INTERNET CONNECTIVITY IN NEW YORK CITY PUBLIC SCHOOLS

AN EXPLORATORY REPORT

In order to create a better understanding of issues impacting internet connectivity and performance in New York City public schools, the Heckscher Foundation for Children commissioned TTM Advisors to research the topic and develop a set of answers to frequently asked questions.

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TTM
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SCHOOL NETWORKS AS CRITICAL EDUCATIONAL INFRASTRUCTURE

Many of the country's K-12 public schools rely on the internet and internet-based resources for everything from curricula to classroom management and school administration, all now done with the help of apps, websites, and platforms that depend on near-constant access to cloud and server resources.

This increased reliance on internet-based resources means that the modern public school must have a reliable, stable, computer network. A school's computer network—its local building network as well as its connection to the public internet—should be considered critical educational infrastructure.

Unfortunately, despite the billions of dollars spent nationwide in federal, state, local, and private education technology investments, our school networks still fall short, especially in our most economically-disadvantaged communities. This is particularly true in New York City.

The root causes that have impeded the implementation and maintenance of fast, reliable school networks need to be better understood before solutions can be found. Finding solutions first requires that those interested in this subject have a shared understanding of the core concepts involved, including fundamental technological underpinnings regarding how networks work in schools.

The Heckscher Foundation for Children, a New York City-based foundation which seeks to level the playing field for underserved youth, particularly in education, sought to help establish this shared understanding and retained TTM Advisors to assist via the production of this report.

HIGH-SPEED INTERNET ACCESS IN NYC PUBLIC SCHOOLS: SUMMARY FINDINGS OF TTM ADVISORS

Effective internet bandwidth at schools is affected by a multi-faceted and complicated set of inter-related issues. There is no one-size-fits-all answer that addresses each particular school's situation. Rather, each school's network issues are typically a unique ratio of the following common problems:

- **Insufficient bandwidth to the school.** The last-mile "pipe" is too small to carry the aggregate bandwidth going to and from the various devices within the school.
- **Too many users.** While, ideally, the last-mile bandwidth capacity should be able to handle growth in use, the network can become overwhelmed if many more devices are on it than the number for which it was built. This can happen when students are given the passcode to connect to the network, for example, and then share it, resulting in many more personal devices connected to the network than planned.
- **Underpowered and overused wireless access points (WAPs).** The WAP in a classroom cannot handle all the students at the same time.
- **WAPs are too far from end users.** WAPs are not located near enough to where users need them.

CONCEPTUALIZING NETWORKS

THE WATER SUPPLY ANALOGY

The most common analogy used to describe computer networks is that of our water supply system. Water embarks on its journey from a reservoir, lake, or well to your bathtub, toilet, or sink in enormous pipelines (aqueducts). As water flows closer to consumers and businesses, it is routed into smaller pipes owned by municipal water companies that distribute water to buildings and people. Finally, water enters a building where it flows through plumbing to various floors and ultimately to bathrooms, laundry rooms, and kitchens.

Similarly, internet data departs a server to travel by satellites or massive trunk lines owned by global telecoms, which compose the core of the public internet (i.e., the "internet backbone"). It then passes from this public internet backbone to towers or pipes that get smaller as they get closer to the end user. Finally, internet data enters a building via a router or modem and then travels through wired cabling or a wireless network (the Local Area Network, or LAN) to the end user.

WATER	DATA
Starts in a well, lake, or reservoir (where it was collected from rain and nearby natural sources such as springs, streams, etc.)	Starts on a remote server (to where it was uploaded by a programmer, author, creator, data scientist, another computer, etc.)
Flows first through large pipelines as it travels to cities and towns	Flows from server facilities across trunk lines that compose the internet backbone
Water enters the smaller system of pipes that compose a municipal water system (i.e., the plants and pumping station as well as the pipes that run under the street and into buildings)	Data enters the network of an Internet Service Provider, where it then transverses a set of lines, usually copper or fiber, also usually underground that are geographically connected from a central connection to the internet backbone to points nearby individual homes and businesses
Water travels through a water service pipe its final few yards from the municipal water main. It then passes through a meter, and then into the buildings' plumbing. Responsibility for both the water and the plumbing now resides with the building owners and tenants	Data travels its "last mile" over a twisted pair, copper, coax, fiber, some hybrid, or something similar, into the home or business. Alternatively, in the case of a wireless device using cellular service, the "last mile" is instead the wireless signal from the local cell tower to the device
Water is routed within the home to sinks, toilets, baths, etc.	Data comes in via a router or modem and is then routed within the business, school, or home internal network, likely using wireless (WiFi) technology to connect individual devices to the network, though servers and desktops may use a wired connection to connect the local network

Ownership, control, and responsibility for the network are useful points of comparison as they illuminate governance and accountability considerations.

WATER	HOME NETWORKS	BUSINESS NETWORKS	NYC SCHOOL NETWORKS
The large pipes that carry high volumes of water within and between states and are controlled and managed by large public or quasi-public agencies	The large trunk lines that form the internet backbone	Same	Same
Municipal water companies control distribution in a geography and own (or control) a network of pipes within a geography	An ISP like Verizon, Spectrum, etc.	An ISP that serves business customers, generally providing higher levels of reliability	The DOE's own private WAN that is composed of leased lines, circuits, and a SONET (syncronous optical networking) ring
Internal plumbing owned by the building owners and maintained by building owners and/or tenants	The internal hardware used for a home network; the modem may be owned by the ISP but any additional hardware (e.g., a wireless access point) is bought and managed by the home owner	Internal hardware owned and managed by a business; ownership and/or management may be outsourced to a 3rd party provider	Network equipment owned and managed by the DOE in school buildings

KEY TERMS

BANDWIDTH

Bandwidth is a measure of internet speed. It specifically indicates the amount of information (data) that can come to a computer from the internet (download speed) and go back from a computer back to the internet (upload speed).

Mbps (for bandwidth) | MB (for files)

Mbps stands for megabits per second and is a common unit used to measure the speed (bandwidth) of internet connections. Just as a car speedometer measures miles per hour, speed on the internet is measured in bits travelled per second to and from your computer. A megabit is 1,000,000 bits. A bit is a single "1" or "0" — it is the most fundamental unit of computing and digital technology in general.

Some context:

- A standard speed offered by Verizon's home FIOS internet service is 100 Mbps, approximately 100x faster than the first-generation "high speed" internet services of 20 years ago.

- Some companies (e.g., Spectrum) now offer 1 Gbps (1000 Mbps) home service, 1,000x that of an early era high-speed connection.

You'll also see Gbps (gigabits per second) and Kbps (kilobits per second). Here's a conversion to keep in mind:

Gbps = 1,000 Mbps = 1,000,000 Kbps = 1,000,000,000 bits per second

(Note: technically these are factors of 1,024 – not 1,000 – but this factor, 1000x, works for general purposes)

Unlike bandwidth, the size of a file is generally measured in bytes, not bits. One byte is equal to 8 bits. A common file measurement is the megabyte, usually abbreviated as "MB." 1 MB = 8 Mb. So when we look to figure out how long it will take to download or upload a file given a particular connection speed, we often have to multiply or divide by 8 as the case may be.

For example, if we wanted to calculate how long it would take to download an MP3 music file on a home 100 Mbps connection, the calculation would be as follows:

- Typical 4 minute MP3 file: 8MB (8 megabytes)
- 8MB = 64Mb (8 * 8)
- 64 Mb / 100 Mbps = .64 sec to download the music file

This previous example of how to consider file measurements in the context of bandwidth measurement leads to another point: networks are imperfect and busy. There is a lot of other traffic on a network, even a home network, and much of it invisible to you. There are different estimates for how much contention, as this is called, may exist on a network, but, for now, let's assume 30%. That would bring down the available bandwidth to 70Mbps, meaning the file would probably take just about a second to download (64 Mb / 70 Mbps).

Now let's assume that 30 students are downloading all different 8MB files more or less simultaneously at a school with a 40 Mbps connection (common in the DOE). What does that look like?

- 30 students x 8 MB files = 240 MB in aggregate requests to the network
- 240MB * 8 bits per byte = 1,920 Mb (= 1.9 Gb)
- 1,920 Mb / (40Mbps * .7) = 68 seconds to download the aggregate requested files from the 30 students (i.e., the average time of each student download will be 68 seconds)

In reality, each student would not wait exactly 68 seconds. Because no single request will be processed at the exact same time, the first few students to start their downloads would probably receive their completed download quickly. Conversely the students who started their downloads even a second or two after the rest of the class would probably see download times much greater than 68 seconds, perhaps even experiencing "time outs" and failed downloads.

FREQUENTLY ASKED QUESTIONS

HOW IS BANDWIDTH SUPPLIED TO NYC SCHOOLS?

New York City, given its prominent global stature, is generously supplied with bandwidth. Internet bandwidth comes through physical lines, owned by large global telecoms, that pass under the Hudson and East Rivers. These telecoms in turn sell internet access to homes and businesses. Some telecoms also choose to resell/wholesale bandwidth to smaller internet service providers who work directly with home and business end users.

The internet traffic for devices of the administrators, teachers, and students working and studying in the 1,300 buildings that comprise the NYC Department of Education is routed, like a funnel, through a single very large internet gateway provided by one of these private internet service providers. The DOE recently completed a bid process, won by Lightower, for a new internet service provider to increase total gateway capacity from 24Gbps to 240Gbps, a 10x increase. Lightower won the contract in late 2017 and is in the process of completing its upgrade.

HOW DOES BANDWIDTH ENTER NYC SCHOOLS?

The problem with internet access to schools really starts with getting enough bandwidth into the school building itself. There are two components to how internet traffic gets from the DOE's internet gateway (provided now by Lightower) to a school.

Internet traffic travels from the DOE's internet connection (Lightower) into large-capacity fiber optic wires, leased by the DOE. These lines create a "ring" around the city that connect seven Department of Education "nodes" located around the five boroughs.

A node (site) is a meeting point of network connections, much like the joints that might connect different water pipes in a plumbing system. Note that as part of the DOE's 2015-2020 Strategic Technology Plan,[1] the DOE is "consolidating (the) existing seven network sites (nodes) to four" as part of its Next Generation Network project.

[1] NYC DOE DIIT. "Strategic Technology Plan 2015 – 2020," http://schools.nyc.gov/NR/rdonlyres/06585363-835B-40B9-9BDF-D75DC0FDFB1F/0/techplanFINAL_021816.pdf.

Figure 1: The citywide "ring" that comprises the DOE backbone visualized on a monitoring screen in the Department of Education's Network Operating Center in Downtown Brooklyn.

- Usually, internet traffic travels to schools via whichever of these seven nodes on the ring is geographically closest to the building. The traffic from the node to the school building goes through a wired connection, called a circuit, provided by either Verizon or Lightower. This node to school connection is sometimes referred to as the "last mile" (and the problem of getting enough bandwidth through that connection is called the "last mile problem"). The speed of this connection may range, presently from 10 Mbps (the standard rolled out in 2007) to 150 Mbps, with some exceptions. The DOE is currently in the process of upgrading all circuits in the city to each school building to 100Mbps for single school campuses and 150 Mbps for shared campuses as part of its "School Circuit Conversion" project. According to a September 28, 2017[2] status report from the NYC DOE Department of Instructional and Information Technology ("DIIT"), "as of mid-April 2017, site surveys are 85% completed, 285 circuits have been migrated, 306 sites have been upgraded, and all school buildings will have upgraded circuits by March 2019."

Collectively, the city's ring of seven (and, in the future, four) nodes/sites, together with the individual circuits used to connect school buildings, are referred to as the DOE's "Wide Area Network" (WAN). This nomenclature helps distinguish these components from both the global public internet and the smaller, local, individual internal school networks (Local Area Networks or "LANs."

[2]NYC DOE DIIT. "2015 – 2017 STRATEGIC TECHNOLOGY PLAN STATUS UPDATE",http://schools.nyc.gov/NR/rdonlyres/78AC88BD-FFB9-4462-9D98-2FB171E304B8/0/Strategic_Tech_Plan_Status_Update_VShare_Final.pdf.

WHY AREN'T NYC SCHOOLS USING WIRELESS CONNECTIONS?

Despite the recent evolution in high bandwidth wireless technologies, the concentration of buildings and obstructions in New York City coupled with bandwidth requirements means that wireless technologies are not yet practical at the price appropriate for connecting NYC schools to the DOE within the city. For the foreseeable future, last mile wired connections will be the norm, though mesh technology merits watching.

HOW MUCH LAST-MILE BANDWIDTH DOES A SCHOOL NEED?

If you have only enough water to run your sink but not your sink and your toilet at the same time, you don't have enough water coming into the house. The same holds true for bandwidth to the internet. Just as there needs to be enough water pressure for each toilet and shower, there needs to be enough internet - enough bandwidth - to serve everyone who wants to use it in a school building.

How much bandwidth is needed in a school? A common refrain is that all schools need "high speed internet" or "broadband." Until 2015, the FCC's general-purpose definition of "high speed" for a U.S. household (not a school) was 4Mbps. The FCC definition, however, has since been upgraded to 25Mbps for a home. As part of this definition the FCC also provides guidelines for how much bandwidth is required for various common internet uses, including:

- General Browsing and Email - 1 Mbps
- File Downloading - 10Mbps
- Streaming Standard Definition Video - 3-4 Mbps

Many schools have yet to benefit from this capital investment to get to the "short term" FCC standards. According to a March 2018 report to the City Council by the Finance Division[4] regarding the FY 2015 – 2019 Capital Plan, "More than half of buildings, 810, are at or below 20 Mbps." Moreover, there are yet to be any public plans to get NYC schools to the longer-term FCC goal of 1 Gbps per 1,000 users.

[3]School Construction Authority. "Capital Plan", https://dnnhh5cc1.blob.core.windows.net/portals/0/Capital_Plan/Capital_plans/02222018_15_19_CapitalPlan.pdf
[4]New York City Council Finance Division. "Report of the Finance Division on theFiscal 2019 Preliminary Capital Budget, the February 2018 Proposed Amendment to the FY2015-2019 Five-Year Capital Plan, and the Fiscal 2018 Preliminary Mayor's Management Report for the Department of Education and the School Construction Authority", https://council.nyc.gov/budget/wp-content/uploads/sites/54/2018/03/FY19-Department-of-Education-and-the-School-Construction-Authority.pdf

WHAT WILL NYC SCHOOLS GET FROM THE IMPLEMENTATION OF THE "SHORT TERM" FCC STANDARD IN ITS SCHOOLS?

The "short term" standard - 100 Mbps per 1,000 users in a school - equates to 100Kbps of bandwidth per user which, it should be noted, is more conservative than the FCC's guidelines in 2015, cited above, for general home use. For example, "general browsing and email" is considered by the FCC to require 1Mbps, which is 10x the school per user bandwidth of 100Kbps.

Let's use the FCC's 2015 bandwidth guidelines for common internet usage scenarios to build up an illustration of network requirements for a single school:

- 10 administrators are using the network for email and general browsing
  10 students x 1Mbps = 10 Mbps
- 30 students are downloading files for a science project
  30 students x 10 Mbps = 300 Mbps
- 20 students in a lab are viewing a streaming video portion of an online literacy program
  20 students x 4 Mbps = 80 Mbps

Total aggregate bandwidth in this very modest usage scenario is 390 Mbps — *nearly 4x the target (100 Mbps) for single school bandwidth in NYC*. As we saw in our school visits to produce this report, it's not uncommon to encounter buildings with 1,000 students but 2,000 to 3,000 devices connected to the network due to personal devices brought into the school. And so the right answer is likely that New York City should be upgrading its schools not to 100 Mbps but right to the 1Gpbs standard, consistent with what other parts of the country (e.g., Colorado) are doing.

Finally, we'd note that even 1 Gbps may be too conservative for the mid- to long-term. Most technology, media, and other private organizations work in environments with greater connectivity out to the public internet than 1 Gbps. If private enterprise is any indication, we can expect to see more and more bandwidth-intensive products and services for education, and so we should be building the infrastructure required.

WHAT HAPPENS WHEN TOTAL BANDWIDTH NEEDED BY STUDENTS AND TEACHERS EXCEEDS WHAT'S AVAILABLE TO A SCHOOL?

In the case of schools and networks, administrators will probably not notice much lag in their most common network application, email. However, this lack of enough bandwidth does mean that students downloading files will spend more time waiting and hence less time on task — bad news. Some students' file downloads may time-out causing them to have to restart downloads, wasting still more time. The students watching video lessons will experience buffering that both distracts from the presentation and makes the video take longer than planned. We've each probably experienced something similar when too many people try and use hot water at the same time in a house— someone ends up with a cold shower.

HOW DOES INTERNET TRAFFIC ONCE IN THE SCHOOL BUILDING GET TO THE USERS WHO WANT TO USE IT?

Today, in most New York City district schools, the various administrators' computers in the main office, along with a desktop computer in a classroom for teacher use, are connected by wire to the overall network and, in turn, the internet itself. The wires are cabling designed for networks that in the jargon are called "CAT 5" or "CAT 6" cables, and are run in the walls. These cables looks like telephone wire (itself technically called "CAT 3") but thicker with slightly bigger, wider jacks.

By contrast, most of a schools' internet users, especially students, do not uses wired connections but instead connect wirelessly using Wi-Fi. Using Wi-Fi, bandwidth comes to their device (e.g., a laptop) through a radio signal than emanates from a nearby "Wireless Access Point" (a "WAP"; example from a DOE school pictured in Figure 2). The "WAP" is connected to the "last mile" using the same physical network of CAT 5 or CAT 6 cables to which office desktops are directly connected.

Figure 2: A WAP

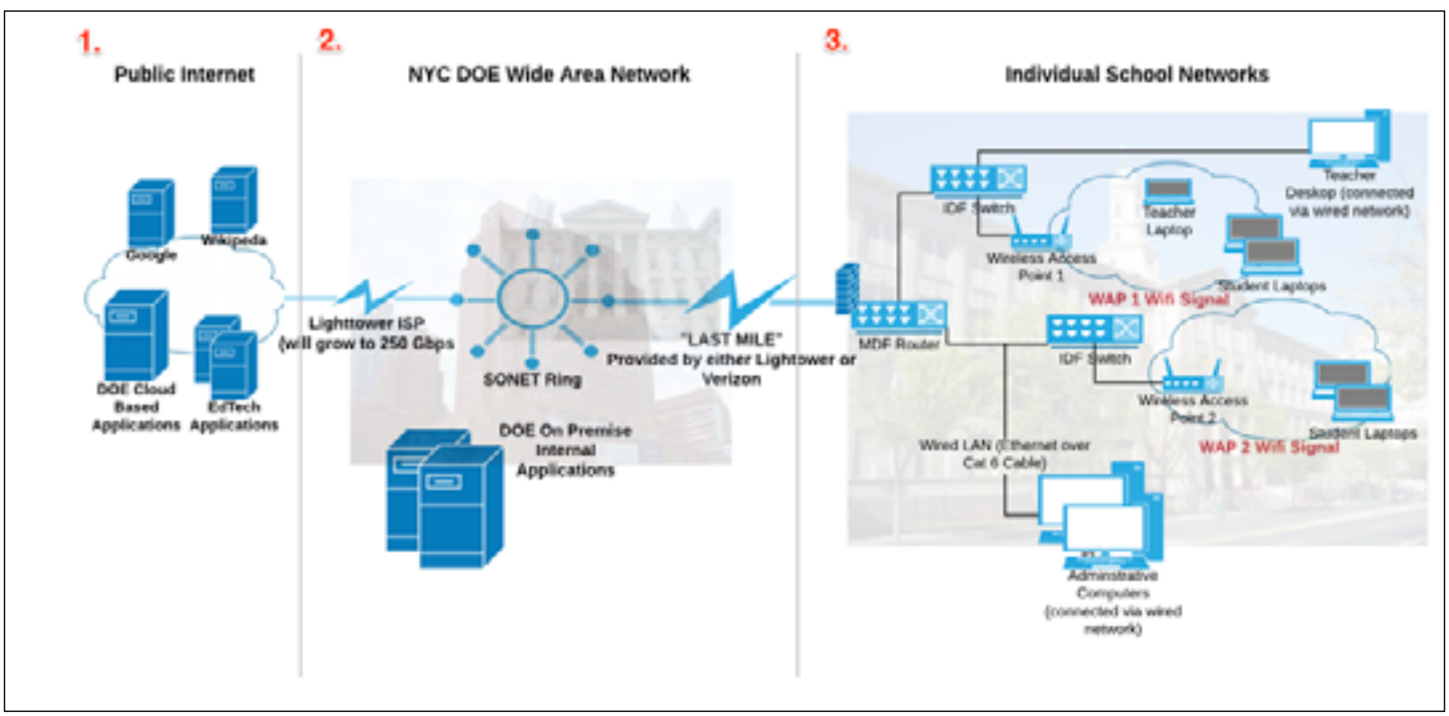
One of the early problems Wi-Fi helped to solve, especially in older schools that may not have had extensive wired networks, was to create more areas in the building where the internet could be used, so long as those devices could be reasonably close to a WAP.

Developments in Wi-Fi technology have improved the range of WAPs as well as the amount of connections a single WAP can handle. But just as technology has improved, so, too, have the amount of devices connecting and the amount of bandwidth each device uses increased.

The amount of WAPs in a school, their location, and their physical power which manifests as the strength of the emitted radio signal are all important factors in the speed and reliability of the Wi-Fi portion of a school network.

HOW DO THESE PIECES FIT TOGETHER?

How does this all — the public internet and the DOE connection to it, the DOE ring and nodes that compose its WAN, the last mile, and schools own network—work in tandem?



The key components are:

- **The public internet.** The internet is the largest wide area network of them all. It connects the various resources a school might access such as Google, Wikipedia, an online learning management system, various "backends" to applications on phones and laptops, and "cloud" services such as Dropbox.

- **The NYC DOE wide area network.** This includes the ring that connects nodes around the city as well as last-mile connections. It also includes any applications and services that are hosted by the DOE itself.

- **A schools' local area network.** This is all of the equipment, cabling, and wireless within the four walls of the school.

UNDERSTANDING FUNDING CHALLENGES

WHAT HAS ALREADY BEEN DONE TO INVEST IN NYC SCHOOL NETWORK INFRASTRUCTURE?

In 2007, New York City began installing cables, connections, and other equipment required to provide high speed internet to school buildings. The city spent a lot of money, over $300 million, and some were critical of the upgrades and the approaches taken.

There have been some unforced errors along the way. A 2011 investigation found that a consultant hired to help upgrade the schools' network and computer infrastructure had stolen $3.6 million in funds associated with the federal government E-Rate program.[5] E-Rate provides federal subsidies to districts and schools upgrading computer networks.

A consequence was that the FCC, which runs E-Rate, temporarily suspended the NYC Department of Education from using E-Rate funds. According to the *New York Times*, Comptroller Scott Stringer found that as of 2014, the NYC DOE had "missed out on as much as $120 million" in funding that could have been used to improve school networks because of this suspension.[6]

[5]Fernanda Santos. "Consultant to the Schools Stole Millions, Officials Say", NYTimes.com, April 28, 2011, https://www.nytimes.com/2011/04/29/nyregion/consultant-to-schools-stole-millions-officials-say.html?_r=0
[6]Elizabeth A. Harris. "New York Schools Lose Millions Amid an Inquiry, Comptroller Says ", NYTimes.com, November 26, 2014, https://www.nytimes.com/2014/11/27/nyregion/new-york-schools-missing-out-on-millions-in-technology-funding-comptroller-says.html
[7]Yoav Gonen. "DOE hiring tech firm linked to kickback scheme", February 24, 2015, https://nypost.com/2015/02/24/doe-hiring-tech-firm-linked-to-kickback-scheme/

In 2015, the consulting firm associated with the 2011 incident was nearly awarded a new $1.1 billion contract[7] before watchdogs noticed and alerted elected officials.

The contract was subsequently broken up into multiple pieces, with a total cost brought down from $1.1 billion to $472 million. Ironically, the accelerated contracting process that led to the previously embroiled consulting firm being chosen may have been motivated in part by a desire to secure $23 million in E-Rate funding that some believed would be lost if a contract was not quickly awarded.

Extenuating circumstances have also created headwinds. The rollout of fiber-optics citywide took longer than expected, especially the work of several large telecoms that provide much of the city's connectivity.

HOW ARE IMPROVEMENTS TO NYC SCHOOLS' NETWORKS FUNDED? WHAT'S BEING DONE CURRENTLY IN THE DEPARTMENT OF EDUCATION AND SCHOOL CONSTRUCTION AUTHORITY?

Improvements to school networks are capital projects and hence are not included in the DOE's annual $30 billion operating budget[8] but rather are part of the NYC Department of Education's Capital Plan developed and administered with the School Construction Authority.

The overall Fiscal Year 2015-2019 Five-Year Capital Plan for the NYC DOE and School Construction Authority initially totaled nearly $14 billion and has since risen as of the latest February 2018 amendment to $16.5 billion.

$6.6 billion of the plan is for "Capital investment" which includes $1.6 billion for "School Enhancement Projects" of which $654 million is for "Technological Enhancements," described in a March 2018 report to the City Council to be used for "increasing bandwidth connectivity in schools as well as increasing capacity to support more widespread and intensive use of web-enabled devices."

[8] NYC DOE. http://schools.nyc.gov/AboutUs/funding/overview/default.htm

The $654 million is broken down in the following chart:

TECHNOLOGY ENHANCEMENTS SUMMARY

ENHANCEMENT	PROPOSED AMENDMENT	2017 ADOPTED AMENDMENT
Next Generation Voice and Data Upgrade	$246.9mm	$246.9mm
Next Generation Access Points Upgrade	$101.8mm	$101.8mm
Next Generation Data Wiring Upgrades	$46.8mm	$46.8mm
School Electrification Upgrades	$246.9mm	$246.9mm
Ancillary Technology Facilities Upgrade	$64.6mm	$64.6mm
Non-Infrastructure Projects	$44.5mm	44.5mm
Technology-SESIS	$4.4mm	$4.4mm
TOTAL	$654.4mm	$654.4mm

Figure 3: Planned Usages of $654m in 2015-2019 Capital Plan (Source: SCA)

RECOMMENDATIONS

TTM Advisors believes that there are very capable, dedicated public servants at both individual schools and in the New York City Department of Education's Division of Instructional and Information Technology (DIIT) making a real difference to improve school networks. That said, due to the geographic size and number of sites that need to be connected, the challenges that the New York City Department of Education faces to create a fast, reliable school network that is both secure and adaptable to rapid evolutions in educational technology are daunting.

As mentioned in this report, TTM Advisors recommends that the Department of Education considers revising its target for "last mile" internet access to schools from 100 Mbps to 1 Gbps. Not only is gigabit internet the Federal Communication Commission's recommended standard for schools, it's the size of "pipe" that we believe many schools in New York City, especially high schools, need right now based on what we have observed in the preparation of this report.

The DIIT is also presently making some early strategic investments in wireless access management tools to give school network administrators on the ground finer-grain controls to throttle and prioritize the most critical and most pedagogically-relevant network traffic over more mundane usage, including inevitable personal use. Wireless access management will also improve security, especially related to the growth in personal devices on networks. We believe this work should be accelerated and prioritized amongst other network improvement projects.

Finally, there has been some discussion over the last few years of the Department of Education, and DIIT specifically, creating a kind of Technology Council to improve communication between education technology vendors and individual schools. Based on our school visits to prepare this report, it appears that such a council could be helpful, especially to help raise awareness and to address some common issues schools encounter with network settings and optimization options to improve the network performance of certain applications on which schools rely heavily.

The issues involving high speed internet access in New York City public schools are complex and require more detailed study than this report provides. We are hopeful that by presenting these limited findings, we can encourage further public discussion of this pressing topic.