity targets by 2018 in the context of various policy decisions the Commission might make.

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[1] Modernizing the E-rate Program for Schools and Libraries, FCC 14-99, WC Docket No. 13-184, Report and Order and Further Notice of Proposed Rulemaking, Order Released July 23, 2014. This Order is hereinafter referred to as "E-rate 2.0 Order."

[2] The analysis contained in this document focuses on America's K-12 schools. It is EducationSuperHighway's understanding that a similar analysis is being conducted by other parties to assess what will be required to meet the connectivity targets established for libraries.

[3] Remarks of FCC Chairman Tom Wheeler, Second Ed Tech Summit: Empowering Educators to Enhance Student Learning in the Digital Era, September 29, 2014.

[4] Ibid, p.4

Approach and Methodology

To estimate the cost of upgrading K-12 public schools to the connectivity targets established by the Commission in the E-rate 2.0 Order, the ESH / CoSN Connectivity Cost Model analyzes four key factors:

1. The annual operating expense incurred by K-12 schools to purchase the Internet access and Wide Area Network (WAN) connectivity they need based on their student and teacher population;
2. The cost of providing access to the physical infrastructure required to enable all schools to purchase the Internet access and WAN connectivity required to meet the Commission's connectivity targets;[5]
3. The $1 billion Category 2 subsidy target established by the Commission in the E-rate 2.0 Order[6]; and
4. The cost savings expected from the phase out of the program's subsidies for legacy services over the next four years.

A detailed description of the methodology used to estimate each of these factors can be found as an Appendix to this document. As with our LAN / Wi-Fi Model, the assumptions in the model were vetted with a significant number of E-rate stakeholders including school districts, telecommunications service providers and networking experts.

Closing the Fiber Access Gap

In *Connecting America's Students: Opportunities for Action*, EducationSuperHighway demonstrated that 98% of America's K-12 public schools will require a fiber connection in order to meet the connectivity targets that have since been adopted by the Commission.[7] This analysis has been supported by comments in the E-rate Modernization Proceeding from a wide range of school districts, state departments of education, research & education networks, service providers, education technology associations and industry experts.

According to the Commission's own analysis, however, only 65% of schools currently have access to a fiber connection.[8] Closing this fiber access gap within the current framework of the E-rate program will require the Commission to take aggressive action to both increase funding and modify rules which limit the flexibility and options schools have to leveraging E-rate to obtain the fiber connectivity they need.

The funding required to close the fiber access gap is a function of the number and geographic location of schools requiring fiber access as well as the approach to funding the construction of these fiber

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[5] As many commenters have noted in the E-rate proceeding, only fiber is sufficiently scalable to meet the connectivity needs of the vast majority of America's K-12 schools. EducationSuperHighway estimates that 98% of schools (all those with greater than 100 students) will require a fiber connection to meet the Commission's connectivity targets.

[6] The ESH / CoSN Connectivity Cost Model assumes that the Commission will extend its $1 billion per year Category 2 funding target and $150 per student budgets beyond the initial two year period. If these are not extended, there is a significant likelihood that many schools will end up meeting the Commission's Internet access and WAN connectivity targets but will lack the LAN / Wi-Fi networks required to extend that connectivity to the classroom and student device.

[7] *See* EducationSuperHighway, *Connecting America's Students: Opportunities for Action* (April 2014), *available at* http://www.educationsuperhighway.org/uploads/1/0/9/4/10946543/esh_k12_e-rate_spending_report_april_2014.pdf ("*Connecting America's Students*").

[8] *See* Wireline Competition Bureau & Office of Strategic Planning & Policy Staff Report, WC Docket 13-184, August 12, 2014 at 11-12

connections. The ESH / CoSN Connectivity Cost Model analyzes five scenarios that incorporate these factors in order to highlight the impact of critical policy choices that the Commission must make. Specifically, the scenarios estimate the cost of connecting increasingly rural groups of schools and the impact of paying for the cost of fiber construction through up-front non-recurring charges or as part of the monthly operating cost charged by service providers. A description of each scenario can be found in the appendix.

Unfortunately, simply addressing the funding issues related to fiber construction will not result in all schools having access to the fiber connectivity they need to meet the E-rate 2.0 Order's connectivity targets. Achieving this goal will also require the Commission to modify program rules that limit the options schools have to obtain access to fiber.[9] These rules include:

- The requirement that school districts fund the unsubsidized non-recurring costs associated with any new fiber construction in the first year of the contract;
- The foreclosure of newly constructed leased dark fiber, dark fiber IRUs and managed dark fiber services as viable solutions due to the unequal treatment of lit and dark fiber by the program; and
- The inability of school districts to self-provision fiber connections when no affordable commercial option is available.

Lowering the Cost of Broadband

The cost of upgrading America's K-12 schools to the Commission's connectivity targets will also be impacted by policies the Commission adopts to lower the cost of broadband. Specifically, EducationSuperHighway believes the following policy actions have the potential to lower the cost of broadband by 15-30%:

1. Increasing price transparency;
2. Increasing the formation of regional consortia by small- and medium-sized school districts;
3. Increasing the use of statewide consortia; and
4. Increasing the use of dark fiber.

An analysis of the impact of these policy options on the cost to upgrade America's K-12 public schools will be submitted to the Commission in the coming weeks.

Analysis and Conclusions

While the actual cost of upgrading America's K-12 public schools to the Commission's connectivity targets cannot be determined in the absence of specific policy decisions the Commission will make with regards to the number of schools it wants to connect to high speed broadband and the cost savings measures it will adopt to lower the ongoing cost of connectivity, several conclusions can be drawn from the ESH / CoSN E-rate Connectivity Cost Model.

1. **The funding required for the E-rate program is highly correlated with closing the fiber access gap.** If the Commission chooses not to provide schools with the resources required to close the fiber access gap nor modify the E-rate rules that inhibit schools from obtaining access to fiber, significantly fewer resources will be required for both fiber construction and recurring Internet access and WAN operating cost subsidies as many schools without fiber are left behind.

[9] See WC Docket 13-184 Reply Comments of EducationSuperHighway at 6-10 (September 30, 2014)

Specifically, the ESH / CoSN Connectivity Cost Model suggests that only a small increase in the fund is required to enable those with fiber to meet the Commission's connectivity targets.

2. **The funding required for the E-rate program will be driven by how much of the rural fiber access gap the Commission decides to address**. The ESH / CoSN Connectivity Cost Model suggests that the cost to connect the 94% of students in metros, suburbs and towns to fiber is only 25% of the cost to connect all students. Similarly, the cost to connect 97% of students (adding in all but remote rural schools) is less than half the cost to connect all students. Significantly, the Commission will need to decide if connecting the most remote 400 schools to fiber is good policy as these schools will cost, on average, over $2.5 million per school.[10]

3. **Closing the fiber access gap within the existing E-rate program requires the modification of rules that limit the options schools have to obtain access to fiber.** As seen in CoSN's Second Annual E-rate Survey, the inability to pay for capital, or up-front non-recurring expense is the second biggest barrier to increasing robust Internet connectivity in school districts.[11] Similarly, the CoSN survey shows that 32% of districts have no choice when procuring broadband infrastructure.[12] As a result, increasing the resources available in the E-rate program without also modifying rules that (i) dramatically reduce the need for districts to fund up-front, non-recurring costs and (ii) make dark fiber and self-provisioning options available to schools, will limit the impact of the Commission's efforts to close the fiber access gap.

4. **The sustainability of the E-rate program will depend on the Commission taking aggressive action to lower the cost of broadband.** Our research with school districts, broadband service providers and R&E Networks demonstrates that K-12 bandwidth demand is growing 50%+ per year, with the highest growth rates occurring in districts that have deployed 1:1 device programs, Bring Your Own Device strategies and robust Wi-Fi networks. This significantly outpaces the natural rate of price deflation in the broadband market. As a result, if the Commission does not utilize policy measures to dramatically lower the cost of broadband, the E-rate program's resources will quickly become insufficient to meet the growing Internet access and WAN connectivity needs of schools.

5. **Subsidizing up-front non-recurring construction charges is significantly more cost effective for the E-rate program than paying for fiber construction charges through monthly operating costs.** Four factors increase the cost effectiveness of subsidizing fiber construction through up-front non-recurring costs. First, this approach creates transparency with regards to the cost of construction. This allows construction costs to be benchmarked against similar projects and enables enforcement of the E-rate's lowest corresponding price rules. Second, eliminating the need for service providers to finance the cost of fiber construction for a multi-year period reduces the E-rate program's cost by eliminating the service provider's need to charge for their cost of capital. Third, paying for construction costs up-front eliminates the all too common situation of service providers continuing to charge for capital cost recovery well beyond the time required to actually recover their investment. Finally, subsidizing up-front construction costs lowers both the up-front

[10] These schools may be more cost effectively served by other technologies such as fixed wireless (e.g. microwave), but the cost will still be substantial.

[11] CoSN's Second Annual E-rate and Infrastructure Survey In Partnership with AASA (the School Superintendents Association) and MDR at 4. http://cosn.org/cosns-second-annual-e-rate-and-infrastructure-survey

[12] Ibid p. 6. 6% of school districts received no responses to their E-rate RFP and 26% of school districts received only one response.

and ongoing cost to the program by increasing competition in terms of both the service options available to schools and the number of viable bidders.

6. **While the ESH / CoSN Connectivity Cost Model is not an analysis of the changes required in the E-rate cap, it does suggest that the program should see long-term cost savings once the fiber access gap has been closed.** Specifically, the model suggests that the on-going cost to provide the Internet access and WAN connectivity for K-12 public schools once the fiber access gap has been closed will be less than annual funding required over the next five years regardless of whether the Commission adopts policy measures to reduce costs through increased transparency, greater consortia purchasing and the use of dark fiber.

The ESH / CoSN Connectivity Cost Model makes clear that the Commission's efforts to support America's schools and libraries in reaching the connectivity targets established in the E-rate 2.0 Order cannot be achieved solely through efficiency gains or by increasing the funding in the E-rate program.

While infusing new investment into the E-rate fund is clearly required, the Commission must also simultaneously adopt pragmatic policy changes which modify rules that currently limit options for schools, prevent robust service provider competition and force schools to fund fiber construction through monthly operating costs, or many schools will be left behind, unable to meet the Commission's connectivity targets to access the broadband they need.

Similarly, if the Commission does not take action to dramatically lower the cost of broadband, the natural growth in demand for broadband will put the program on an unsustainable trajectory as bandwidth costs quickly outstrip the funding available in the program, even if the E-rate cap is increased. If the Commission is to meet its bandwidth targets and ensure the sustainability of the program for the next school year and the next generation, it is imperative that the Commission take action across all these dimensions as it implements its next E-rate modernization order.

Model Summary

	FY2014	FY2015	FY2016	FY2017	FY2018	
Total Costs						
Category 1 - Scenario 1 (No Non-Recurring Cost Subsidies for Fiber Construction)	**$1,927,230,875**	**$2,124,205,174**	**$2,321,179,472**	**$2,518,153,771**	**$2,715,128,070**	
- Internet Access	$716,736,949	$853,536,390	$990,335,831	$1,127,135,272	$1,263,934,712	
- District WAN	$1,075,105,424	$1,099,706,383	$1,124,307,342	$1,148,908,301	$1,173,509,260	
- Copper-Based Services	$135,388,502	$104,225,591	$73,062,681	$41,899,770	$10,736,860	
- Allowance for new builds paid through OpEx		$66,736,809	$133,473,619	$200,210,428	$266,947,238	
- Non-Recurring Cost Subsidies for Fiber Construction	**$0**	**$0**	**$0**	**$0**	**$0**	$0
Category 1 - Scenario 2 (Urban, Suburban, Town)	**$1,927,230,875**	**$2,141,505,864**	**$2,355,780,853**	**$2,570,055,842**	**$2,784,330,831**	
- Internet Access	$716,736,949	$878,807,850	$1,040,878,751	$1,202,949,652	$1,365,020,553	
- District WAN	$1,075,105,424	$1,124,232,117	$1,173,358,811	$1,222,485,505	$1,271,612,198	
- Copper-Based Services	$135,388,502	$103,174,106	$70,959,711	$38,745,315	$6,530,920	
- Allowance for new builds paid through OpEx		$35,291,790	$70,583,580	$105,875,370	$141,167,159	
- Non-Recurring Cost Subsidies for Fiber Construction	**$0**	**$275,277,183**	**$275,277,183**	**$275,277,183**	**$275,277,183**	$1,101,108,731
Category 1 - Scenario 3 (Urban, Suburban, Town, Rural Distant)	**$1,927,230,875**	**$2,153,636,681**	**$2,380,042,486**	**$2,606,448,292**	**$2,832,854,097**	
- Internet Access	$716,736,949	$894,473,329	$1,072,209,709	$1,249,946,089	$1,427,682,469	
- District WAN	$1,075,105,424	$1,135,887,569	$1,196,669,714	$1,257,451,859	$1,318,234,004	
- Copper-Based Services	$135,388,502	$102,335,026	$69,281,550	$36,228,074	$3,174,598	
- Allowance for new builds paid through OpEx		$20,940,757	$41,881,513	$62,822,270	$83,763,026	
- Non-Recurring Cost Subsidies for Fiber Construction	**$0**	**$489,110,513**	**$489,110,513**	**$489,110,513**	**$489,110,513**	$1,956,442,051
Category 1 - Scenario 4 (Urban, Suburban, Town, Rural Distant, 80% Rural Remote)	**$1,927,230,875**	**$2,160,550,048**	**$2,393,869,220**	**$2,627,188,393**	**$2,860,507,566**	
- Internet Access	$716,736,949	$904,548,149	$1,092,359,349	$1,280,170,549	$1,467,981,749	
- District WAN	$1,075,105,424	$1,143,737,150	$1,212,368,877	$1,281,000,604	$1,349,632,330	
- Copper-Based Services	$135,388,502	$101,760,485	$68,132,468	$34,504,451	$876,434	
- Allowance for new builds paid through OpEx		$10,504,263	$21,008,526	$31,512,789	$42,017,052	
- Non-Recurring Cost Subsidies for Fiber Construction	**$0**	**$750,022,851**	**$750,022,851**	**$750,022,851**	**$750,022,851**	$3,000,091,406
Category 1 - Scenario 5 (All Locales)	**$1,927,230,875**	**$2,154,683,991**	**$2,382,137,108**	**$2,609,590,224**	**$2,837,043,340**	
- Internet Access	$716,736,949	$908,284,095	$1,099,831,242	$1,291,378,388	$1,482,925,534	
- District WAN	$1,075,105,424	$1,144,858,519	$1,214,611,615	$1,284,364,710	$1,354,117,806	
- Copper-Based Services	$135,388,502	$101,541,377	$67,694,251	$33,847,126	$0	
- Allowance for new builds paid through OpEx		$0	$0	$0	$0	
- Non-Recurring Cost Subsidies for Fiber Construction	**$0**	**$1,012,629,426**	**$1,012,629,426**	**$1,012,629,426**	**$1,012,629,426**	$4,050,517,704
Legacy Services Phase-Out	**$1,578,056,731**	**$1,262,445,385**	**$946,834,038**	**$631,222,692**	**$315,611,346**	(voice, etc.)
Category 2	**$1,428,571,429**	**$1,428,571,429**	**$1,428,571,429**	**$1,428,571,429**	**$1,428,571,429**	($1B E-rate budget)
E-rate Discount (OpEx)	**70%**					
E-rate Discount (Non-Recurring Cost Subsidies for Fiber Construction)	**90%**					

E-rate Costs

	2014	2015	2016	2017	2018	% of students	% schools
E-rate Total - Scenario 1 (No Non-Recurring Cost Subsidies for Fiber Construction)	$ 3,453,701,324	$ 3,370,655,391	$ 3,287,609,458	$ 3,204,563,524	$ 3,121,517,591	89.8%	86.8%
E-rate Total - Scenario 2 (Urban, Suburban, Town)	$ 3,453,701,324	$ 3,630,515,339	$ 3,559,579,889	$ 3,488,644,439	$ 3,417,708,989	97.2%	94.0%
E-rate Total - Scenario 3 (Urban, Suburban, Town, Rural Distant)	$ 3,453,701,324	$ 3,831,456,907	$ 3,769,013,029	$ 3,706,569,150	$ 3,644,125,272	99.2%	97.4%
E-Rate Total - Scenario 4 (Urban, Suburban, Town, Rural Distant, 80% Rural Remote)	$ 3,453,701,324	$ 4,071,117,369	$ 4,013,512,848	$ 3,955,908,326	$ 3,898,303,805	99.9%	99.7%
E-rate Total - Scenario 5 (All Locales)	$ 3,453,701,324	$ 4,303,357,046	$ 4,241,646,286	$ 4,179,935,525	$ 4,118,224,764	100.0%	100.0%

2018 Bandwidth Needs

		Tiny (1 school)	Small (2-5 schools)	Medium (6-15 schools)	Large (16-50 schools)	Mega (51+ schools)	Total
Base Info (NCES 2011-2012)	# of Districts	4,390	7,607	3,023	861	202	16,083
	# of Schools	4,390	23,969	26,103	22,510	22,818	99,790
	# of Users	1,429,901	8,660,711	13,558,871	14,310,943	14,662,319	52,622,745
	# of Students	1,344,743	8,111,171	12,780,794	13,522,940	13,836,603	49,596,251
	# of Teachers	85,158	549,540	778,077	788,003	825,716	3,026,494
	% of Districts	27.3%	47.3%	18.8%	5.4%	1.3%	100%
	% of Schools	4.4%	24.0%	26.2%	22.6%	22.9%	100%
	% of Users	2.7%	16.5%	25.8%	27.2%	27.9%	100%
	Avg. Users/District	326	1,139	4,485	16,621	72,586	3,272
	Schools < 100 Students	150	474	2,164	2,654	2,956	8,398
	Schools > 1000 Students	1,024	3,219	2,549	1,541	1,295	9,628
Target	2018 Bandwidth per Student (Mbps)	1	1	1	1	1	1
	2018 Minimum per School (Mbps)	100	100	100	100	100	100
Need	IA Concurrency Ratio	1.0	1.0	2.0	3.0	4.0	1.33
	WAN Aggregation Concurrency Ratio	1.0	1.0	1.5	2.0	2.5	1.17
	Total Bandwidth (Gbps)	1,430	8,661	6,779	4,770	3,666	25,306
	IA Bandwidth per District (Mbps)	326	1,139	2,243	5,540	18,146	1,573
	Implied 2014 IA Bandwidth @50% CAGR	64	224	441	1,090	3,570	310
	IA Bandwidth per School (Mbps)	326	361	260	212	161	322
Bandwidth Mix (%) - Internet Access	% 100Mbps	18%	10%	0%	0%	0%	10%
	% 1Gbps	80%	80%	75%	30%	0%	75%
	% 10Gbps	2%	10%	24%	55%	35%	13%
	% 20Gbps	0%	0%	1%	13%	50%	2%
	% 100Gbps	0%	0%	0%	2%	15%	0%
Bandwidth Mix (%) - District Aggregation WAN	% 1Gbps	0%	10%	0%	0%	0%	5%
	% 10Gbps	0%	55%	80%	20%	0%	42%
	% 20Gbps	0%	10%	15%	70%	40%	12%
	% 100Gbps	0%	0%	0%	10%	60%	1%
	% No Separate Connection	100%	25%	5%	0%	0%	40%
Bandwidth Mix (%) - School WANs	% 100Mbps	0%	20%	20%	20%	20%	19%
	% 1Gbps	0%	40%	55%	60%	60%	51%
	% 10Gbps	0%	15%	20%	20%	20%	18%
	% VPN	0%	25%	5%	0%	0%	7%
	% No WAN	100%	0%	0%	0%	0%	4%
Internet Access - Scenario 1 (No Non-Recurring Cost Subsidies for Fiber Construction)							
% on Fiber	% on high-speed services	84%	79%	91%	87%	94%	87%
	% on copper-based services	16%	21%	9%	13%	6%	13%
Bandwidth Mix (#)	# 100Mbps	661	4,152	1,002	0	0	5,815
	# 1Gbps	2,938	4,819	2,070	225	0	10,052
	# 10Gbps	73	602	662	412	67	1,817
	# 20Gbps	0	0	28	97	95	220
	# 100Gbps	0	0	0	15	29	44
	Total	3,673	9,573	3,762	750	190	17,947
Additional IA connections (for VPN)			3,549	1,002			4,552
# on copper							2,687
Internet Access - Scenario 2 (Urban, Suburban, Town)							
% on Fiber	% on high-speed services	90%	86%	99%	96%	100%	94%
	% on copper-based services	10%	14%	1%	4%	0%	6%
Bandwidth Mix	# 100Mbps	708	4,495	1,085	0	0	6,288
	# 1Gbps	3,145	5,207	2,237	247	0	10,836
	# 10Gbps	79	651	716	453	71	1,969

(#)	# 20Gbps	0	0	30	107	101	238
	# 100Gbps	0	0	0	16	30	47
	Total	3,931	10,353	4,067	824	202	19,378
Additional IA connections (for VPN)			3,844	1,085			4,929
# on copper							1,635
Internet Access - Scenario 3 (Urban, Suburban, Town, Rural Distant)							
% on Fiber	% on high-speed services	95%	93%	100%	99%	100%	97%
	% on copper-based services	5%	7%	0%	1%	0%	3%
Bandwidth Mix (#)	# 100Mbps	747	4,691	1,124	0	0	6,562
	# 1Gbps	3,320	5,659	2,261	255	0	11,494
	# 10Gbps	83	707	724	467	71	2,051
	# 20Gbps	0	0	30	110	101	241
	# 100Gbps	0	0	0	17	30	47
	Total	4,150	11,057	4,139	849	202	20,396
Additional IA connections (for VPN)			3,983	1,124			5,107
# on copper							795
Internet Access - Scenario 4 (Urban, Suburban, Town, Rural Distant, 80% Rural Remote)							
% on Fiber	% on high-speed services	98%	98%	100%	100%	100%	99%
	% on copper-based services	2%	2%	0%	0%	0%	1%
Bandwidth Mix (#)	# 100Mbps	778	4,823	1,150	0	0	6,752
	# 1Gbps	3,459	5,968	2,266	257	0	11,949
	# 10Gbps	86	746	725	472	71	2,100
	# 20Gbps	0	0	30	111	101	243
	# 100Gbps	0	0	0	17	30	47
	Total	4,324	11,537	4,171	858	202	21,091
Additional IA connections (for VPN)			4,077	1,150			5,227
# on copper							219
Internet Access - Scenario 5 (100% - All Locales)							
% on Fiber	% on high-speed services	100%	100%	100%	100%	100%	100%
	% on copper-based services	0%	0%	0%	0%	0%	0%
Bandwidth Mix (#)	# 100Mbps	790	4,851	1,154	0	0	6,795
	# 1Gbps	3,512	6,086	2,267	258	0	12,123
	# 10Gbps	88	761	726	474	71	2,118
	# 20Gbps	0	0	30	112	101	243
	# 100Gbps	0	0	0	17	30	48
	Total	4,390	11,698	4,177	861	202	21,328
Additional IA connections (for VPN)			4,091	1,154			5,245
# on copper							0
District WAN - Scenario 1 (No Non-Recurring Cost Subsidies for Fiber Construction)							
% on Fiber	% on high-speed services	85%	87%	87%	87%	87%	87%
	% on copper-based services	15%	13%	13%	13%	13%	13%
School WAN Bandwidth Mix (#)	# 100Mbps	0	4,160	4,533	3,911	3,973	16,577
	# 1Gbps	0	8,319	12,467	11,733	11,918	44,438
	# 10Gbps	0	3,120	4,533	3,911	3,973	15,537
	# VPN	0	5,200	1,133	0	0	6,333
	Total	0	20,799	22,667	19,556	19,864	82,885
Schools on Copper WAN							12,515
District Aggregation	# 1Gbps	0	660	0	0	0	660
	# 10Gbps	0	3,630	2,100	150	0	5,880

Point Bandwidth Mix (#)	# 20Gbps	0	660	394	524	70	1,648
	# 100Gbps	0	0	0	75	106	180
	# No Separate Connection	3,730	1,650	131	0	0	8,368
Total WAN Bandwidth Mix (#)	# 100Mbps	0	4,160	4,533	3,911	3,973	16,577
	# 1Gbps	0	8,980	12,467	11,733	11,918	45,098
	# 10Gbps	0	6,750	6,633	4,061	3,973	21,417
	# 20 Gbps	0	660	394	524	70	1,648
	# 100 Gbps	0	0	0	75	106	180
	# VPN	0	5,200	1,133	0	0	6,333
	Total	0	25,749	25,160	20,304	20,040	91,253
District WAN - Scenario 2 (Urban, Suburban, Town)							
% on Fiber	% on high-speed services	93%	94%	94%	94%	94%	94%
	% on copper-based services	7%	6%	6%	6%	6%	6%
School WAN Bandwidth Mix (#)	# 100Mbps	0	4,505	4,908	4,233	4,295	17,942
	# 1Gbps	0	9,011	13,497	12,700	12,885	48,092
	# 10Gbps	0	3,379	4,908	4,233	4,295	16,815
	# VPN	0	5,632	1,227	0	0	6,859
	Total	0	22,527	24,540	21,166	21,474	89,708
Schools on Copper WAN							5,692
District Aggregation Point Bandwidth Mix (#)	# 1Gbps	0	715	0	0	0	715
	# 10Gbps	0	3,932	2,274	162	0	6,368
	# 20Gbps	0	715	426	567	76	1,784
	# 100Gbps	0	0	0	81	114	195
	# No Separate Connection	4,090	1,787	142	0	0	9,062
Total WAN Bandwidth Mix (#)	# 100Mbps	0	4,505	4,908	4,233	4,295	17,942
	# 1Gbps	0	9,726	13,497	12,700	12,885	48,807
	# 10Gbps	0	7,311	7,182	4,395	4,295	23,183
	# 20 Gbps	0	715	426	567	76	1,784
	# 100 Gbps	0	0	0	81	114	195
	# VPN	0	5,632	1,227	0	0	6,859
	Total	0	27,889	27,240	21,976	21,664	98,769
District WAN - Scenario 3 (Urban, Suburban, Town, Rural Distant)							
% on Fiber	% on high-speed services	97%	97%	97%	97%	97%	97%
	% on copper-based services	3%	3%	3%	3%	3%	3%
School WAN Bandwidth Mix (#)	# 100Mbps	0	4,668	5,085	4,385	4,447	18,585
	# 1Gbps	0	9,337	13,983	13,155	13,340	49,815
	# 10Gbps	0	3,501	5,085	4,385	4,447	17,418
	# VPN	0	5,835	1,271	0	0	7,107
	Total	0	23,342	25,423	21,926	22,234	92,924
Schools on Copper WAN							2,476
District Aggregation Point Bandwidth Mix (#)	# 1Gbps	0	741	0	0	0	741
	# 10Gbps	0	4,074	2,355	168	0	6,598
	# 20Gbps	0	741	442	587	79	1,848
	# 100Gbps	0	0	0	84	118	202
	# No Separate Connection	4,259	1,852	147	0	0	9,389
Total WAN Bandwidth Mix (#)	# 100Mbps	0	4,668	5,085	4,385	4,447	18,585
	# 1Gbps	0	10,078	13,983	13,155	13,340	50,556
	# 10Gbps	0	7,576	7,440	4,553	4,447	24,015
	# 20 Gbps	0	741	442	587	79	1,848
	# 100 Gbps	0	0	0	84	118	202
	# VPN	0	5,835	1,271	0	0	7,107
	Total	0	28,898	28,220	22,764	22,430	102,313
District WAN - Scenario 4 (Urban, Suburban, Town, Rural Distant, 80% Rural Remote)							
% on Fiber	% on high-speed services	100%	100%	100%	100%	100%	100%
	% on copper-based services	0%	0%	0%	0%	0%	0%

School WAN Bandwidth Mix (#)	# 100Mbps	0	4,778	5,204	4,487	4,549	19,018
	# 1Gbps	0	9,556	14,310	13,462	13,647	50,975
	# 10Gbps	0	3,584	5,204	4,487	4,549	17,824
	# VPN	0	5,973	1,301	0	0	7,274
	Total	0	23,891	26,018	22,437	22,745	95,091
Schools on Copper WAN							309
District Aggregation Point Bandwidth Mix (#)	# 1Gbps	0	758	0	0	0	758
	# 10Gbps	0	4,170	2,411	172	0	6,752
	# 20Gbps	0	758	452	601	81	1,891
	# 100Gbps	0	0	0	86	121	207
	# No Separate Connection	4,374	1,896	151	0	0	9,609
Total WAN Bandwidth Mix (#)	# 100Mbps	0	4,778	5,204	4,487	4,549	19,018
	# 1Gbps	0	10,314	14,310	13,462	13,647	51,734
	# 10Gbps	0	7,754	7,614	4,659	4,549	24,576
	# 20 Gbps	0	758	452	601	81	1,891
	# 100 Gbps	0	0	0	86	121	207
	# VPN	0	5,973	1,301	0	0	7,274
	Total	0	29,577	28,881	23,295	22,946	104,699

District WAN - Scenario 5 (All Locales)

% on Fiber	% on high-speed services	100%	100%	100%	100%	100%	100%
	% on copper-based services	0%	0%	0%	0%	0%	0%
School WAN Bandwidth Mix (#)	# 100Mbps	0	4,794	5,221	4,502	4,564	19,080
	# 1Gbps	0	9,588	14,357	13,506	13,691	51,141
	# 10Gbps	0	3,595	5,221	4,502	4,564	17,882
	# VPN	0	5,992	1,305	0	0	7,297
	Total	0	23,969	26,103	22,510	22,818	95,400
Schools on Copper WAN							0
District Aggregation Point Bandwidth Mix (#)	# 1Gbps	0	761	0	0	0	761
	# 10Gbps	0	4,184	2,418	172	0	6,774
	# 20Gbps	0	761	453	603	81	1,898
	# 100Gbps	0	0	0	86	121	207
	# Total	4,390	1,902	151	0	0	9,640
Total WAN Bandwidth Mix (#)	# 100Mbps	0	4,794	5,221	4,502	4,564	19,080
	# 1Gbps	0	10,348	14,357	13,506	13,691	51,902
	# 10Gbps	0	7,779	7,639	4,674	4,564	24,656
	# 20 Gbps	0	761	453	603	81	1,898
	# 100 Gbps	0	0	0	86	121	207
	# VPN	0	5,992	1,305	0	0	7,297
	Total	0	29,674	28,975	23,371	23,020	105,040

2018 Service Mix

Connection Type	Speed Category	# of Connections (per scenario)					Connection Type	% of Connections by Service Type	# of Connections by Service Type (per scenario)					% of total
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5			Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	
Internet Access	100 Mbps	5,815	6,288	6,562	6,752	6,795	Lit Fiber DIA	60%	3,489	3,773	3,937	4,051	4,077	19%
							Consumer Small Business DIA (DOCSIS, PON)	30%	1,744	1,886	1,968	2,025	2,039	10%
							Fixed Wireless DIA (incl. LTE-A)	10%	581	629	656	675	680	3%
	1 Gbps	10,052	10,836	11,494	11,949	12,123	Lit Fiber DIA	100%	10,052	10,836	11,494	11,949	12,123	57%
	10 Gbps	1,817	1,969	2,051	2,100	2,118	Lit Fiber DIA	80%	1,454	1,575	1,641	1,680	1,695	8%
							Transport to POP + ISP	20%	363	394	410	420	424	2%
	2x10 Gbps	220	238	241	243	243	Lit Fiber DIA	80%	176	190	193	194	195	1%
							Transport to POP + ISP	20%	44	48	48	49	49	0%
	100 Gbps	44	47	47	47	48	Transport to POP + ISP	100%	44	47	47	47	48	0%
District WAN	100 Mbps	16,577	17,942	18,585	19,018	19,080	Leased Lit Fiber	80%	13,262	14,353	14,868	15,214	15,264	15%
							Fixed Wireless	5%	829	897	929	951	954	1%
							Leased Dark Fiber + Electronics	5%	829	897	929	951	954	1%
							Owned Dark Fiber WAN + Electronics	10%	1,658	1,794	1,858	1,902	1,908	2%
	1 Gbps	45,098	48,807	50,556	51,734	51,902	Leased Lit Fiber	75%	33,823	36,605	37,917	38,800	38,926	37%
							Fixed Wireless	5%	2,255	2,440	2,528	2,587	2,595	2%
							Leased Dark Fiber + Electronics	10%	4,510	4,881	5,056	5,173	5,190	5%
							Owned Dark Fiber WAN + Electronics	10%	4,510	4,881	5,056	5,173	5,190	5%
	10 Gbps	21,417	23,183	24,015	24,576	24,656	Leased Lit Fiber	80%	17,134	18,546	19,212	19,661	19,725	19%
							Leased Dark Fiber + Electronics	10%	2,142	2,318	2,402	2,458	2,466	2%
							Owned Dark Fiber WAN + Electronics	10%	2,142	2,318	2,402	2,458	2,466	2%
	2x10 Gbps	1,648	1,784	1,848	1,891	1,898	Leased Lit Fiber	80%	1,318	1,427	1,479	1,513	1,518	1%
							Leased Dark Fiber + Electronics	10%	165	178	185	189	190	0%
							Owned Dark Fiber WAN + Electronics	10%	165	178	185	189	190	0%
	100 Gbps	180	195	202	207	207	Leased Lit Fiber	80%	144	156	162	165	166	0%
							Leased Dark Fiber + Electronics	10%	18	20	20	21	21	0%
							Owned Dark Fiber WAN + Electronics	10%	18	20	20	21	21	0%
	VPN	6,333	6,859	7,107	7,274	7,297	Site-to-site VPN	100%	6,333	6,859	7,107	7,274	7,297	7%

Service Pricing

Internet Access	Monthly Cost (2013)	Annual Price Decline 2014	2015	2016	2017	2018	Monthly Cost (2018)	CapEx
100Mbps Lit Fiber DIA	$2,520	15%	10%	10%	7%	4%	$1,549	$0
100Mbps Consumer Small Business DIA (DOCSIS, PON)	$328	10%	10%	10%	10%	10%	$194	$0
100Mbps Fixed Wireless DIA (incl. LTE-A)	$2,500	0%	0%	0%	0%	0%	$2,500	$0
1Gbps Lit Fiber DIA	$7,401	10%	10%	10%	10%	10%	$4,370	$0
10Gbps Lit Fiber DIA	$41,061	12%	12%	10%	10%	10%	$23,181	$0
10Gbps Transport to POP + ISP	$30,000	12%	12%	10%	10%	10%	$16,936	$5,000
2x10Gbps Lit Fiber DIA	$82,123	12%	12%	10%	10%	10%	$46,361	$0
2x10Gbps Transport to POP + ISP	$60,000	12%	12%	10%	10%	10%	$33,872	$10,000
100Gbps Transport to POP + ISP	$240,000	15%	15%	15%	15%	15%	$106,489	$20,000

WAN	Monthly Cost (2013)	Annual Price Decline 2014	2015	2016	2017	2018	Monthly Cost (2018)	CapEx
100 Mbps Leased Lit Fiber WAN	$1,026	10%	7%	7%	4%	4%	$736	$0
100 Mbps Fixed Wireless	$1,784	0%	0%	0%	0%	0%	$1,784	$5,000
1 Gbps Leased Lit Fiber WAN	$1,631	10%	10%	10%	10%	10%	$963	$0
1 Gbps Fixed Wireless	$1,784	0%	0%	0%	0%	0%	$1,784	$10,000
10 Gbps Leased Lit Fiber WAN	$4,509	15%	15%	15%	15%	15%	$2,001	$0
2x10 Gbps Leased Lit Fiber WAN	$9,018	15%	15%	15%	15%	15%	$4,001	$0
100Gbps Leased Lit Fiber WAN	$54,000	15%	15%	15%	15%	15%	$23,960	$0
Leased Dark Fiber WAN (just electronics capex)	$767	5%	5%	5%	3%	3%	$619	$5,000
Owned Dark Fiber WAN (just electronics capex)	$200	0%	0%	0%	0%	0%	$200	$5,000
Site-to-Site VPN WAN	$0	0%	0%	0%	0%	0%	$0	$5,000

Fiber Construction

		Urban / Suburban (11, 12, 13, 21, 22, 23)		Town (31, 32, 33, 41)		Rural Distant (42)		Rural Remote (43) - all schools		Rural Remote (43) - 80%		Rural Remote (43) - 20%	
Key										80%		20%	
Input / Assumption													
Calculation													
Total Number of Builds		# of units	% of locale	# of units	% of locale	# of units	% of locale	# of units	% of locale	# of units		# of units	
Schools without fiber	**31,236**	14,622	27%	8,518	30%	4,838	41%	3,258	45%	2607		652	
Base Cost Scenarios		Cost per Mile	% of Builds	Cost per Mile	% of Builds	Cost per Mile	% of Builds	Cost per Mile	% of Builds	Cost per Mile	% of Builds	Cost per Mile	% of Builds
Aerial / Existing Conduit		$ 20,000	25%	$ 20,000	50%	$ 20,000	60%	$ 20,000	60%	$ 20,000	60%	$ 20,000	60%
Underground Plowed		$ 40,000	38%	$ 40,000	25%	$ 40,000	30%	$ 40,000	30%	$ 40,000	30%	$ 40,000	30%
Underground Bored		$ 80,000	38%	$ 80,000	25%	$ 80,000	10%	$ 80,000	10%	$ 80,000	10%	$ 80,000	10%
Avg. Cost per Mile		*$ 50,000*		*$ 40,000*		*$ 32,000*		*$ 32,000*		*$ 32,000*		*$ 32,000*	
Cost Variance Scenarios		Add'l Cost per Mile	Chance per Mile	Add'l Cost per Mile	Chance per Mile	Add'l Cost per Mile	Chance per Mile	Add'l Cost per Mile	Chance per Mile	Add'l Cost per Mile	Chance per Mile	Add'l Cost per Mile	Chance per Mile
Right-of-way issues (incl. detour costs and pole replacement)		$ 40,000	40%	$ 40,000	40%	$ 20,000	30%	$ 20,000	30%	$ 20,000	30%	$ 20,000	30%
Crossings (e.g., highway, water, railroad)		$ 100,000	20%	$ 100,000	10%	$ 100,000	10%	$ 100,000	10%	$ 100,000	10%	$ 100,000	10%
Environmental protection, historical preservation, etc.		$ 50,000	5%	$ 50,000	5%	$ 20,000	20%	$ 20,000	20%	$ 20,000	20%	$ 20,000	20%
Cost per School													
Weighted Avg Cost per Mile		*$ 88,500*		*$ 68,500*		*$ 52,000*		*$ 52,000*		*$ 52,000*		*$ 52,000*	
Avg. Miles (McKinsey)		0.4		1.0		3.4		12.4		7.7		31.0	
Cost per Build		*$ 35,400*		*$ 68,500*		*$ 176,800*		*$ 642,720*		*$ 400,400*		*$ 1,612,000*	
Total Cost	**$4,050,517,704**	*$517,604,773*		*$583,503,958*		*$855,333,320*		*$2,094,075,652*		*$1,043,649,354*		*$1,050,426,298*	
		13%		*14%*		*21%*		*52%*		*26%*		*26%*	

Backup: Fiber Build Scenarios

# of schools on fiber connections in 2018	No Build Fund	Urban and Towns	+ Rural 42	+ 80% Rural 43	All Schools
Urban / Suburban	95%	100%	100%	100%	100%
Town	85%	100%	100%	100%	100%
Rural Distant	71%	71%	100%	100%	100%
Rural Remote	64%	64%	64%	90%	100%

# of schools switched to fiber via Non-Recurring Cost Subsidies	No Build Fund	Urban and Towns	+ Rural 42	+ 80% Rural 43	All Schools
Urban / Suburban	0	14,622	14,622	14,622	14,622
Town	0	8,518	8,518	8,518	8,518
Rural Distant	0	0	4,838	4,838	4,838
Rural Remote	0	0	0	2,607	3,258
Total	**0**	**23,140**	**27,978**	**30,584**	**31,236**

% of unbuilt schools building via OpEx	No Build Fund	Urban and Towns	+ Rural 42	+ 80% Rural 43	All Schools
Urban / Suburban	80%	0%	0%	0%	0%
Town	50%	0%	0%	0%	0%
Rural Distant	30%	30%	0%	0%	0%
Rural Remote	20%	20%	20%	10%	0%

# of schools switching to fiber via OpEx per year	No Build Fund	Urban and Towns	+ Rural 42	+ 80% Rural 43	All Schools
Urban / Suburban	2,924	0	0	0	0
Town	1,065	0	0	0	0
Rural Distant	363	363	0	0	0
Rural Remote	163	163	163	81	0
Total	**4,515**	**526**	**163**	**81**	**0**

Average Cost per Build
$35,400
$68,500
$176,800
$642,720

Total Annual OpEx increase (5 year amort)	No Build Fund	Urban and Towns	+ Rural 42	+ 80% Rural 43	All Schools
	$69,062,546	$33,770,756	$20,940,757	$10,470,378	$0

# of schools still on copper	No Build Fund	Urban and Towns	+ Rural 42	+ 80% Rural 43	All Schools
Urban / Suburban	2,924	0	0	0	0
Town	4,259	0	0	0	0
Rural Distant	3,387	3,387	0	0	0
Rural Remote	2,607	2,607	2,607	326	0
Total	**13,176**	**5,993**	**2,607**	**326**	**0**

Avg. # students by locale	All scenarios
Urban / Suburban	566
Town	478
Rural Distant	289
Rural Remote	158

# students still on copper	No Build Fund	Urban and Towns	+ Rural 42	+ 80% Rural 43	All Schools
Urban / Suburban	1,655,166	0	0	0	0
Town	2,035,875	0	0	0	0
Rural Distant	978,699	978,699	0	0	0
Rural Remote	411,830	411,830	411,830	51,479	0
Total	5,081,569	1,390,528	411,830	51,479	0

Distribution of Schools by Locale	Tiny	Small	Medium	Large	Mega
Urban / Suburban	45%	20%	73%	45%	96%
Town	23%	35%	23%	41%	4%
Rural Distant	17%	26%	4%	10%	0%
Rural Remote	15%	19%	1%	4%	0%

% of Districts on Fiber IA	Tiny	Small	Medium	Large	Mega
No Non-Recurring Cost Subsidies for Fiber Builds	84%	79%	91%	87%	94%
Urban and Towns	90%	86%	99%	96%	100%
+ Rural 42	95%	93%	100%	99%	100%
+ 80% Rural 43	98%	98%	100%	100%	100%
All Schools	100%	100%	100%	100%	100%

Distribution of Schools by district size	Tiny	Small	Medium	Large	Mega
Urban / Suburban	2.2%	4.9%	11.3%	15.5%	20.0%
Town	1.2%	8.3%	10.6%	5.4%	2.2%
Rural Distant	0.9%	6.2%	2.9%	1.3%	0.2%
Rural Remote	0.8%	4.7%	1.3%	0.3%	0.0%

# of schools on Copper	Tiny	Small	Medium	Large	Mega
No Non-Recurring Cost Subsidies for Fiber Builds	660	3170	3436	2954	2954
Urban and Towns	300	1442	1563	1344	1344
+ Rural 42	131	627	680	584	584
+ 80% Rural 43	16	78	85	73	73
All Schools	0	0	0	0	0

% of schools on Fiber	Tiny	Small	Medium	Large	Mega
No Non-Recurring Cost Subsidies for Fiber Builds	85.0%	86.8%	86.8%	86.9%	87.1%
Urban and Towns	93.2%	94.0%	94.0%	94.0%	94.1%
+ Rural 42	97.0%	97.4%	97.4%	97.4%	97.4%
+ 80% Rural 43	99.6%	99.7%	99.7%	99.7%	99.7%
All Schools	100.0%	100.0%	100.0%	100.0%	100.0%

Summary	No Non-Recurring Costs	Urban and Towns	+ Rural 42	+ 80% Rural 43	All Schools
Additional non-recurring cost subsidies for option	$0	$ 1,101,108,731	$ 855,333,320	$ 1,043,649,354	$ 1,050,426,298
Additional schools connected	0	23,140	4,838	2,607	652
Additional % of schools connected (with NRC subsidies)	0.0%	23.2%	4.8%	2.6%	0.7%
Additional % of schools connected (with opex)	18.1%	2.1%	0.7%	0.3%	0.0%
Cumulative % of schools connected	**86.8%**	**94.0%**	**97.4%**	**99.7%**	**100.0%**
Cumulative % of students connected	**89.8%**	**97.2%**	**99.2%**	**99.9%**	**100.0%**
Total NRC investment	**$0**	**$ 1,101,108,731**	**$ 1,956,442,051**	**$ 3,000,091,406**	**$ 4,050,517,704**
Build Cost absorbed into existing NRC provisions	$1,334,736,188	$705,835,797	$418,815,130	$210,085,260	0
Monthly additional OpEx per school building via OpEx	$1,232	5593.915633	$10,712	$10,747	0
Total Additional OpEx per year	$66,736,809	35291789.87	$20,940,757	$10,504,263	0
% of Total Builds		74%	15%	8%	2%
% of Total Cost		27%	21%	26%	26%

Backup: Total Cost

Internet Access

Number of connections by bandwidth need

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
100 Mbps	5,815	6,288	6,562	6,752	6,795
1 Gbps	10,052	10,836	11,494	11,949	12,123
10 Gbps	1,817	1,969	2,051	2,100	2,118
20 Gbps	220	238	241	243	243
100 Gbps	44	47	47	47	48
Total	17,947	19,378	20,396	21,091	21,328

Number of connections by service type

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
100Mbps Lit Fiber DIA	3,489	3,773	3,937	4,051	4,077
100Mbps Consumer Small Business DIA (DOCSIS, PON)	1,744	1,886	1,968	2,025	2,039
100Mbps Fixed Wireless DIA (incl. LTE-A)	581	629	656	675	680
1Gbps Lit Fiber DIA	10,052	10,836	11,494	11,949	12,123
10Gbps Lit Fiber DIA	1,454	1,575	1,641	1,680	1,695
10Gbps Transport to POP + ISP	363	394	410	420	424
2x10Gbps Lit Fiber DIA	176	190	193	194	195
2x10Gbps Transport to POP + ISP	44	48	48	49	49
100Gbps Transport to POP + ISP	44	47	47	47	48
Total	17,947	19,378	20,396	21,091	21,328
Districts on copper-based services	2,303	1,401	681	188	-

OpEx - monthly cost per connection

100 Mbps Lit Fiber DIA	$1,549
100 Mbps Consumer Small Business DIA (DOCSIS, PON)	$194
100 Mbps Fixed Wireless DIA (incl. LTE-A)	$2,500
1 Gbps Lit Fiber DIA	$4,370
10 Gbps Lit Fiber DIA	$23,181
10 Gbps Transport to POP + ISP	$16,936
2x10 Gbps Lit Fiber DIA	$46,361
2x10 Gbps Transport to POP + ISP	$33,872
100 Gbps Transport to POP + ISP	$106,489
Copper-based services	$333

OpEx - total cost by service type

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
100 Mbps Lit Fiber DIA	$64,863,370	$70,136,871	$73,191,987	$75,310,461	$75,799,273
100 Mbps Consumer Small Business DIA (DOCSIS, PON)	$4,054,510	$4,384,149	$4,575,119	$4,707,542	$4,738,097
100 Mbps Fixed Wireless DIA (incl. LTE-A)	$17,444,991	$18,863,298	$19,684,971	$20,254,734	$20,386,200
1 Gbps Lit Fiber DIA	$527,154,283	$568,291,506	$602,806,189	$626,691,029	$635,799,819
10 Gbps Lit Fiber DIA	$404,354,563	$438,247,645	$456,514,946	$467,281,153	$471,386,985
10 Gbps Transport to POP + ISP	$73,856,963	$80,047,669	$83,384,264	$85,350,754	$86,100,700
2x10 Gbps Lit Fiber DIA	$98,030,100	$105,917,331	$107,480,738	$108,017,868	$108,222,709
2x10 Gbps Transport to POP + ISP	$17,905,586	$19,346,220	$19,631,783	$19,729,892	$19,767,307
100 Gbps Transport to POP + ISP	$55,658,178	$59,785,865	$60,412,473	$60,638,316	$60,724,444
Total	$1,263,322,544	$1,365,020,553	$1,427,682,469	$1,467,981,749	$1,482,925,534

CapEx - one-time cost per connection

100Mbps Lit Fiber DIA	$0
100Mbps Consumer Small Business DIA (DOCSIS, PON)	$0
100Mbps Fixed Wireless DIA (incl. LTE-A)	$0
1Gbps Lit Fiber DIA	$0
10Gbps Lit Fiber DIA	$0
10Gbps Transport to POP + ISP	$5,000
2x10Gbps Lit Fiber DIA	$0
2x10Gbps Transport to POP + ISP	$10,000
100Gbps Transport to POP + ISP	$20,000

CapEx - total cost by service type

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
100Mbps Lit Fiber DIA	$0	$0	$0	$0	$0
100Mbps Consumer Small Business DIA (DOCSIS, PON)	$0	$0	$0	$0	$0
100Mbps Fixed Wireless DIA (incl. LTE-A)	$0	$0	$0	$0	$0
1Gbps Lit Fiber DIA	$0	$0	$0	$0	$0
10Gbps Lit Fiber DIA	$0	$0	$0	$0	$0
10Gbps Transport to POP + ISP	$329,262	$367,338	$387,860	$399,955	$404,568
2x10Gbps Lit Fiber DIA	$0	$0	$0	$0	$0
2x10Gbps Transport to POP + ISP	$85,129	$93,990	$95,746	$96,350	$96,580
100Gbps Transport to POP + ISP	$197,777	$213,928	$216,379	$217,263	$217,600
Total	$612,168	$675,256	$699,986	$713,568	$718,748

Total Internet Access Cost

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Total CapEx	$612,168	$675,256	$699,986	$713,568	$718,748
Total OpEx	$1,263,322,544	$1,365,020,553	$1,427,682,469	$1,467,981,749	$1,482,925,534
Total Cost	$1,263,934,712	$1,365,695,809	$1,428,382,455	$1,468,695,317	$1,483,644,282

District WAN

Number of connections by bandwidth need

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
100 Mbps	16,577	17,942	18,585	19,018	19,080
1 Gbps	45,098	48,807	50,556	51,734	51,902
10 Gbps	21,417	23,183	24,015	24,576	24,656
20 Gbps	1,648	1,784	1,848	1,891	1,898
100 Gbps	180	195	202	207	207
VPN	6,333	6,859	7,107	7,274	7,297
Total	91,253	98,769	102,313	104,699	105,040

Number of connections by service type

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
100 Mbps Leased Lit Fiber WAN	13,262	14,353	14,868	15,214	15,264
100 Mbps Fixed Wireless	829	897	929	951	954
1 Gbps Leased Lit Fiber WAN	33,823	36,605	37,917	38,800	38,926
1 Gbps Fixed Wireless	2,255	2,440	2,528	2,587	2,595
10 Gbps Leased Lit Fiber WAN	17,134	18,546	19,212	19,661	19,725
2x10 Gbps Leased Lit Fiber WAN	1,318	1,427	1,479	1,513	1,518
100 Gbps Leased Lit Fiber WAN	144	156	162	165	166
Leased Dark Fiber WAN + Electronics	7,663	8,294	8,591	8,792	8,820
Owned Dark Fiber WAN + Electronics	8,492	9,191	9,521	9,743	9,774
Site-to-Site VPN WAN	6,333	6,859	7,107	7,274	7,297
Total	91,253	98,769	102,313	104,699	105,040

OpEx - monthly cost per connection

100 Mbps Leased Lit Fiber WAN	$736
100 Mbps Fixed Wireless	$1,784
1 Gbps Leased Lit Fiber WAN	$963
1 Gbps Fixed Wireless	$1,784
10 Gbps Leased Lit Fiber WAN	$2,001
2x10 Gbps Leased Lit Fiber WAN	$4,001
100 Gbps Leased Lit Fiber WAN	$23,960
Leased Dark Fiber WAN + Electronics	$619
Owned Dark Fiber WAN + Electronics	$200
Site-to-Site VPN WAN	$0
Copper-based connections	$333

OpEx - total cost by service type

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
100 Mbps Leased Lit Fiber WAN	$117,095,613	$126,734,603	$131,278,706	$134,339,017	$134,776,205
100 Mbps Fixed Wireless	$17,747,880	$19,208,837	$19,897,575	$20,361,419	$20,427,682
1 Gbps Leased Lit Fiber WAN	$390,865,825	$423,013,838	$438,169,356	$448,376,124	$449,834,233
1 Gbps Fixed Wireless	$48,283,408	$52,254,632	$54,126,784	$55,387,619	$55,567,739
10 Gbps Leased Lit Fiber WAN	$411,346,482	$445,259,901	$461,247,684	$472,014,956	$473,553,137
2x10 Gbps Leased Lit Fiber WAN	$63,295,925	$68,528,580	$70,995,407	$72,656,738	$72,894,071
100 Gbps Leased Lit Fiber WAN	$41,474,116	$44,858,757	$46,454,376	$47,528,975	$47,682,490
Leased Dark Fiber WAN + Electronics	$56,898,330	$61,582,099	$63,790,165	$65,277,228	$65,489,666
Owned Dark Fiber WAN + Electronics	$20,380,854	$22,058,568	$22,849,491	$23,382,153	$23,458,248
Site-to-Site VPN WAN	$0	$0	$0	$0	$0
Total	$1,167,388,434	$1,263,499,814	$1,308,809,544	$1,339,324,230	$1,343,683,471

CapEx - one-time cost per connection

100 Mbps Leased Lit Fiber WAN	$0
100 Mbps Fixed Wireless	$5,000
1 Gbps Leased Lit Fiber WAN	$0
1 Gbps Fixed Wireless	$10,000
10 Gbps Leased Lit Fiber WAN	$0
2x10 Gbps Leased Lit Fiber WAN	$0
100 Gbps Leased Lit Fiber WAN	$0
Leased Dark Fiber WAN + Electronics	$5,000
Owned Dark Fiber WAN + Electronics	$5,000
Site-to-Site VPN WAN	$5,000

CapEx - total cost by service type

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
100 Mbps Leased Lit Fiber WAN	$0	$0	$0	$0	$0
100 Mbps Fixed Wireless	$0	$0	$0	$0	$0
1 Gbps Leased Lit Fiber WAN	$0	$0	$0	$0	$0
1 Gbps Fixed Wireless	$2,719,145	$3,182,799	$3,401,379	$3,548,585	$3,569,615
10 Gbps Leased Lit Fiber WAN	$0	$0	$0	$0	$0
2x10 Gbps Leased Lit Fiber WAN	$0	$0	$0	$0	$0
100 Gbps Leased Lit Fiber WAN	$0	$0	$0	$0	$0
Leased Dark Fiber WAN + Electronics	$3,401,682	$4,190,205	$4,561,938	$4,812,289	$4,848,053
Owned Dark Fiber WAN + Electronics	$0	$82,183	$494,122	$771,550	$811,183
Site-to-Site VPN WAN	$0	$657,198	$967,021	$1,175,676	$1,205,484
Total	$6,120,827	$8,112,384	$9,424,459	$10,308,100	$10,434,335

Total District WAN Cost

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Total CapEx	$6,120,827	$8,112,384	$9,424,459	$10,308,100	$10,434,335
Total OpEx	$1,167,388,434	$1,263,499,814	$1,308,809,544	$1,339,324,230	$1,343,683,471
Total Cost	$1,173,509,260	$1,271,612,198	$1,318,234,004	$1,349,632,330	$1,354,117,806

Backup: Est. 2014 Service Mix

Internet Access			
Total connections on high-speed services	13,396		
Service Mix			*Item 21 analysis*
Lit Fiber	**69%**	9,220	69.4%
Cable Modem	**27%**	3,668	27.6%
Fixed Wireless	**3%**	392	3.0%
10 Gbps Transport to POP + ISP	*1%*	100	-
2x10 Gbps Transport to POP + ISP	*0.1%*	10	-
100 Gbps Transport to POP + ISP	*0.0%*	4	-

District WAN			
Total connections on high-speed services	91,253		
Service Mix			*Item 21 analysis*
Leased Lit Fiber	**75%**	68,647	90.6%
100 Mbps Fixed Wireless	**1%**	1,167	1.5%
1 Gbps Fixed Wireless	**1%**	1,038	1.4%
Leased Dark Fiber + Electronics	**5%**	4,942	6.5%
Owned Dark Fiber WAN + Electronics	*10%*	9,125	-
Site-to-site VPN	*7%*	6,333	-

Appendix: Detailed Description of Model Components

The E-Rate Connectivity Cost Model includes five key sections, each located on a separate tab and explained in detail in the sections that follow:

- **Model Summary:** Shows the total projected costs to upgrade America's K-12 public schools according to five scenarios, providing a perspective on what level of investment is required to close the fiber access gap and enable increasing numbers of schools to meet FCC connectivity targets.
- **2018 Bandwidth Needs:** Details the approach to modeling the 2018 demand for Internet access and WAN connections.
- **2018 Service Mix:** Defines the service types included in the analysis and explains why these were selected and under what circumstances they are likely to be useful, explaining the distribution of connections by service type at each connection speed.
- **Service Pricing:** Explains current pricing assumptions and the rationale for the rate of price declines for each service type
- **Fiber Construction Costs:** Shows the total number of fiber builds expected by locale, the cost per mile for typical build scenarios, cost variance for common challenges that arise during the fiber build out, and a summary of the total costs.

Model Summary Tab

This section shows the total projected costs for the E-Rate program according to five scenarios, providing a perspective on what level of investment is required to close the fiber access gap and enable all schools to meet the Commission's connectivity targets by 2018.

All costs listed in the model are the total cost for the service before any E-rate discount is applied. For each funding year, the costs are summarized as follows:

- **Internet Access**, covering only high-speed Internet access connections. The national aggregate cost increases as more schools are connected to fiber and are thereby able to increase their bandwidth purchases to meet their predicted growing demand (and the Commission's connectivity targets).
- **District WAN**, covering high-speed WAN connections. As with Internet access connections, the cost for these connections increases as more schools are connected to fiber because schools are able to purchase more bandwidth to meet growing needs.
- **Copper-based Services:** The cost for schools remaining on older technologies (e.g., T1, T3, DSL) that have not yet been upgraded to provide adequate bandwidth. Usage of these services is projected to decline over time in all scenarios as schools transition to high-speed connections, but the rate of decline is faster in scenarios with non-recurring cost subsidies for fiber construction costs.
- **Allowance for new builds paid through OpEx:** The added operating expense incurred when schools enter into service provider contracts in which providers reflect the upfront investment for fiber construction in the monthly charges paid by districts.
- **Non-Recurring Construction Costs:** This is the cost for additional construction of fiber to schools, as described in the Fiber Construction section below, split over the four future funding years

considered by the model. These costs are separate from the ongoing operating expenses captured in the Internet Access and District WAN figures.

Construction Scenarios

The model presents five scenarios which increase the number of schools connected to fiber and the proportion of construction costs funded through non-recurring cost subsidies:

1. No non-recurring cost subsidies, 86.8% of schools and 89.8% of students are able to achieve FCC connectivity targets.
2. Non-recurring cost subsidies sufficient to connect all schools in scenario 1, plus those in urban / suburban locales and towns, connecting 94.0% of schools and 97.2% of students to fiber.
3. Non-recurring cost subsidies sufficient to connect all schools in scenario 2, plus those in distant rural locales, connecting 97.4% of schools and 99.2% of students.
4. Non-recurring cost subsidies sufficient to connect all schools in scenario 3, plus 80% of those in remote rural locations, connecting 99.7% of schools and 99.9% of students.
5. Non-recurring cost subsidies sufficient to connect all schools and all students to fiber.

Legacy Services Phase-Out

Consistent with the rules adopted by the Commission in the E-rate 2.0 order, the pre-discount cost currently devoted to legacy services is reduced 20% per year. The 2014 cost was calculated from 2014 funding request data pulled from the USAC Data Retrieval Tool.

Category 2 Services

The costs shown here are pre-discount and reflect an annual E-Rate target budget of $1 billion, as described in the E-rate 2.0 Order.[13] Based on our LAN/Wi-Fi model we expect the full budget to be utilized for the foreseeable future.

Total E-Rate Costs

- **Discount Rates:** Allows the Commission to input an average discount rate for operating expenses and a separate discount rate for non-recurring cost subsidies related to closing the fiber access gap, with default assumptions of 70% and 90%, respectively.
- **Cost and Value by Scenario:** For each scenario, shows the total costs for the E-Rate program as well as the number of students and schools able to meet FCC connectivity targets.

[13] E-rate 2.0 Order at 78.

2018 Bandwidth Demand Tab

This tab models the predicted 2018 demand for Internet access and WAN connections for schools and districts. The output of this tab is the total number of connections needed, and the speed for each.

Reference Data

The base information about schools and local education agencies (school districts) referenced in the model is taken from the Common Core of Data provided by the National Center for Education Statistics (NCES). The 2011-2012 dataset was used, which is the most recent complete set available, and a review of data sets from past years indicates this data is reasonably stable over time. The total number of network users was determined as the sum of students and teachers.

Consistent with our LAN/Wi-Fi model, we have grouped public school districts in the United States by size, as measured by number of schools in the district:

- Tiny (1 school)
- Small (2-5 schools)
- Medium (6-15 schools)
- Large (16-50 schools)
- Mega (51+ schools)

This grouping allows us to validate assumptions by comparing modeled bandwidth levels to real world districts within each category, and to properly reflect size-based factors driving network complexity. For example, districts with fewer schools are more likely to use virtual WANs, while larger districts can support higher concurrency ratios at aggregation points.

In order to allow us to confirm that the model results reflect intuition and support further analysis, we calculated some useful statistics, including the percentage of districts, schools and users in each district size, the average number of users for each district size, and how many schools in each district size had fewer than 100 students and more than 1000 students.

Connection Types

A general assumption in the model is that each district has a WAN between all school locations and a district office location that serves as the network aggregation point. Based on this configuration, we considered three types of connections and calculated the expected bandwidth need for each:

1. **Internet access.** The connection between the district aggregation point and an upstream Internet service provider (ISP).
2. **District aggregation WAN:** The additional connection into a service provider managed WAN from the district aggregation point (usually a district office), since the aggregation point is typically not located at a school.
3. **School WAN:** The WAN connection at each school to deliver adequate connectivity to serve the school building.

Connection Sizing

The overall bandwidth targets in the model are based on the 1 Mbps per student long term goal outlined in the E-rate 2.0 Order and the NCES data on student enrollment to calculate bandwidth need at the school

and district level. We have also assumed a minimum bandwidth need of 100 Mbps per school to reflect relatively higher bandwidth needs on a per-user basis in small schools, in order to drive interactive responsiveness when there are very few users.

For the Internet access and aggregated WAN connections at the district office level, we have adjusted bandwidth demand needs to factor in the concurrency benefits of aggregating multi-site networks with large user bases.[14] The concurrency ratio used is significantly lower for WAN aggregation compared to Internet access due the the expected impact of caching (especially as it becomes more common, now that caching is an eligible Category 2 service) and because the WAN carries a greater percentage of non-user driven traffic with a lower demand peak ratio.

To improve our ability to compare the model projections with current real world observations, we calculated what the 2018 bandwidth targets imply for the current year bandwidth need, assuming a compound annual growth rate of 50% between today and 2018.

Because pricing for bandwidth on a per-megabit basis is highly sensitive to the total amount of bandwidth purchased and follows a non-linear price curve, we chose to model all district purchases of both Internet Access and WAN bandwidth at a fixed number of speed points. We chose bandwidth tiers that reflect physical interface speeds of electronics equipment and thus usually represent the optimal value points for a customer. While we believe school districts are most likely to choose these levels of service for their network, we also expect that some districts will opt for reduced speeds compared to what the model predicts if it represents a significant savings over the modeled speed, which makes the model a slightly conservative estimate of Internet Access costs in particular.

We then estimated the percentage of districts that would need each connection speed level for each district size considered in the model. For example, the average Internet access bandwidth need in a tiny school district is 323 Mbps. This means that the majority of districts will need to purchase a 1 Gbps connection to meet their projected needs, but some districts on the lower end of the demand curve could meet connectivity needs with a 100 Mbps service. The distribution of speeds within each category reflects the distribution of student population sizes as well as current bandwidth purchasing trends.

Special Network Designs

While we generally aimed to keep the model as simple as possible by assuming the stereotypical district network design, there were three common variations we wanted to consider:

- Tiny (1 school) districts do not require any additional WAN connections, since they consist of only one campus location.
- A relative minority of districts are located in areas where 100 Mbps consumer small business Internet access is an available and affordable option. In these cases, many smaller districts elect to purchase direct Internet access to each school and then set up a virtual private WAN with VPN hardware for secure connections between district locations. Larger districts rarely implement these kinds of networks, due to very different cost and operational management tradeoffs.
- Many smaller districts have their district office co-located with a school or otherwise choose to place their core WAN equipment at a school site rather than a separate office facility. We have modeled those districts as needing no separate connection to an aggregation facility in this case.

[14] Networks with larger user bases will have relatively flatter demand peaks, particularly because peak demand in the school setting is driven by active consumption of video streaming. Based on feedback from district and state technology leaders, we believe our assumptions for concurrency benefits err on the conservative side.

Construction Scenario Calculations

Below the core calculations of bandwidth needs, each set of needs is adjusted for the various fiber construction scenarios considered in the model. These sections of the tab only serve to show the changed number of connections purchased in each scenario and contain no new assumptions.

2018 Service Mix Tab

This section of the model defines the distribution of service types at each connection speed. Overall, we assumed the following types of high-speed broadband service to be in wide use by 2018:

- **Lit Fiber Direct Internet Access (DIA):** Fiber-based circuits provided as a lit (managed) service managed by a service provider. This is the easiest option for schools, where it is available, so we anticipate that this service will be by far the most common across all connection speeds.
- **Transport to POP with ISP:** Districts use a point-to-point WAN transport connection to connect to a point of presence (POP) operated by a state network or carrier hotel where they connect directly to an ISP backbone. Because of the higher complexity of this solution, it's typically only cost-effective at higher bandwidth amounts.
- **Lit Fiber WAN:** Fiber-based circuits provided as a lit (managed) service managed by a service provider. This is the easiest option for schools, where it is available, so we anticipate that this service will be by far the most common across all connection speeds.
- **Leased Dark Fiber:** Fiber connections between two locations provided without any electronics on either end. These connections are an appealing option for districts seeking to decouple cost and demand, since they can be scaled to higher capacity with a one-time investment in new electronics.
- **Owned Dark Fiber:** Fiber connections where the physical cable plant is owned by the district itself and managed by the district directly. Owned fiber is particularly advantageous for districts in areas without many fiber options from traditional service providers.
- **Fixed Wireless:** This category includes both traditional point-to-point wireless solutions (e.g., microwave) as well as emerging solutions based on mobile network standards (e.g., LTE-A). Since these technologies do not have the bandwidth scalability of fiber, we expect them to be used primarily in areas that lack other connectivity options where a fiber build is likely to be very expensive.
- **Consumer Small Business DIA:** This is primarily an option only for districts who will need less than a gigabit of total bandwidth by 2018. While these services can have a number of disadvantages compared to commercial fiber service (e.g. much more limited service level agreements) they often present a very compelling option when available due to their low recurring costs.
- **Virtual Private Network (VPN):** See the Special Network Designs section above.

For each tier of bandwidth in the bandwidth mix, we identify the appropriate service types for providing that bandwidth and estimated the proportional usage of each service type within each bandwidth tier.

Service Pricing Tab

This tab considers the price for each service listed on the Service Mix tab. The majority of prices in the model are based on our Item 21 data collection from 2013. For some of the highest connection speeds, which are not yet widely in use, prices are estimated based on discussions with technology directors of state networks and large districts who are purchasing at these speeds today.

To arrive at the costs of each service in 2018, we modeled the annual price decline of each service over the time period covered by the model. The rate of price decline varies by connection speed, since high bandwidth services based on new-to-market technology have rapid price declines as the underlying technology becomes more widely adopted, more competitors offer the new services, and initial capital investments are paid off. Similarly, price declines of lower bandwidth lit fiber services level off as the underlying technology becomes more mature, a greater percentage of the cost is customer service, and vendor margins narrow.

Unlike lit fiber services, we have modeled minimal to no decline in the prices of leased and owned dark fiber WANs, because there are no electronics provided as part of the service, and the current market pricing represents primarily the costs of laying the fiber as well as the operational costs related with the maintenance of the physical plant. We do not expect either of these cost areas to significantly decrease in the foreseeable future.

Though relatively minimal compared to the operating expenses, we also modeled capital expenses representing the cost of equipment associated with dark fiber and fixed wireless solutions. Note that the capital costs associated with owned (self-provisioned) fiber networks are not considered in this baseline model since those costs are not currently supported by the E-rate program.

Fiber Construction Costs Tab

This section estimates the cost of fiber construction to those schools who do not yet have the physical infrastructure for high-speed broadband. All costs are estimated assuming the extension of existing service provider networks[15], not the construction of a new independent network, since we expect that existing service provider networks will continue to serve most schools. After these capital investments have been made, we expect that service providers will generally be able to provide service at the speeds and prices projected in the other parts of the model.

The costs of fiber construction are highly dependent on the availability of existing fiber plant to extend, and the physical environment, so our analysis divides all schools into four locale groups to separate more urban and more rural build environments. Each school has been mapped into these categories based on ULOCAL codes in the NCES data set, as follows:

- Urban / Suburban (11, 12, 13, 21, 22, 23)
- Town (31, 32, 33, 41)
- Rural Distant (42)
- Rural Remote (43)

[15] We recognize that some service providers will have to invest more broadly in their networks in order to increase the speed of a wider set of core routing and switching infrastructure. We have not included these upgrades in the model, since we believe they represent the normal costs of business for the carrier network maintenance over the long term.

To calculate the total number of builds needed, we used version 5 of the FCC Fiber Map[16] to project the percent of schools needing fiber in each of the locale groups defined above. We used only the sample of schools for which access to fiber was known (either yes or no), and excluded schools for which access was unknown.[17] The percentage of schools needing fiber in each locale group was then applied to the total number of schools in each locale group, from NCES, to estimate total number of schools needing fiber.

For each locale, we estimated a base cost per mile that takes into account the basic options for fiber construction and the relative prevalence of those building methods:

- **Aerial or Existing Conduit:** attachment of fiber to existing utility poles, or adding fiber cables to existing conduit. This method is less common in urban areas where underground utilities are more prevalent, and more common in rural areas where the higher mileage required for each build magnifies the cost savings.
- **Underground Plowed and Bored:** These approaches involve fiber buried in the ground, often in conduit. Plowed or trenched construction is significantly more cost effective where soil conditions and the built environment make it possible. Underground boring is the most expensive option, but often necessary in difficult terrain.

After considering the base costs, we applied a number of adjustments to account for the notoriously high variation of fiber construction costs due to location-specific challenges. We have modeled broad categories of commonly encountered issues, including:

- **Right-of-way Issues**, including permitting fees, detour costs, and pole replacement fees charged by incumbent utilities. We estimate both the likelihood (on a per-mile basis) of this occurring and the costs to address the issues, which are higher in urban, suburban, and town areas due to the increased complexity of the built environment.
- **Crossings**, including the cost of changes to routing or construction techniques (likely both) due to highways, waterways, and railroads. Similar to right-of-way issues, we expect the per-mile likelihood of occurrence to be higher in urban areas.
- **Environmental Protection, Historical Preservation, etc:** Additional mileage to complete additional regulatory processes, mitigate potential construction issues through, or detour around areas protected under environmental or historical preservation regulations.

With the base construction costs and per-mile adjustment identified, we calculated a weighted average cost per mile by applying the cost variance scenarios to the base cost scenarios, and then multiplied that by an average number of miles per school based on a study by McKinsey & Company.[18] Since the average distance per school in the Rural Remote category varies widely, we further divided this locale into two sub-categories based on mileage to better illustrate the distribution of costs. Based on this analysis, we estimate that 80% of schools in this category could be connected on average at 7.7 miles, while the 20%

[16] Published October 8th, 2014 to the E-rate Modernization Data page at http://www.fcc.gov/encyclopedia/e-rate-modernization-data.

[17] We used the FCC fiber map data for all states except Arkansas, where ESH has conducted an in-depth statewide data collection that covers a larger sample than the Fiber Map data. Comparison with the Arkansas data and anecdotal evidence from EducationSuperHighway field work suggests that the number of schools with existing fiber infrastructure may be significantly higher than the current FCC fiber map data suggests, but we believe that any discrepancy will be heavily skewed toward urban, suburban, and town districts, and thus will have a relatively low impact on the overall costs projected by this model.

[18] "Sizing the Infrastructure Gap in America's K-12 Schools", Appendix D. December 22, 2012.

hardest to reach schools would take fiber runs averaging 31 miles.[19] Accordingly, we expect that many of these most-remote schools will be more cost effectively served by long-range fixed wireless technologies rather than fiber construction, but we still expect the one-time investment costs to be significant in that case due to the lack of useable tower infrastructure in such remote locations.

Supplementary Calculations (Backup) Tabs

Supplementing the core model tabs outlined above, the following additional sections provide the calculations used to compute and summarize the model:

- **Fiber Build Scenarios:** The calculations in this tab provide a baseline of the number of schools that have fiber by 2018 in each of the fiber build scenarios, the total cost of reaching those schools (through both a build-out fund and funded via operating expense), and the percentage of schools and students that are connected to fiber by 2018 for each scenario.
- **Total Cost:** The calculations in this tab take the results of the bandwidth needs, service mix, and pricing analyses to calculate the total annual 2018 cost for Internet access and WAN under each fiber build scenario.
- **Est. 2014 Service Mix:** The analysis in this tab estimates the usage of different service types today; the purpose of this analysis is to quantify the number of districts and schools transitioning to new service types each year, which is used to calculate one-time capital expenditures associated with certain service types (mostly equipment for fixed wireless and dark fiber).

[19] ESH worked with SGSI to analyze location data for all California schools and calculate the shortest distance from each school to the nearest neighboring school or district site. While this is not an exact measure of the mileage needed to extend fiber to a school, because in reality the connection may extend from existing service provider facilities, we believe that on average, it is a reasonable estimate for the mileage needed to reach rural schools. We took these mileages calculated for all schools in the ULOCAL 43 category, removed significant outliers resulting from edge cases (e.g. virtual schools), and then calculated the average mileage for the 80% of schools with the shortest mileages and the average mileage for the 20% of schools with the highest mileages.