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Fiber Network Strategic Analysis

DRAFT

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1. Executive Summary

The City of Alexandria operates a high-speed communications network over fiber optic connections provided by Comcast in accordance with a Fiber Use Agreement, which was negotiated in connection with its cable television franchise agreement. This “dark fiber” Institutional Network (I-Net) is comprised of fiber cables owned and maintained by Comcast, but is otherwise separate from Comcast’s network and service offerings. Connected only to equipment owned and operated by the City and Alexandria City Public Schools (ACPS), the I-Net offers similar levels of scalability, security, and flexibility as would City-owned fiber. In total, the I-Net is comprised of 76 fiber connections to City and the ACPS locations, not including several City-owned connections, at cost to the City of $456,000 per year. Separately, the City leases fiber to six public safety radio sites at a cost of $50,400 per year, two of which overlap with I-Net sites, for a total of $506,400 in annual payments to Comcast for network connections. We expect this will increase significantly when the Fiber Use Agreement expires in October 2016, or relatively soon thereafter.

The I-Net has allowed the City and Schools to stay ahead of their own communications needs, preventing a lack of affordable connectivity from creating barriers to the adoption of new technology. Both the City and ACPS have become almost entirely dependent on the I-Net for internal communications and data networking. Today, the City and Schools operate I-Net connections at speeds of 10 gigabits per second (Gbps) and 1 Gbps, respectively.

In light of the City’s uncertain future for network connectivity and the long-term budgetary risks the current situation presents, the City retained CTC Technology & Energy (CTC) to examine its options for serving these sites. The City’s goal is to identify the most cost-effective and future-proof solution—whether that is to lease dark fiber from Comcast (if offered); buy leased managed Ethernet transport services from Comcast; acquire transport services or lease fiber from another provider; or construct and operate its own fiber network connecting the sites.

Our analysis reveals that a City-owned and City-operated fiber optic network represents the most prudent approach to address City and ACPS needs, rooted in a solid business case based only on cost-avoidance, and would provide long-lasting infrastructure offering protection against the risks posed by growing capacity needs and unknown commercial service pricing. Moreover, our analysis explores additional benefits of a City-owned fiber optic network, ranging from direct revenues from potential fiber leasing to off-the-balance-sheet benefits facilitated by a network design optimized for City and ACPS requirements, including supporting economic development objectives. In particular, a City-owned fiber network will, if engineered correctly, have sufficient excess fiber capacity to be leased to a private investor to serve as the backbone for a fiber-to-the-premises (FTTP) deployment. The network can thus not only secure lease revenues, but can also serve as an incentive for private investment in next generation infrastructure to reach homes and businesses throughout Alexandria.

1.1 Constructing and Owning Fiber Will Likely Cost the City Less Over Time

To assess options for meeting internal connectivity needs currently supported by the I-Net, CTC compared the likely range of costs for commercial leased network services to that of constructing and operating its own fiber network.

1.1.1 Estimated Cost for Leased Transport Service

To replace the I-Net, the City would need to serve the 76 sites with connections ranging in capacity from 1 Gbps to 10 Gbps. To benchmark potential rates for these services, we surveyed the costs of comparable transport services offered in other localities in the region. (These examples are provided in Appendix A.) We estimate that the monthly recurring cost (MRC) for a 1 Gbps transport service will range from $530 to $1,064 per month per site, and that a 10 Gbps service will cost $3,200 to $6,360 per month per site.

To establish a conservative baseline for capacity requirements, we assume that 69 sites could be served with 1 Gbps connections, and that seven “core” City and ACPS sites would require 10 Gbps connections. To replace the City’s existing I-Net connections with leased services, then, would cost $708,000 to $1.42 million per year—a total cost that is 56 percent to 210 percent higher than the City’s current dark fiber costs under the Comcast Fiber Use Agreement.

The actual leased service pricing would vary with the term of the contract. It is important to note, too, that the lower end of the pricing range is very aggressive (and unlikely to be available to the City); we expect the actual pricing to be in the middle to upper end of this range.

1.1.2 Estimated Cost of Construction of City-Owned Network

If the City were instead to construct a fiber network to replace the Comcast I-Net fiber connections, it would need to finance or fund the build-out of the network and cover the annual cost of operations and maintenance. We developed a high-level design and cost estimate for a City-owned network that would serve the sites. The network would consist of a total of 35.75 miles of underground fiber, and would connect the 76 existing I-Net sites (including two public safety radio sites), the four standalone public safety radio sites, and six additional sites requiring upgrades to existing City fiber connections. The total cost for the outside plant construction (OSP) to connect the 86 sites is estimated to be approximately $8.8 million, not including approximately $754,000 for network electronics that might be required to facilitate the transition and a significant increase in capacity and network resiliency. A breakdown of the total implementation costs is provided in Table 1.

Table 1: Summary of Estimated Costs for Implementation of a City-Owned Network

Cost Component	Estimated Cost
Outside Plant Fiber Construction	
Engineering	$646,000
Project Management / Quality Assurance	$247,000
General Outside Plant Construction	$7,115,000
Railroad, Bridge, and Interstate Crossings	$268,000
Outside Plant Fiber Splicing	$170,000
Fiber Termination / Building "Entrance"	$381,000
Fiber Construction Subtotals:	$8,827,000
Network Electronics	
Core/Distribution Electronics	$754,000
Edge Site Electronics	$0
Network Electronics Subtotals:	$754,000
Total:	***$9,581,000***

Our estimate for the operations and maintenance (O&M) costs for the fiber network is $183,000 in year one (or about $177 per site per month, on average). In our analysis, we escalate O&M costs at 3 percent per year over the life of the network. (We discuss this analysis in Section 5.) In order to finance the fiber network, the City could consider securing a bond for a 20-year or 30-year term. The monthly principal and interest (P&I) payment in this case would be $747 (20-year term) or $577 (30-year term) per site. Table 2 compares the current average monthly cost per site ($528) to the estimated monthly costs the City would incur with either a 20-year bond ($924 per site) or a 30-year bond ($754 per site). Note that the gap between the current cost and the potential future cost per month per site will widen as O&M costs increase each year.

Table 2: Comparison of Monthly Costs per Site in Year 1 for City-Owned Network

	O&M	P&I	Total
20-Year Bond	$177	$747	$924
30-Year Bond	$177	$577	$754
Current	-	-	$528

1.1.3 Evaluation of Business Case for Constructing a City-Owned Network

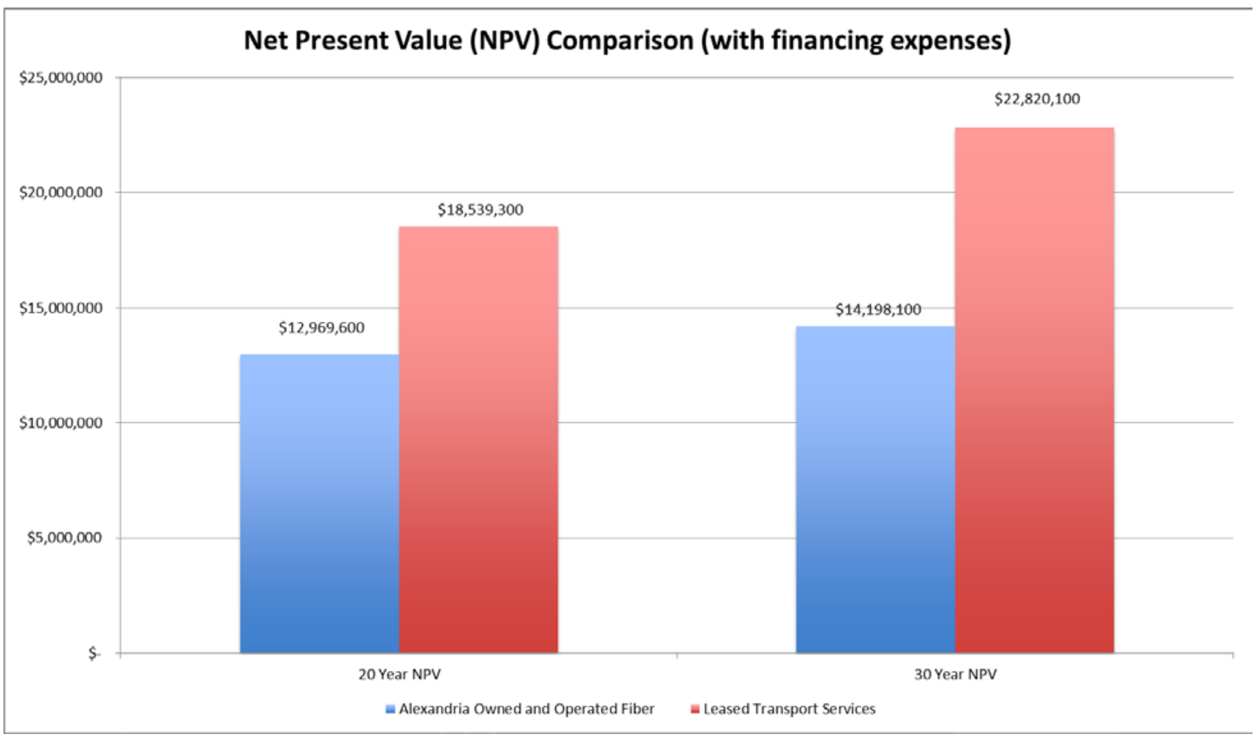
To determine whether a business case exists for the City to build a fiber network to connect its 86 sites (and, potentially, to meet other needs), we examined the 20-year and 30-year financial results of multiple scenarios with variations in the costs of leased transport services, increases in the number of sites that receive 10 Gbps service, and a combination of these factors.

These scenarios illustrate that the Net Present Value (NPV) of the City's capital and operating costs over the 30-year analysis would be lower than the cost of leased transport services over the same time period in all scenarios except for one (which is based on sample Comcast pricing in another jurisdiction that we do not believe will be available to the City).

The scenario we believe will most closely match the City's experience in terms of managed services fees is based on the cost of services available within the region, recently offered by Comcast through competitive bidding processes. In these cases, the cost of Comcast transport services was $1,064 per month for a 1 Gbps service and $6,360 for a 10 Gbps service. We factored in a 5 percent decrease in pricing every five years (as has been the trend in the market).

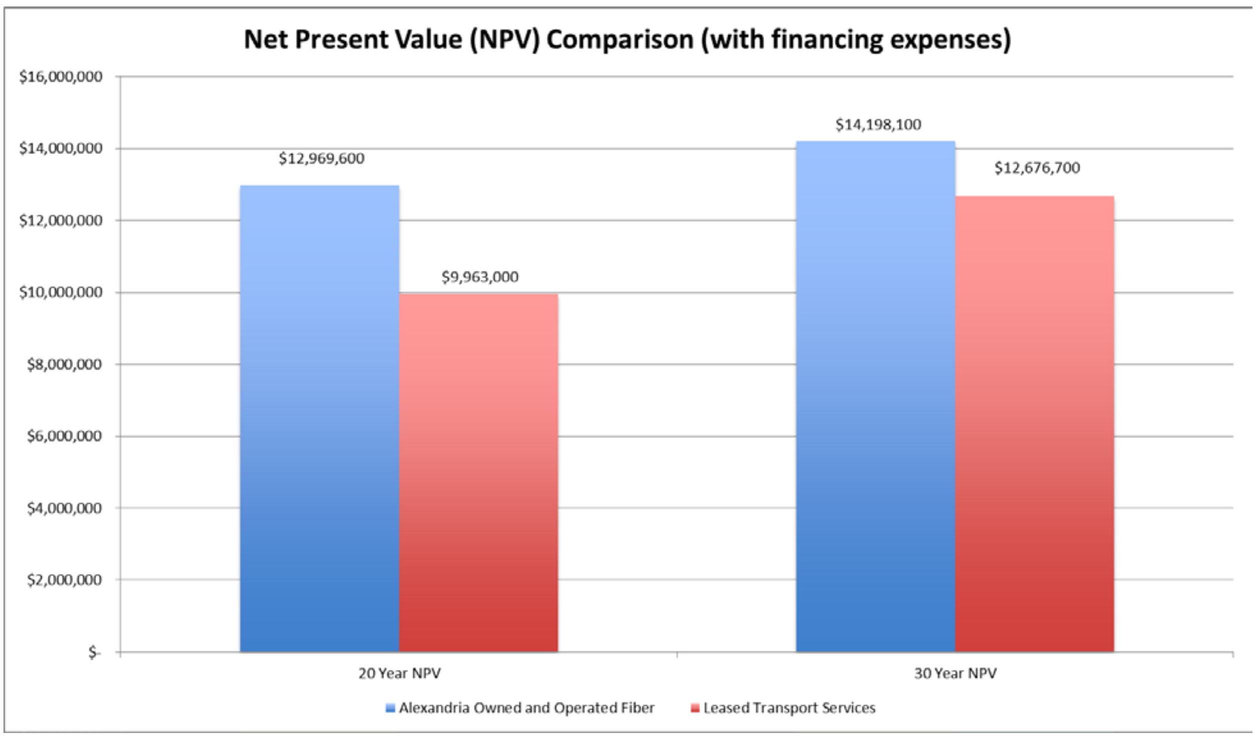
In this base case scenario, the NPV of the City-owned fiber network compared to that of the leased transport network is lower over both 20 years and 30 years, as depicted in Figure 1.

Figure 1: Net Present Value for Base Case Scenario



If we compare City-owned fiber against leased service pricing at the low end of the potential spectrum, well below rates seen in this region, the financial analysis does not present as obvious of a business case on the basis of cost-avoidance alone. In this scenario ("Scenario Two," described in more detail in Section 5.2), the NPV of the City-owned fiber network compared to that of the leased transport network is somewhat higher over both 20 year and 30 year terms, as depicted in Figure 2. As we discuss in more detail in later sections, we present this scenario only as a worst case, and expect actual pricing for leased services will be substantially more. Furthermore, this does not take into account the wide range of other functional and financial benefits of City-owned fiber, not the least of which is the potential to capture revenues through dark fiber leasing.

Figure 2: NPV Comparison with Low-End Managed Service Pricing



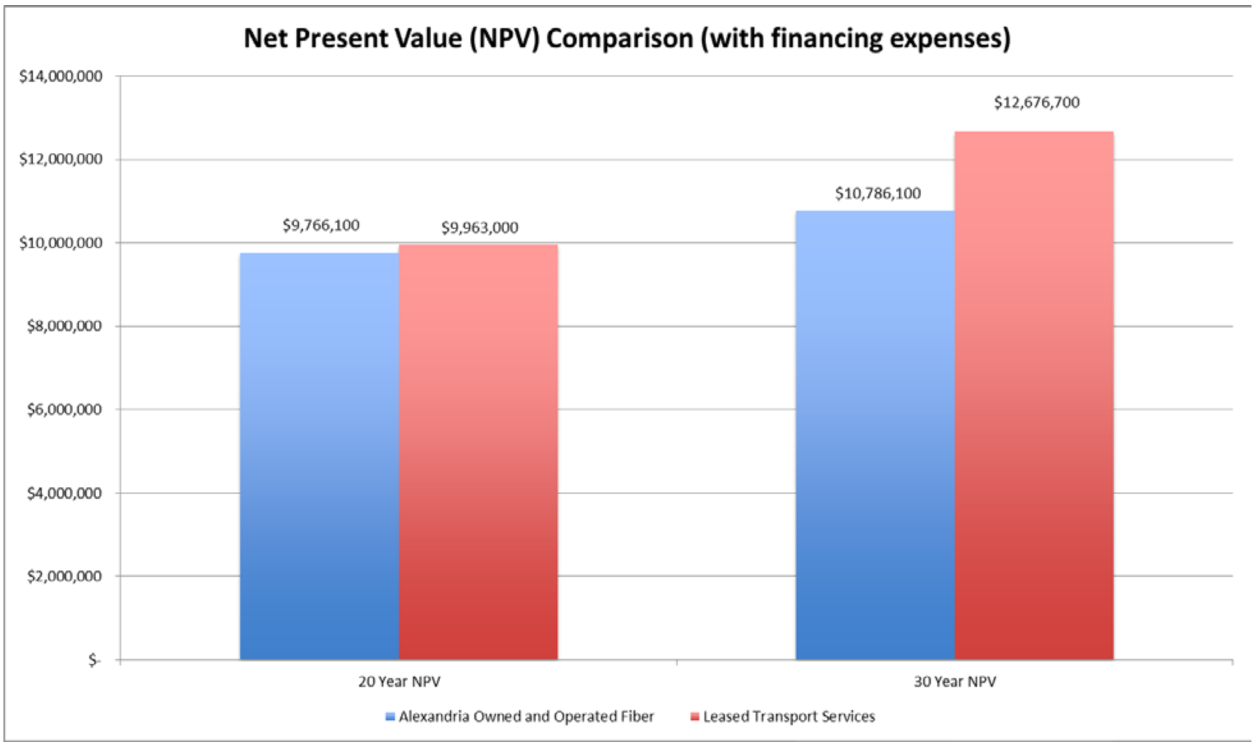
The other scenarios we explored, which are described in Section 5, give us a better understanding of the factors that would affect the sensitivity of the NPV analysis to variations in leased service pricing and levels of capacity purchased.

1.2 Potential Revenue Opportunities Related to City-Owned Network

With a City-owned fiber network, the City would retain the ownership of the fiber assets and would be positioned to provision services according to its evolving needs without being tied to a carrier's contract or pricing. The City might also have opportunities to earn revenue (such as by leasing excess dark fiber) or otherwise monetize its network, as described in Section 6. While we do not include these potential revenues in our base financial analyses for constructing a City fiber network, the potential is significant and serves to strengthen the business case for a City fiber network even in the unlikely event there exists an adequate commercial leased network service offering that costs less than City fiber over time.

We explore one such candidate scenario in which, even when compared to the low-end leased fiber pricing described above, the addition of potential revenues from long term leases presents a strong business case for City fiber. In this scenario, described in more detail in Section 6.1.2, we assume long-term leases of only 48 fiber strands within the proposed 288-strand backbone to two commercial operators - one seeking to offer residential and small business FTTP services, and another seeking to serve large enterprise customers. In this case, the NPV of the City-owned fiber network compared to that of the leased transport network is lower over both 20 years and 30 years, as depicted in Figure 3.

Figure 3: NPV Comparison with Low End Managed Service Pricing including Candidate Fiber Lease IRUs



1.3 Summary of Recommendations

Based on overall strong business case for a City fiber network, and recognizing that City-owned fiber provides the greatest flexibility to meet current needs and to respond to future requirements, we recommend that the City proceed with certain steps towards constructing a fiber network and seeking private partnerships further supporting this direction.

Specifically, we recommend that the City:

1) Initiate planning and engineering of a City fiber network as soon as possible to minimize the amount of time the City may be required to entertain either higher cost dark fiber leases or managed network services from Comcast;

2) Develop and release an RFP soliciting public-private partnerships informed by the City's ongoing efforts to design a fiber network, and supported by its earnest intent to construct fiber with or without private support; and

3) Update the fiber network construction business case financial analysis with direct cost inputs from future Comcast proposals and fiber construction bids to refine and validate the recommended strategy, as well as to serve as a tool to compare the financial impact on this strategy of potential proposals from private partners.

2. Introduction: Why Is Alexandria Considering a City-Owned Fiber Network?

2.1 The Benefits Enjoyed by the I-Net Are Likely Coming to an End

The City's fiber optic Institutional Network ("I-Net") was largely constructed more than two decades ago in accordance with the City's cable television franchise agreement with Jones Intercable of Alexandria, Inc., which was transferred to Comcast in 1999. The I-Net was constructed by Jones in conjunction with fiber optic upgrades to its own system at a small fraction of the cost to build the network on a standalone basis, and was provided to the City as part of the franchise agreement until 2011. During this time, the City enjoyed the benefits of a dark fiber network at no cost, able to activate these connections at any speeds supported by its own network electronics, with full control over network configurations and technology choices.

In 2011, the current Fiber Use Agreement was negotiated in conjunction with the renewal of the Franchise Agreement, under which the City now leases dark fiber from Comcast to connect 76 I-Net sites, including 21 Alexandria City Public School (ACPS) locations, at a total annual cost of $456,000.[1] Separate from this agreement, Comcast leases fiber to a total of six public safety radio locations, two of which overlap with I-Net sites, at an annual cost of $50,400 per year. In total, the City pays Comcast $544,000 per year for one or more fiber connection to each of 80 locations.

Even at the current cost, the Comcast-provided fiber represents a reasonably cost-effective approach for connectivity of City and ACPS sites, offering most of the functional benefits of a private fiber network: physical security of data connections over which City and ACPS traffic is not comingled with Comcast's commercial customers; scalability to increase connection speeds to any level supported by City equipment without increased recurring fees; and the flexibility to manage network traffic, capacity, and features without limitations imposed by any commercial provider's technology or design choices.

Unlike City-owned fiber, the I-Net can only be used for internal City and ACPS purposes, precluding many types of uses targeting economic development objectives that might require connectivity of the I-Net fiber to other commercial providers or business customers. When the Fiber Use Agreement expires in October 2016, we expects it will be renewed only at a

[1] The City pays $500 per month to connect the 76 I-Net sites, for a total annual cost of $456,000. Six public safety radio sites are connected at a total annual cost of $50,400 (or $700 per site per month), two of which overlap with City I-Net locations—incurring costs for both I-Net and public safety radio connections. Combined, the City pays about $528 per month, on average, to connect each of the 80 unique sites.

significant increase in costs to the City, whether for continued use of the dark fiber, or more likely, for lesser leased transport services (i.e., managed Ethernet service) to these sites.

Given the long-standing dependence on the Comcast fiber to support a wide range of critical communications systems impacting the day-to-day operations of nearly every City agency and ACPS, identifying a suitable replacement strategy for the I-Net is essential. Constructing its own fiber optic network is one candidate strategy available to the City - one which is singularly capable of: 1) providing a physical network design that is optimized for City and ACPS facilities; 2) providing the greatest degree of long-term control over risks associated with unknown demands and costs; and 3) affording the greatest flexibility to leverage the network to promote economic development objectives and to generate new revenue streams.

2.2 A City-Owned Fiber Network Would Enable Significant Public Safety and Other Operating Benefits

Reliable high-speed networks are critical to meeting the changing needs of local governments, with a specific emphasis on law enforcement and public safety agencies, including maintaining security around business districts, critical public infrastructure, and schools. In addition to the many wireless applications that can help emergency personnel cut precious seconds off their response times, robust wireline networks play a critical role in public safety, due to their speed, bandwidth, and reliability.

The City of Alexandria has a long history of leveraging advanced communications applications to improve efficiencies of government services and to promote public safety: criminal arraignments can be conducted using videoconferencing technologies, saving the government thousands and avoiding the dangerous task of transporting prisoners; traffic systems, including traffic signals wired with fiber optics, can be monitored and adjusted in real-time in response to traffic incidents; roadway accidents, weather events, and other emergencies can be broadcast to thousands of users simultaneously through public alert systems via e-mail or text message. The improvement to efficiencies in public safety created by high-speed network service is hard to overstate.

During large-scale regional emergencies, secure multi-party communications are often required, and wireless facilities may become overwhelmed and unusable. Many local jurisdictions nationwide have taken steps to address these needs. In particular, Alexandria has been a key participant in many National Capital Region (NCR) initiatives to enhance regional interoperability of public safety communications systems, including the construction of a fiber optic network known as NCRnet. Built for "security, reliability, and high bandwidth," NCRnet was created specifically to address the needs of first responders and emergency support personnel.[2] The high capacity and redundancy of the fiber network structure lends itself to a wide range of demanding communications applications, including computer aided dispatch system interoperability (i.e. “CAD2CAD”) and reliable videoconferencing capacity[3], ensuring the ability for real-time coordination during a regional emergency.

Aside from public safety purposes, day-to-day use of government enterprise applications deployed using virtualization, including those leveraging cloud-hosted and distributed architectures, turn reliable networks into a basic government requirement. In schools and governments for example, desktop virtualization leveraging the deployment of “thin” clients can substantially lower IT support costs, but require very robust network architectures ensuring low-latency and reliable transport of data that are often out of reach for school systems and local governments.

The variety and scale of government applications demands the big bandwidth that fiber provides. As populations grow, institutional broadband needs will grow accordingly; and as data storage and applications move off of conventional hard drives and into the cloud, government institutions will become increasingly bandwidth hungry. These realities point to the need for future-proof institutional network infrastructure, which fiber provides.

Alexandria has enjoyed the benefits of dark fiber capacity, scalability, and flexibility without even the relatively limited drawbacks of maintaining the outdoor fiber optic plant. The City’s future is likely to require a shift to one or the other end of the spectrum between City-owned versus leased infrastructure. Local governments that meet their public safety communications networking needs with leased circuits enjoy a number of operational benefits. For example, they do not require internal staff to operate and maintain the portion of the network outside their facilities. Constructing a City-owned and operated fiber network, on the other hand, offers some critical functional and technical benefits over leased circuits— making that approach a much more desirable long-term strategy. Specifically:

- The ever-increasing demand for public safety IT services means that the City will need to continuously increase its leased circuit capacity—at an ever-increasing recurring cost; fiber networks can be easily and cost-effectively scaled to meet demand.
- The City cannot fully evaluate the reliability or availability of a leased circuit because it has no knowledge of the service provider’s proprietary network or physical

[2] http://www.broadband.gov/docs/ws_pshs/pshs_afflerbach_reference.pdf
[3] http://www.ncrnet.us/

infrastructure, and has no control or management of the services. In contrast, a City-owned fiber network is completely under the City's control.

- Leased services are not independent of the networks used by the public and are therefore less secure and reliable. A City-owned network is independent of the public infrastructure.

- The City does not have control over network security between endpoints on a leased circuit. The City would completely control the network security on its own network.

Each of these factors is addressed in detail below.

2.2.1 A City-Owned Fiber Network Would Provide Capacity Superior to Leased Services

A City-owned fiber network operates at the speed of its physical interfaces to the fiber—typically a 1 Gbps or 10 Gbps interface. This provides far superior network capacity compared to Metro Ethernet services obtained from Comcast, Verizon, or other prospective commercial providers. Although those services are capable of 1 Gbps or greater speeds, the increased speed comes at a significantly greater cost (Section 5.6) because the service providers meter the service, and the City needs to carefully assess capacity needs and establish a limit to fit that budget.

2.2.2 A City-Owned Fiber Network Would Facilitate Control and Management of the City's IT Infrastructure

A network built on leased network services obtained from a service provider cannot provide the City with the control and management that would be available on a City-owned fiber network. For example, linking two-way radio communications systems, supporting videoconferencing over Internet protocol (IP), or using time division multiplexing (TDM) connections all require the ability to manage bandwidth across the entire network. Although enhanced and even guaranteed quality of service (QoS) can be provisioned at increased cost when using a managed service provider for connectivity, a City-owned fiber network would provide the control and capability to increase bandwidth based on the City's needs without incurring additional recurring costs. Further, it would offer the ability to implement advanced QoS mechanisms that could be enforced on a network-wide, end-to-end basis, again without paying additional recurring fees for "premium" classes of service.

Leased network services are in essence a "black box" in terms of control, management, and physical network architecture attributes impacting performance and reliability. The City is forced to rely on a service provider to maintain and operate the core equipment of a leased service, including tasks such as configuring the equipment, monitoring the hardware and physical infrastructure, and performing routine maintenance. Under the leased model, the City must pay for the service provider to make changes in the core of the network for a new application, increased bandwidth, or implementation of new policies for enhanced QoS. Moreover, the City is not able to control who manages and maintains the core of the network.

In contrast, with a City-owned fiber network, each piece of the communications network is controlled and managed by the City. Choices regarding the management and expansion of the network are in the hands of the City—not the phone or cable company.

In exchange for limited control and visibility into the network architecture, commercial providers generally offer service level agreements (SLAs) that specify minimum performance parameters. One key performance parameter stipulated in most SLAs is network availability, defined as the percentage of time the network is functioning at minimum performance levels over some specific measurement timeframe.[4] In a leased circuit network, the customer is not aware of all of the potential risks to network service availability, nor provided the information necessary to determine whether a network is constructed to meet actual availability requirements.

Although commercial providers offer financial damages when SLA parameters are not met, typically limited to some percentage of the monthly service fees, these damages are generally not significantly stringent to warrant the engineering of a "public safety grade" network by commercial providers. In other words, it may be more cost-effective for a provider to discount monthly fees on relatively rare occasions than to build a network with sufficient resiliency to serve first responders in a disaster situation, assuming damages even apply in a force majeure event. This may not be acceptable for public safety communications systems relying on the network, which must be architected and operated according to standards that recognize even momentary outages can result in the loss of human life—indeed, providing public safety grade resiliency is rarely viable on the basis of purely economic considerations for a commercial provider.

The availability of a communications link is derived from the probability of a failure within the network between two points; several key factors that affect availability and cannot be determined by the City in terms of its leased service options include:

- Physical redundancy in the plant
- Physical redundancy in the building entrances

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[4] Most commercial providers will offer 99.9 percent availability, or less than 45 minutes of outage per month, for standard connections, whereas services delivered over fully diverse connection paths and redundant electronics can achieve 99.999 percent availability, or less than 30 seconds of outage per month.

- Physical redundancy in the networking equipment
- Proper configuration and regular testing of network equipment to take advantage of hardware and link redundancy
- Redundancy for power and HVAC
- The number of facilities the circuit crosses between endpoints
- Whether the plant is located underground or aerial
- Who has access to the core networking equipment and plant
- How old or well maintained the core equipment is
- How the system is monitored and maintained
- The single points of failure in the communications link

Many of these factors can be approximated and the leased circuit provider may be able to provide relative numbers. However, for critical public safety services, these approximations—and the network's availability—may not meet the requirements of the emergency support functions it serves. For example, in the case of physical architecture issues, such as the physical routes of cabling, approximations are simply not sufficient—and detailed maps are usually considered proprietary and confidential to a commercial provider.

In addition, lessees are subject to the lessor's schedule for repair and maintenance of the circuit. Although it may be possible to include provisions in the service level agreement (SLA) for special priority service restoration, it is unlikely that providers will adhere to SLAs during major disaster events. Further, there may be no way to ensure that a leased circuit for public safety is the first link to be repaired during a major disaster.

A similar problem can arise in scheduled and unscheduled maintenance of a leased circuit. The timing of these maintenance downtimes may not correspond to available downtimes in a public safety network. Maintenance on a City-owned fiber network can be coordinated to minimize downtime and so that the City can prepare for an outage by adapting operational procedures.

2.2.3 A City-Owned Fiber Network Would Offer Independence from Public Networks

A City-owned communications network does not rely on physical infrastructure, equipment, or other resources that carry public traffic for residents and businesses. The advantage of an independent network, then, is that it is not affected by public traffic or public network outages.

During major public safety incidents, for example, public networks such as the Public Switched Telephone Network (PSTN) and the Internet are often overloaded. This can lead to busy signals on the PSTN and slow or unusable connectivity on the Internet. Privately owned networks typically do not experience the same traffic increases and can be designed to handle any expected traffic increase during a major incident.

In the event of an incident, priority and preemption is critical for public safety networks. However, the operators of many public networks (e.g., the Internet, cellular networks) are only in the planning and early implementation stages of providing priority and preemption capabilities, so those capabilities are not yet universally available, and not always entirely effective.

In addition, a City-owned fiber network can prioritize bandwidth both in the core and at the edge. This capability would allow the City to prioritize by location and preempt all traffic other than public safety traffic, if necessary. More importantly, a City-owned infrastructure can be allocated so that sensitive traffic always has dedicated capacity, because capacity can be readily scaled.

In contrast, managed network service providers routinely use shared resources to reduce their cost. Commercial carriers intentionally oversubscribe their networks to minimize costs (and maximize profits), because all of their customers are not likely to simultaneously use their services to full capacity all of the time.

The only way to ensure that there is adequate bandwidth is to overbuild a network to support maximum capacity demand, not average utilization (while absorbing the cost even if the bandwidth is not used). A City-owned fiber network would be a more reliable, higher capacity, flexible network infrastructure because it would be designed to support a broad range of initiatives and to easily and seamlessly scale to meet new bandwidth requirements.

2.2.4 A City-Owned Fiber Network Would Enable Control Over Network Security

Implementation of network security on a leased circuit typically occurs at the edge of the network. Many leased connections use end-to-end encryption to securely transmit data over networks that share a core network with public users. Frequently, the provider of a leased circuit may dictate what types of end-to-end security are allowed on a leased circuit (IP managed services, for example), and generally offer limited insights into their own internal security controls.

On a City-owned fiber network, the City could control end-to-end security throughout the network infrastructure. In addition to data security, the fiber network would allow the City to manage physical security as well as network security and the staff who manage and operate the network. This includes:

- Access to facilities and networking rooms
- Passwords to edge equipment and firewalls
- Network access and authentication
- Monitoring of networking rooms, including security alarms and surveillance cameras
- Desktop security
- Equipment placement and provisioning

2.3 A City-Owned Fiber Network Would Complement Private Sector Broadband Initiatives

There are a number of private sector fiber build-outs we can expect in the long term. Comcast will eventually need to expand fiber resources to serve residential customers at capacity levels that keep pace with nationwide trends. Comcast and Verizon also serve the enterprise market, and will continue to build fiber on an as-needed basis to reach these customers. Carriers like Zayo, Crown Castle/Sunesys, and Level(3) are also likely to compete in the enterprise space, and possibly will seek to build fiber to cellular towers and small cell and/or distributed antenna systems (DAS) as commercial wireless carriers require additional capacity. Based on recent responses to the City's municipal fiber request for information (RFI), there may even be interest by certain providers seeking to invest in Fiber-to-the-Premises (FTTP) to serve residential and business customers in direct competition to existing broadband offerings from Comcast and Verizon.

The City's network will need to be built to meet the needs of its internal users, but can be architected to complement these potential private network build outs. The City can optimize its design to take advantage of opportunities for joint build and resource sharing or trading where the networks overlap.

One of the largest catalysts of the construction of new fiber in the past decade has been Fiber to the Cell Tower (FTT). As bandwidth demands intensify, the carriers have been migrating to fiber from SONET and TDM based services for backhaul. In 2005, it was common for a cell tower to only be connected with less than a DS-3 (45 Mbps) telecommunications circuit. Even though some of this was deployed on fiber, it was generally purchased from the traditional carriers at a circuit-based level, which is not scalable to higher speeds nor compatible with the current Long Term Evolution (LTE) technology now favored by wireless providers. Hundreds of megabits per second (Mbps) are needed for high-speed LTE services, and backhaul will need to be expandable beyond that for future 5G services

The major expansions are at various phases in their deployment, and the City of Alexandria can capitalize on these network synergies. AT&T Wireless, Verizon Wireless, Sprint and T-Mobile do not generally build their own fiber backhaul, rather they choose to outsource this and buy Ethernet services from a third party. They typically hold RFI and RFP selection processes to select an infrastructure partner, such as Crown Castle and Zayo, to provide a turnkey service in the area.

These many network buildouts are good news for the City of Alexandria. However, there still may be gaps in coverage. And we know, again from the experience of other cities, that incumbents and prospective market entrants may not have sufficient demand to trigger building its infrastructure in all of the City's neighborhoods—and that the neighborhoods that are not built are often lower-income areas where residents cannot or choose not to make the financial commitment to that service. We expect very little of this "redlining" in Alexandria, to the extent an FTTP provider were to invest in the City, given its particular demographics and affluence; that said, one of the many benefits of a City-owned fiber network is that it could be used to attract private investment sooner by reducing market entry costs and time to market, and potentially fill in service gaps if that proves necessary (i.e., if the private sector does not make the necessary investment).

2.4 Capacity Needs of K-12 Educational Institutions Require Fiber Today

Educational institutions have consistently driven the upper limits of demand for Internet capacity since the inception of the Internet, with its very origins rooted in government funded research and interconnectivity of university labs. Today, Internet2 exists solely as a network to support exchange of massive datasets and to provide a testbed for emerging technologies over links supporting speeds of 100 Gbps and higher. At the K-12 level, a shift in pedagogical models across the Country, often characterized by computers and tablet devices being provided in the classroom to each student, is driving unprecedented capacity demands for both Internet and internal network capacity.

Increased adoption of Internet-based systems for the administration of standardized testing in public schools, including computerized adaptive testing (CAT), requires more reliable, higher-speed connectivity to ensure these tests can be performed without technical challenges that might invalidate the results. Learning management systems, from companies like Blackboard, Inc., provide online tools that are commonly used by instructors, students, and parents to communicate, assign homework, submit homework, collaborate on assignments, and manage use of social media. Digital text books, video, and other educational reference materials aligned with curriculum standards are more commonly being produced and used in the classroom.

The drivers for bandwidth are numerous, and only increasing. Deployments of advanced Wi-Fi networks within schools across the Country has become commonplace to support the increased number of devices being connected and the broader use of digital content and online resources within schools. However, connectivity between schools and to the Internet still represent a challenge and a significant cost in many school districts.

In acknowledgement of the need and the associated challenges with providing the necessary capacity to schools in particular, the Federal Communications Commission (FCC) has modernized its rules for the E-Rate Program in support of an expressed goal to deliver 1 Gbps of Internet connectivity to every 1,000 students, and internal Wide Area Network (WAN) connectivity of 10 Gbps to every 1,000 students[5]. Assuming these targets reflect similar needs in Alexandria, an average of more than 8 Gbps per ACPS school facility is warranted now or in the near term to serve its almost 15,000 students across 17 primary school locations.

2.5 A City-Owned Fiber Network Would Mitigate the Risk of Unknown Future Costs

In contrast to leased circuits, dark fiber owned and “lit” by the end user(s) can be upgraded to higher capacity at no increase in recurring costs. In other words, a fiber network owned by the City would offer a mechanism to mitigate the risk that future needs will exceed the capacity of commercial services that each entity can afford, thereby containing the associated exposure to price increases. The fiber network will offer capabilities that leased circuits cannot, and will do so at a known cost that will remain relatively constant; if the City and/or ACPS are required to lease circuits to meet internal needs, each will likely pay higher annual prices *ad infinitum*, and may be forced to make do with less-than-adequate connections now or at some point in the future.

While there is no precise way to scientifically project capacity needs over the long lifespan of fiber optic cables, past trends offer some insight. Neilson’s Law,[6] which states that a high-end user's connection speed grows by 50 percent per year, suggests that only 100 Mbps of utilization today forecasts more than 5 Gbps (5,000 Mbps) of capacity demand in just ten years. As noted, schools represent some of the heaviest institutional users of network capacity, with multi-gigabit per second capacity demands more likely to occur in the near term..

There is no practical way to project whether commercial service levels at a given price point will come close to keeping pace with the increase in demands, but lacking meaningful competition from providers having the same level of existing fiber infrastructure to the same sites in Alexandria as Comcast, we cannot expect that the benefits of technological advances will be passed along to the City and ACPS. This represents a significant area of ongoing risk associated with relying on commercial leased services.

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[5] "In the Matter of Modernizing the E-rate Program for Schools and Libraries," Report and Order and Further Notice of Proposed Rulemaking, WC Docket No. 13-184, Federal Communications Commission, FCC 14-99, July 11, 2014. https://www.fcc.gov/document/fcc-releases-e-rate-modernization-order.

[6] https://www.nngroup.com/articles/law-of-bandwidth/

On the other hand, the City already operates 10 Gbps connections to each site, and the schools operate 1 Gbps connections to each site. The next network equipment refresh for ACPS, which will be required in the near-term whether or not dark fiber is available, will migrate connections to a at least 10 Gbps - the de facto standard offered by the most commonly available hardware for medium to large enterprise networks. The next emerging network hardware standard providing 100 Gbps connections, already available at cutting edge pricing, will continue to drop in price over the years and provide the next upgrade path at predictable costs, again without increasing operating costs.

2.6 Local Governments Have a Long-Term Record of Successful Fiber Networks for Government Use

The City of Alexandria desire to examine the feasibility of constructing fiber optic infrastructure is part of a broader trend among local governments. Indeed, localities have exercised significant leadership in broadband innovation in the United States. For more than 15 years, a significant minority of localities have chosen to build or purchase fiber for themselves.[7] In this model, the locality negotiates, purchases, or constructs fiber optics to serve its own needs and those of its local community anchor institutions (CAIs)—connecting over fiber entities such as schools, libraries, public safety departments, and government buildings, and perhaps senior centers, public housing projects, or healthcare institutions.

Alexandria is among many hundreds of communities that have considered, or have implemented, low-risk fiber deployment strategies. In the NCR and surrounding communities, these include Washington, D.C., Arlington County, VA, Montgomery County, MD, Carroll County, MD, Harford County, MD, Baltimore, MD, Howard County, MD, Anne Arundel County, MD, and others. Across the nation, these cities include San Antonio, New York City, Raleigh, Los Angeles, Atlanta, Seattle, San Francisco, Boston, and hundreds of urban, suburban, and rural Cities and counties.

We anticipate that this trend, which has continued unabated over the past decade and a half, is likely to continue into the future. The Broadband Technology Opportunities (BTOP) grant program under the federal Recovery Act has, in some parts of the country, accelerated this trend by enabling localities and regional consortia to build more fiber to public sector and other anchor institutions. American communities are increasingly interested in this type of network to achieve self-reliance in communications, and treat broadband and Internet access as the critical "core utility" that it is.

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[7] These internally focused projects contrast to those that are public-facing: networks built by public entities for the purpose of serving residential and business consumers where the private market has failed to deliver adequate service or has failed to deliver competition.

3. Existing I-Net Technical Overview and Assessment

This section provides a brief technical overview and assessment of the existing I-Net so as to provide a basis for comparison to the proposed City-owned fiber optic network described in Section 4.

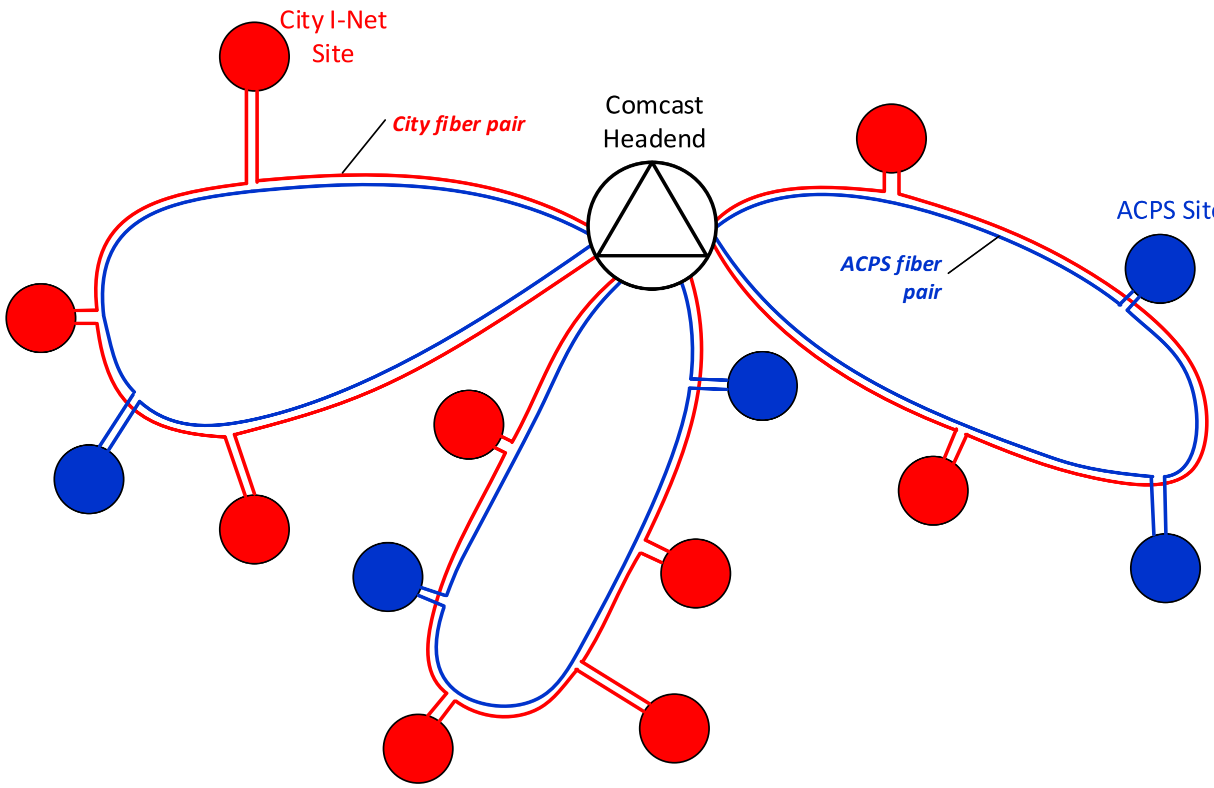
3.1 The I-Net Provides Scalability for City IT Services Comparable to City-Owned Fiber

The I-Net is comprised of "dark" fiber owned and maintained by Comcast, but which is dedicated for use by City and ACPS sites. This means that as currently configured, fiber between City sites only connects to network electronics owned and operated by the City; likewise, fiber between ACPS sites only connects to network electronics owned and operated by ACPS.

Comcast's role in this network is limited to maintaining the physical infrastructure, consisting of fiber optic cables containing strands dedicated for the I-Net, as well as physical space within the Comcast headend for City and ACPS electronics. Comcast is in no way involved in technology choices or configuration decisions impacting City or ACPS IT services, which enables the City and ACPS to leverage the full capacity of the fiber optic strands and benefit fully from technology advancements and periodic hardware upgrades.

The I-Net fiber was built in parallel with a fiber optic deployment performed by Comcast's predecessor, and thus mirrors the physical architecture of the cable subscriber network. Specifically, all fiber cables emanate from the Comcast headend, and form multiple rings throughout the City that each terminate back at the headend. Along the way, these rings are interrupted by laterals that provide connections to individual City and ACPS sites. Within each of the applicable rings, the City and ACPS are each allocated a single pair of fiber strands, which are spliced such that the rings pass through each I-Net site in a logical sense (Figure 4).

Figure 4: I-Net Logical Fiber Architecture



Over the years, the City and ACPS have transitioned through several generations of network electronics on the I-Net, with each upgrade providing vast increases in capacity and functionality—all over the same fiber optics and without impact to fees paid to Comcast. The seven to ten year lifecycle of network equipment requires these periodic upgrades whether or not the City has access to dark fiber, but having access to the fiber ensures that the full potential of the hardware and new technologies can be used to benefit City services, rather than providing a mechanism for a commercial provider to generate more revenue over the same infrastructure. History has shown that we can expect exponential increases in capacity with each new generation of network hardware, and at approximately the same price point each time.

For example, the City implemented its initial I-Net deployment between 1998 and 1999 using Asynchronous Transfer Mode (ATM) technology, which provided backbone rings operating at 155 Mbps shared by between two to 11 sites per ring. This was considered state-of-the-art at the time. In 2004, the City replaced this hardware with Gigabit Ethernet (GE) equipment operating at 1 Gbps (1,000), and also offering less complicated configurations and greater fault tolerance. In fact, this upgrade resulted in as much as 8 Gbps (8,000 Mbps) of capacity per fiber pair (50 fold increase), leveraging Course Wave Division Multiplexing (CWDM) to provide multiple GE links over each backbone fiber ring. Today, all City backbone links utilize 10 Gigabit Ethernet (10GE), with each link operating at 10 Gbps and providing 20 Gbps of capacity per ring.

With each equipment upgrade, the dark fiber I-Net has allowed the City to achieve exponential increases in capacity to keep ahead of demand, while making technology choices that reduced complexity of the network and enhanced network resiliency. Meanwhile, 40 Gbps and 100 Gbps technologies are already commercially available within the same enterprise market sector, with technologies targeting the commercial carriers that are capable of operating at many thousands of gigabits per second (terabits per second, or Tbps)—all capable of operating over fiber optic cable installed decades ago and foreshadowing future capabilities for decades to come.

3.2 Limited Fiber Strand Count Hinders Flexibility and Increases Network Electronics Costs

Despite the virtually unlimited capacity of a single strand of optical fiber, the limited number of strands comprising the current I-Net has required the City and ACPS to make tradeoffs between functionality and network hardware costs.

The logical ring topology can require a larger number of higher speed optical interfaces than would a network in which dedicated strands could be allocated between hub locations and each site, since capacity in a ring configuration of this type is shared by multiple sites. For example, rather than installing a mix of GE and 10GE interfaces to meet varying site requirements, the ring topology requires that all sites be equipped with 10GE interfaces if any of the sites on a particular ring require that level of capacity—in other words, each ring is only as fast as its weakest link.

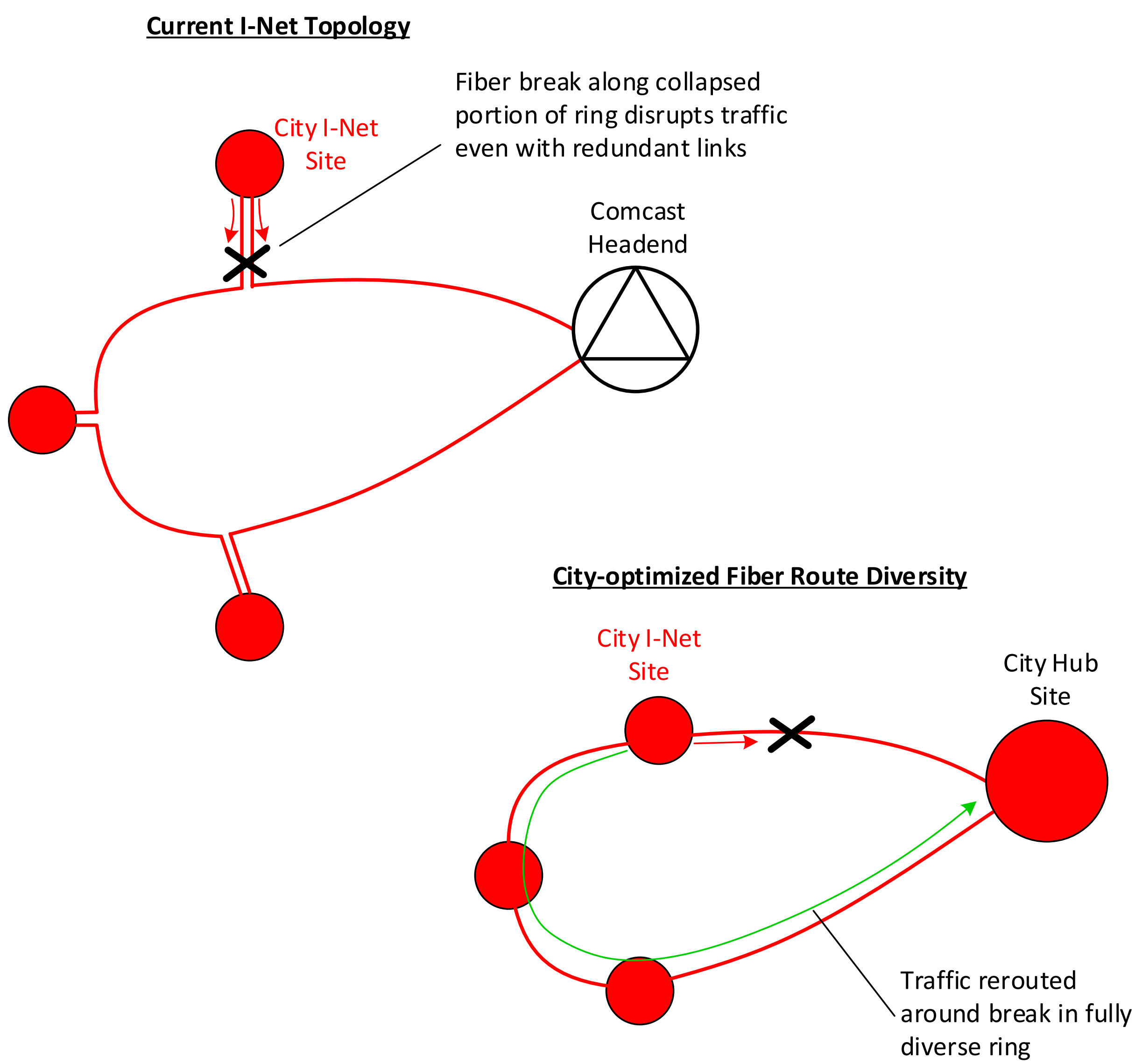
Furthermore, without the use of an underlying optical platform capable of carrying multiple wavelengths of light over a single fiber strand (i.e. Wave Division Multiplexing, or WDM), the limited number of strands precludes the use of dedicated fiber strands for application-specific purposes having particularly unique requirements around security, capacity, or both - such as public safety radio trunk connections; storage area network (SAN) connectivity for data mirroring between redundant datacenters; and providing transport to and through Alexandria for other governmental networks, such as NCRnet.

3.3 I-Net Path Diversity Is Not Optimized for City Sites

Although the Comcast cable television network is configured with rings of fiber, both sides of the fiber ring "collapse" onto the same physical path for lateral connections to I-Net sites. Whether a few hundred feet or a mile, these laterals represent a single point of failure that reduces network resiliency. Aside from the risk to connectivity for a particular site, a fiber break at or near City Hall, the Public Safety Center, or other key sites might cut the rest of the City off from Internet service and/or other important applications and data that reside at that these sites. The Comcast headend also represents a single point of failure in terms of physical fiber connectivity and electrical power for core City and ACPS electronics. In the event of a disaster scenario, such as a fire, all network connectivity could be interrupted for a long period of time.

A City-owned fiber network can be designed so that backbone ring path diversity is optimized for City sites, thus eliminating or drastically reducing single points of failure (Figure 5). Also, rather than a single core site, multiple core sites can be included in the architecture to allow fiber path diversity to compliment physical datacenter redundancy, thereby eliminating nearly all risk of IT service outages due to loss of network connectivity.

Figure 5: I-Net Single Points of Failure



3.4 I-Net Fiber Has Limited Economic Development Potential

The existing I-Net Fiber Use Agreement limits the use of the fiber to non-commercial, governmental purposes, and precludes the City from using the fiber to provide services that in any way would "result in business competition between [Comcast] to third parties or that may result in loss of business opportunity for the Company."

Simply put, if the City is seeking to promote competition within the local broadband market by reducing barriers of entry for competitive providers, the I-Net fiber is not likely to be part of that solution. City-owned fiber, on the other hand, can be built with sufficient fiber strand capacity to support a wide range of candidate approaches to encourage private investment in competitive service offerings and/or create the potential for direct fiber lease revenues, including:

- Providing low-cost access to City fiber to serve as a backbone for last-mile FTTP providers;
- Providing dark fiber connectivity between enterprise customers and middle-mile providers;
- Facilitating access to ACPS and Alexandria Library sites for innovative providers of E-rate eligible Wide Area Network (WAN) and Internet services; and
- Interconnecting business incubators with potential federal government agencies customers.

4. Fiber Network System Level-Design and Cost Estimates

Construction of a fiber optic network designed specifically to meet City and ACPS requirements is an alternative to commercial services that may offer long-term cost savings and provide technical advantages. In this section, we provide an overview of a technical approach and cost estimates developed to examine the feasibility of constructing a fiber network.

4.1 System-Level Design Overview

CTC developed a system-level design for a fiber optic network to serve as the basis for estimating costs. Design priorities targeted by this conceptual design include:

1) Providing fiber connectivity to all City and ACPS facilities for which leased service fees can be avoided at any level, including four public safety radio sites not overlapping with the current I-Net site list;

2) Maximizing network resiliency for all City and core ACPS facilities primarily, and secondarily, for all remaining ACPS sites;

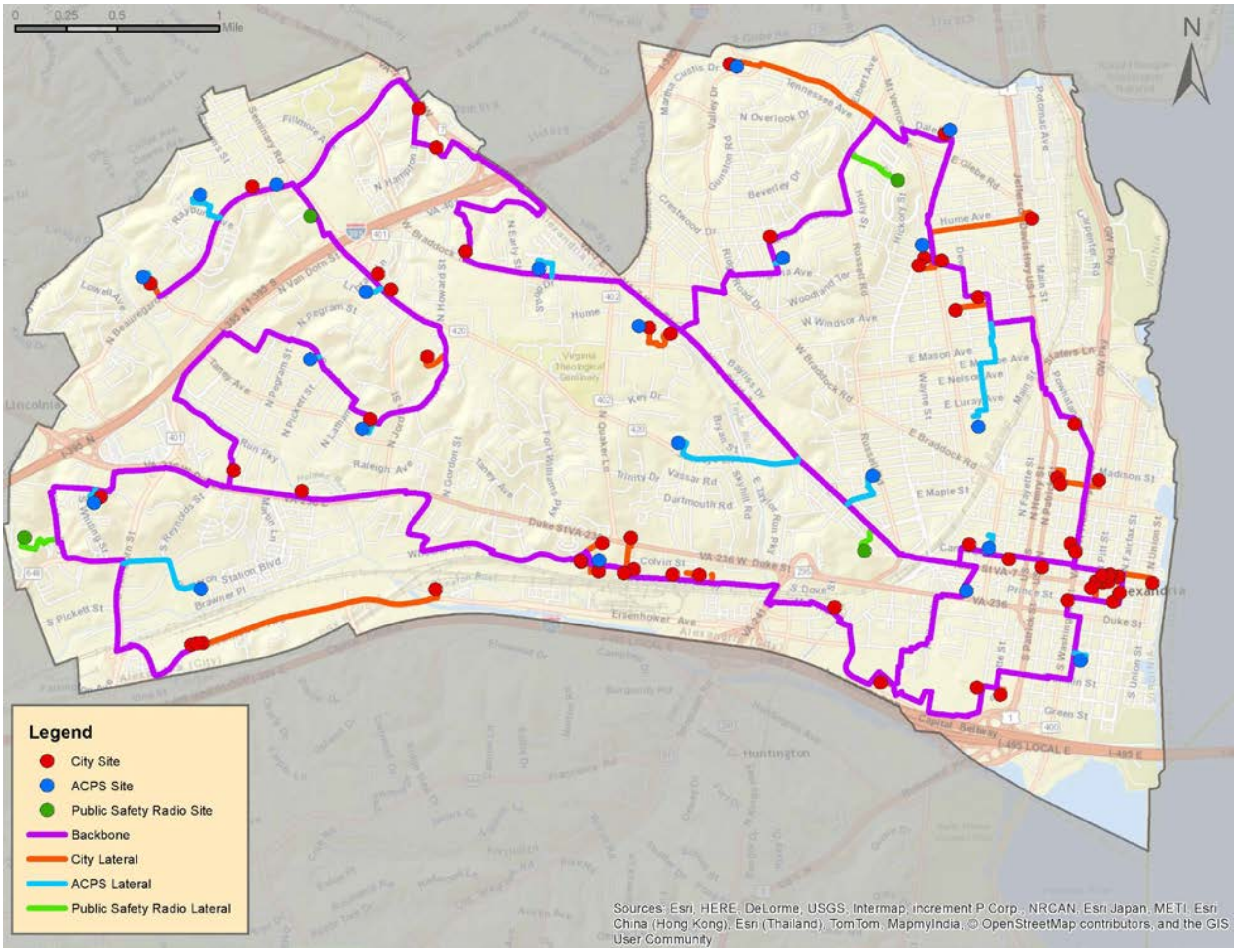
3) Minimizing costly railroad and Interstate crossings to meet basic connectivity objectives; and

4) Maximizing opportunities to support economic development and fiber lease opportunities by optimizing routing to pass by or within close proximity to large businesses, business parks, and residential developments.

4.1.1 Physical Fiber Architecture and Cost Considerations

The physical network architecture resulting from the specified criteria, illustrated in Figure 6, is comprised of approximately 35.8 route miles of fiber connecting all 86 designated sites (Appendix C-2), including the 76 existing I-Net sites, four additional standalone public safety radio sites, and six City facilities connected "downstream" from I-Net site via City-owned multimode fiber. We include this latter category in the design and cost estimates, as the locations sit on the planned backbone routes, and would benefit from the capacity and performance benefits of newer, singlemode fiber optic connectivity. Moreover, the ownership status of the supporting infrastructure, including conduit and utility pole attachments, are in question in some cases, and may be impacted by any change in the City's arrangement with Comcast.

Figure 6: System-Level Fiber Network Architecture



The backbone paths form three rings targeting core City and ACPS sites with maximum path diversity, where reasonably practical. The cost estimates are based on a flexible approach to splicing and fiber termination, and include a backbone consisting of 288-strand cable. Depending on splicing configurations, logical connections between particular sites can be established with or without route diversity over backbone rings, and can include dedicated paths between any sites without the need for "patching" between intermediate sites. Appendix C provides more detailed maps and a site list.

The path diversity achievable with this complete architecture allows for connections to be activated with redundant electronics capable of maintaining service availability even in the event that a single path is disrupted due to a fiber break, enabling it to support critical network services requiring upwards of 99.999 percent network availability (less than 30 seconds of outage or less per month), or better, for most sites. This gold standard for network availability is only achievable with physical diversity of network connectivity, because a single fiber break can require between several hours to several days to repair.

Beyond the physical fiber optic cable routing, there are a number of technical design and construction attributes impacting the cost estimates presented in the following section, including the following:

Fiber strand count—The number of individual fiber strands provided in a single cable correlates to the capacity of the cable. Due to the vast effective bandwidth of fiber, it is feasible to scale the rate of data transmission carried by even a single fiber strand to meet all of the City's needs indefinitely; however, the cost of network electronics increases exponentially with this capacity. On the other hand, the material cost of fiber strands represents a very minor component of the overall cost of fiber construction (about $0.01 per strand per foot, compared to $25 to $35 per foot for the total cost of typical construction); it is thus prudent to install a cable of sufficient size to meet any conceivable requirements to ensure these needs can be met with a configuration of electronics that are as low-cost as possible.

In fact, with sufficient fiber strands, the City can increase network capacity many orders of magnitude above current levels with little or no change to its network electronics. While we anticipate no portion of the network will require more than about 80 to 100 strands, even with redundancy and substantial spare capacity, cost estimates are based on the installation of a 288-count cable along most segments of the network. This will ensure sufficient capacity for nearly any conceivable expansion of internal needs, fiber leasing, or even future support of business or residential services.

***Underground versus aerial construction*—**Budgetary cost estimates utilized for the business case analysis anticipate completely underground construction of the fiber, with fiber cables placed in a two-inch conduit. Cost savings may be possible by employing "aerial" construction (attaching fiber to utility poles), as discussed further in Section 4.4. Since the City does not own its own utility poles, aerial construction would require negotiating pole attachment agreements with Dominion Virginia Power and any joint pole owners. These agreements generally require recurring fees per pole, and generally require the attacher to pay the cost of any upgrades or modifications to the utility poles necessary to support the new attachment. These "make-ready" costs can vary drastically depending on the crowding on the poles, condition and age of the poles, and the pole owner's technical standards.

Conduit size and quantity – While it is possible to install fiber cable directly underground, this complicates installation and makes repairs difficult to implement without creating permanent impairments to the communications path. Instead, the cost estimates are based on the installation of flexible plastic conduit that provides a path into which fiber cable can be installed, allowing for cable slack to be pulled to accommodate repairs, or for new cable to be installed to expand capacity. Cost estimates are based on the placement of two conduits along all backbone routes to provide capacity for future scalability, conduit leasing, etc. It should be noted that placing additional conduits simultaneously results in relatively minor increases in cost, within limits. Depending on material prices, 2-inch conduit is preferable along backbone routes, as it can accommodate one or more additional large-strand-count fiber cables in each, with sufficient space for placing additional smaller cables to for purposes of placing "lateral" connections to future locations.

Underground construction methodology—A wide range of methodologies are available for underground construction of conduit. Trenching is common in unpaved areas, allowing for relatively quick installation of any number of conduits. Where paved surfaces are concerned, this requires special cutting equipment and generally expensive restoration.

More recently, "micro-trenching" has begun to gain popularity, wherein narrow cuts are made at a depth of less than 12-inches, generally along the edge between the asphalt paving and concrete curb or gutter. These micro-trenches support placement of a narrow, specialized conduit, and the cuts can generally be restored quickly with common asphalt patching materials. As micro-trenching is relatively new, its long-term impact on total cost of ownership is not well understood, with reduced upfront costs but potentially higher costs for maintenance and repairs due to the shallow placement of the conduit.

Our cost estimates are based on the placement of conduit using horizontal directional drilling (or "directional boring"). Directional boring allows conduit to be installed long distances, ranging from several hundred to over 1,000 feet at a time, between two small pits dug on either end. One advantage of directional boring is the ability to place conduit at varying depths to avoid existing utilities. Another advantage is that the surface above the bore does not have to be disturbed, except at the entrance and receiving pits, as well as at small "test pits" dug to verify existing utilities to prevent accidental damage where the bore will cross.

Although generally considered more expensive in the past, labor costs for directional boring are now fairly comparable to that of trenching, while reducing surface restoration costs. Furthermore, unlike micro-trenching, large conduits can be placed to offer longer term scalability. The cost benefit of directional boring in terms of reducing restoration is diminished as congestion of existing utilities increases. Whereas directional boring and conduit placement in relatively uncongested, unpaved areas may cost less than $10 per foot, we anticipate per foot costs to average over $70 per foot in the City's downtown areas, and nearly $30 per foot elsewhere.

Handhole placement and size—Handholes are enclosures installed underground in which conduit terminates for the purpose of providing access to conduit for installing cable, as well as to house cable splice enclosures and cable slack loops required for future repairs. Handholes generally must be placed at intersections of multiple conduit paths, or where the conduit path makes a sharp change in direction. Handholes provide important access points to underground conduit, enabling expansion of the conduit infrastructure (i.e., installation of a lateral connection to a new network location) without disrupting conduit or installed cables. While cable can be pulled upwards of several thousand feet at a time, cost estimates for the City network assume installation of handholes every 500 feet on average, ensuring that the infrastructure supports cost-effective expansion to new sites, including access to businesses that might be targets of commercial network operators seeking to lease City fiber (or conduit space).

Right-of-way restoration and fees—The network cost estimates assume that the City will pay no encroachment fees for construction along or under City and State roads, but may incur railroad crossing application and licensing fees totaling upwards of $15,000 per crossing, not including special construction costs, which generally entail steel encasement of conduit. The cost estimates assume that the City will incur typical costs for limited permanent asphalt and concrete restoration required for utility "test pitting" necessary to verify the location of other utilities in the path of the fiber to prevent damage—generally this consists of excavation within small areas of less than 2-feet in diameter. For downtown areas where little or no greenspace exists in the right-of-way, representing approximately 10 percent of the total routes, we assume more significant costs for test pit restoration in concrete, asphalt, and other paved surfaces.

4.1.2 Network Logical Topology and Electronics

A wide range of logical topologies and network equipment configurations are feasible given the physical architecture of the proposed fiber network. An example of one candidate logical network topology facilitated by the proposed physical architecture is illustrated conceptually in Figure 7 and Figure 8 for the City and ACPS, respectively.

In each case, we propose that the fiber is configured to provide diverse backbone rings between select hub sites, separately for each the City and ACPS, with each hub site designated to aggregate point-to-point connections from "edge" sites. Moreover, edge site connections should be configured to provide redundant uplinks to the two nearest hub sites, with fiber strands traversing physically diverse paths to the extent enabled by the physical architecture. In most cases, the sites sit physically on or near these backbone rings so that the network can support highly resilient services, and in most cases prevent loss of service even in the event of a fiber cut. The proposed hub sites are selected based on their network connectivity needs, their current role in the network design, and to balance physical link distances from hub sites to edge sites.

Figure 7: Proposed City Logical Fiber Network Topology

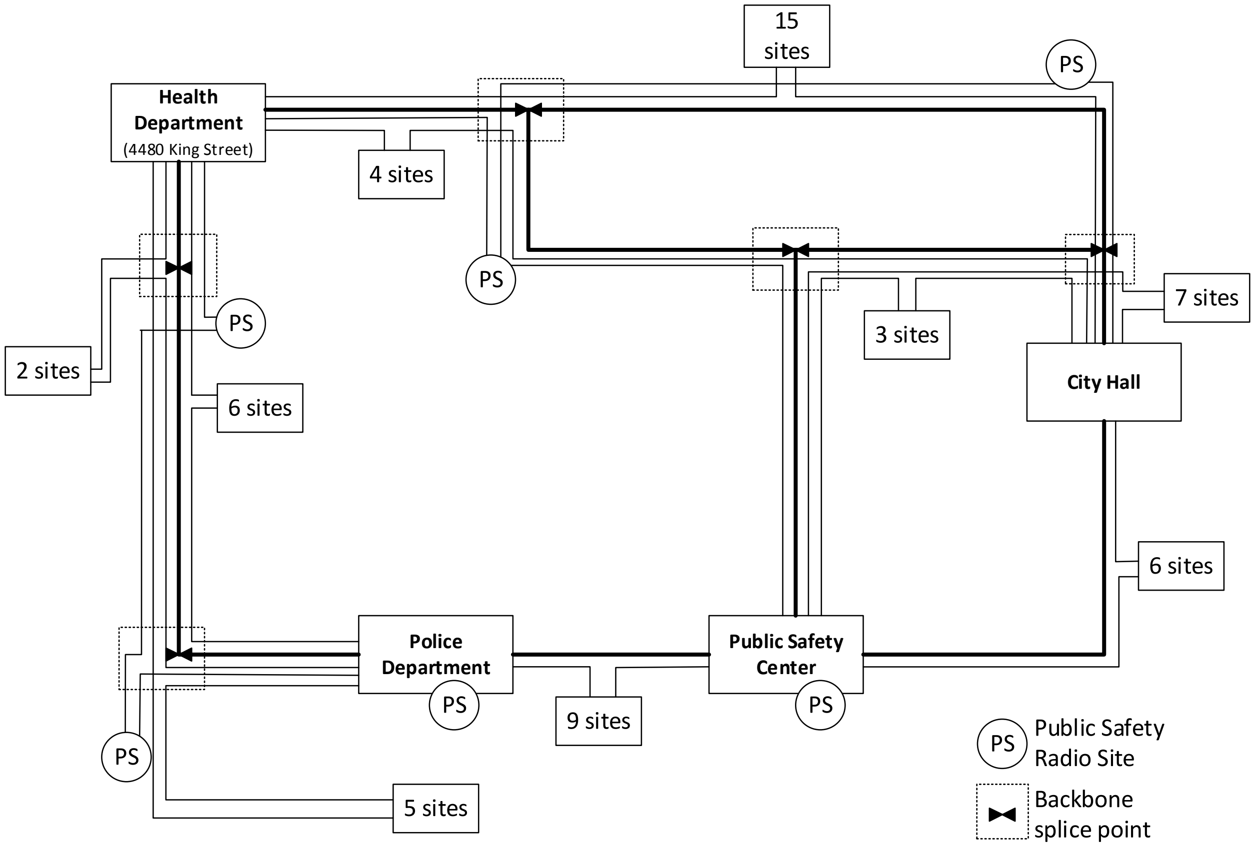
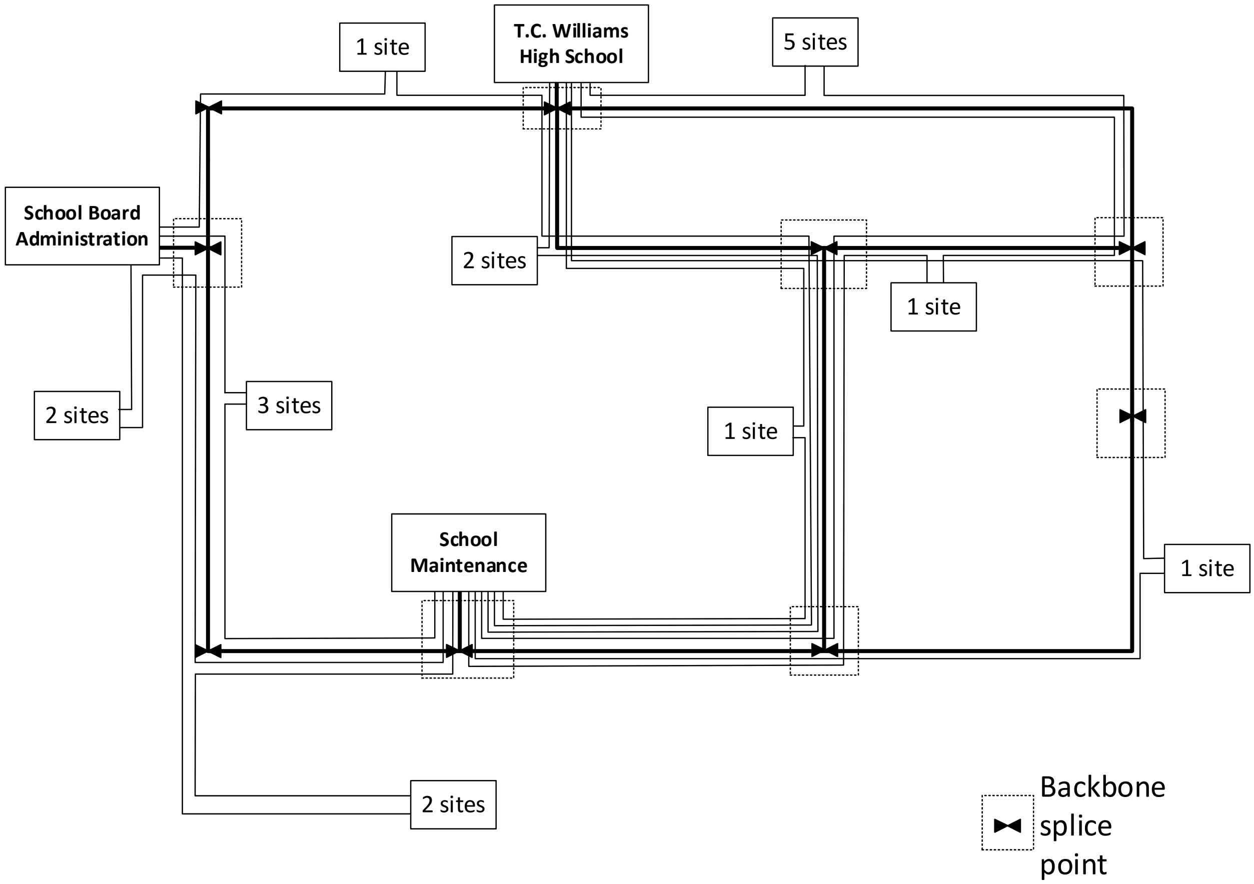


Figure 8: Proposed ACPS Logical Fiber Network Topology



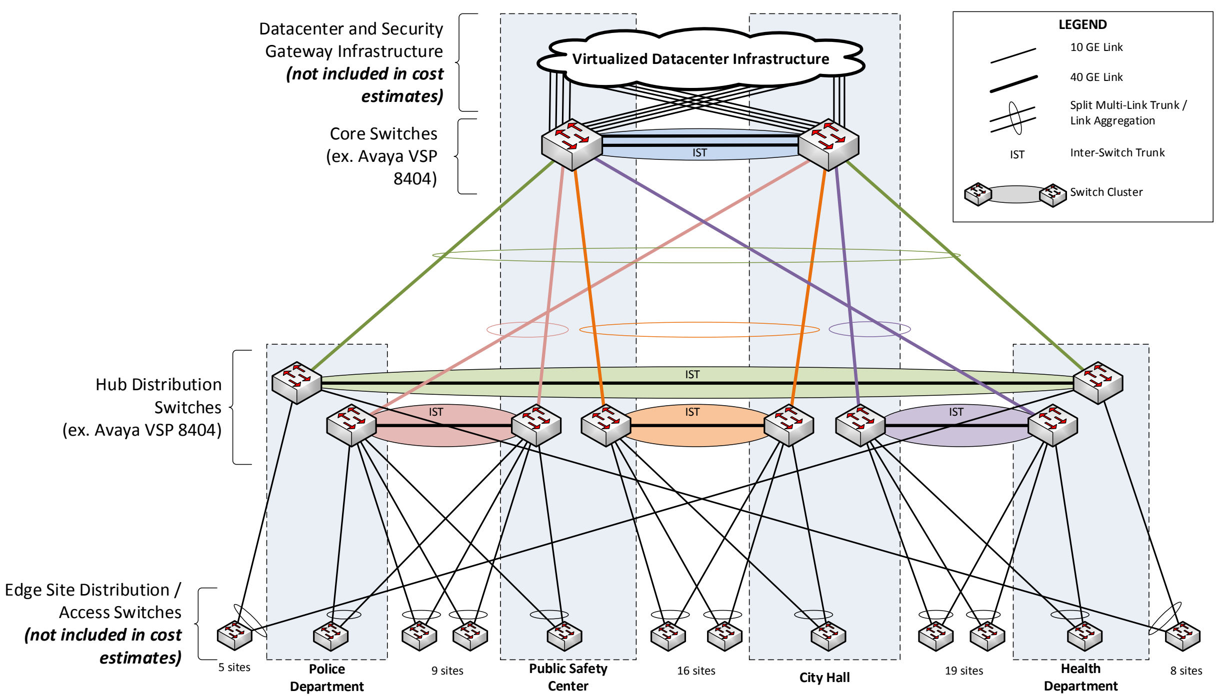
The network electronics configurations proposed to leverage these logical topologies consists of new switching hardware in the core and distribution layers of each the City and School networks, allowing these backbone networks to be stood up in parallel to the existing core switch hardware, currently located in the Comcast headend, without disrupting current services. Moreover, this will allow the cutover of edge sites to the new backbone in a controlled and more gradual manner to minimize the risk of disruption to network services, while facilitating a refresh of aging core equipment and an increase in capacity. There exists a wide range of hardware configurations from an equally diverse range of hardware manufacturers. Building from the City's current, proven network approach, we based the proposed network architecture and cost estimates on the Avaya Virtual Services Platform (VSP).

For the City, we propose that a new core/distribution-layer network is established between four primary hub locations (Figure 9). Our design model incorporates a fully redundant core network comprised of two VSP 8404 switches, interconnected over an inter-switch trunk (IST) comprised of dual, aggregated 40 GE links. The core switch cluster will support split multi-link trunking (SMLT) from distribution layer and datacenter switches, providing load balancing over redundant links and sub-second failover in the event of outage. The proposed core configuration is equipped with sufficient line cards and optical transceivers to support eight 40 GE unlinks (320 Gbps) from the distribution layer, and a minimum of twenty-four (24) 10 GE (240 Gbps) interfaces (or 1 GE interfaces, as needed) to datacenter infrastructure—and is scalable well beyond this in the same switch chassis, as demand requires.

At the distribution layer, we include four switch clusters distributed across the four hub locations so that each edge site can connect to a fully diverse switch cluster, each comprised of a pair of VSP 8404 switches interconnected via 40 GE IST interfaces. Each cluster is equipped with sufficient line cards and optical transceivers to support redundant 40 GE uplinks to the core, as well as redundant 10 GE interfaces to each edge site.

All City network edge switches have been recently upgraded, primarily using the Avaya VSP 4450 platform, with each site equipped to support redundant 10 Gigabit Ethernet (10 GE) uplinks from "edge" sites.

Figure 9: Proposed City Network Core/Distribution Network Electronics Architecture

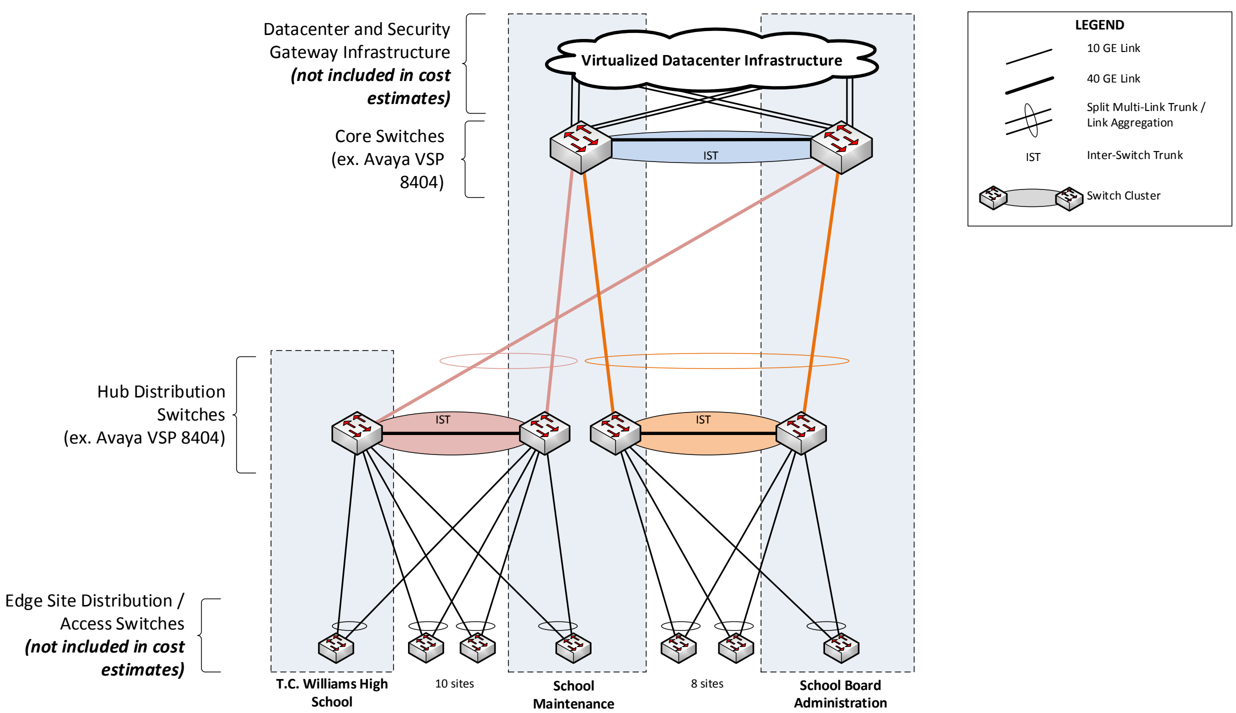


Similarly, for ACPS we assume a new backbone is established between three hub locations (Figure 10), supporting 1 GE or 10 GE uplinks from edge site switches. Our design model incorporates a fully redundant core network comprised of two VSP 8404 switches, interconnected over an IST comprised of a single 40 GE link. The core cluster will support SMLT from distribution layer and datacenter switches uplinks. The core is equipped with sufficient line cards and optical transceivers to support four 40 GE unlinks (160 Gbps) from the distribution layer, and a minimum of twenty (20) 10 GE (200 Gbps) interfaces (or 1 GE interfaces, as needed) to datacenter infrastructure—and is scalable well beyond this in the same switch chassis, as demand requires.

At the distribution layer, we include two switch clusters distributed across the three hub locations so that each edge site can connect to a fully diverse switch cluster pair, each comprised of a pair of VSP 8404 switches interconnected via 40 GE IST interfaces. Each cluster is equipped with sufficient line cards and optical transceivers to support redundant 40 GE uplinks to the core, as well as redundant 10 GE interfaces to each edge site.

ACPS network edge switches are currently equipped with 1 GE, Course Wave Division Multiplexing (CWDM) optics, which can be modularly upgraded to support 1 GE uplinks using standard wavelengths (1550 nm or 1310 nm) within the proposed budgetary cost estimates. If instead the network migration can be synchronized with edge switch replacements, expected to be required in the near term, the proposed BOM and cost estimates include 10 GE interfaces in the distribution layer to support uplinks from new edge switches (not included in the cost estimates).

Figure 10: Proposed ACPS Network Core/Distribution Network Electronics Architecture



Larger format schematics of the backbone designs are provided in Appendix F.

The proposed physical fiber architecture facilitates the implementation of the independent topologies shown for both the City and ACPS, with no integration between these entities' networks beyond having physical fiber strands carried side-by-side in common cable sheaths - simultaneously, the physical architecture facilitates any level of integration of network electronics between the individual entities, if so desired. Whether initially or in the future, the fiber network could allow for consolidation of network systems and datacenter sites, or simply sharing redundant datacenter space to provide lower cost options for disaster recovery and data mirroring.

4.2 Estimated Cost to Construct and Operate a City-Owned Network

Table 3 provides a summary of estimated costs and project metrics for fiber construction (not including network electronics), broken down on the basis of backbone, City laterals, ACPS laterals, and connectivity to the public safety radio locations. The total capital cost for the outside plant construction (OSP) to the 86 sites is estimated at approximately $8.8 million.

Table 3: Estimated OSP Costs for Construction of City-Owned Network

Scope	Mileage	Cost	Anchor Sites	Cost Per Site	Cost Per Mile
Backbone	26.65	$6,402,000	0	N/A	$240,230
City Laterals	5.46	$1,626,000	61	$26,656	$297,563
ACPS Laterals	2.97	$655,000	21	$31,190	$220,730
Public Safety Radio	0.66	$144,000	4	$36,000	$216,801
Totals:	35.75	$8,827,000	86	$102,640	$246,940

Appendix D contains a more detailed breakdown of estimated capital construction-related costs. Cost estimates are inclusive of all engineering, project management, quality assurance, and construction labor anticipated to be necessary to implement the network on a turnkey basis, and are based on relatively conservative pricing assumptions. The following summarizes the scope anticipated by each of the cost components itemized in the table above:

- ***Engineering –*** includes system level architecture planning, preliminary designs and engineering field walk-outs to determine candidate fiber routing; development of detailed engineering prints and preparation of permit applications; and post-construction "as-built" revisions to engineering design materials.

- ***Project Management / Quality Assurance*** – includes expert quality assurance field review of final construction for acceptance, review of invoices, tracking progress, and coordination of field changes.

- ***General Outside Plant Construction*** – consists of all labor and materials related to "typical" underground outside plant construction, including conduit placement, utility pole make-ready construction, fiber installation, and surface restoration; includes all work area protection and traffic control measures inherent to all roadway construction activities.

- ***Railroad, Bridge, and Interstate Crossings*** – consists of specialized engineering, permitting, and incremental construction (material and labor) costs associated with crossings of railroads, bridges, and interstate / controlled access highways.

- ***Outside Plant Fiber Splicing*** – includes all labor related to fiber splicing of outdoor fiber optic cables.

- ***Fiber Termination / Building Entrance*** – consists of all costs related to fiber lateral installation into network sites, including outside plant construction on private property, building penetration, inside plant construction to a typical backbone network service "demarcation" point, fiber termination, and fiber testing.

In addition to fiber construction costs, our estimates include the relatively minor costs associated with network electronics to leverage a City-owned fiber network. Specifically, our estimates include costs for the core and distribution-layer network electronics to facilitate the network migration depicted in Section 4.1.2, inclusive of integration services, to be $504,000 for the City and $250,000 for ACPS. We assume these network electronics to be a one-time capital expense to facilitate the cutover that do not impact the City's operating costs negatively; in other words, whether or not the City builds a fiber network, equivalent costs for maintenance and support of network electronics will be incurred. Depending on when the migration occurs in relation to existing network hardware refresh cycles, these costs may not be required, but are included to provide a comprehensive and conservative assessment of potential costs. Appendix E contains a sample bill of materials (BOM) for both the City and ACPS network equipment.

Note that edge site network equipment is not included in these estimates. Existing City equipment is configured to support redundant 10 GE connections from each edge site over I-Net fiber, and can be transitioned directly into the proposed architecture without upgrades. ACPS edge equipment is due for replacement, and can migrated to the new network as these replacements occur, or can be modularly upgraded within the estimated budgetary figures to transition to the new fiber at current, 1 Gbps speeds.

The total estimated capital costs to migrate to a City-owned fiber network is provided in Table 4, including a breakdown all fiber construction costs and estimated network electronics and related integration costs.

Table 4: Estimated City Fiber Network Implementation Costs

Cost Component	Backbone	City Laterals	ACPS Laterals	Public Safety Radio	Estimated Cost
Outside Plant Fiber Construction					
Engineering	$481,800	$98,800	$53,700	$12,000	$646,000
Project Management / Quality Assurance	$184,400	$37,800	$20,500	$4,600	$247,000
General Outside Plant Construction	$5,470,500	$1,036,900	$496,500	$110,600	$7,115,000
Railroad, Bridge, and Interstate Crossings	$249,100	$18,600	$0	$0	$268,000
Outside Plant Fiber Splicing	$16,000	$128,500	$21,300	$4,500	$170,000
Fiber Termination / Building "Entrance"	$0	$305,600	$63,400	$12,100	$381,000
Fiber Construction Subtotals:	$6,402,000	$1,626,000	$655,000	$144,000	$8,827,000
Network Electronics					
Core/Distribution Electronics	$0	$504,000	$250,000	$0	$754,000
Edge Site Electronics	$0	$0	$0	$0	$0
Network Electronics Subtotals:	$0	$504,000	$250,000	$0	$754,000
Total:	***$6,402,000***	***$2,130,000***	***$905,000***	***$144,000***	***$9,581,000***

We estimate the yearly operation and maintenance cost to be $183,000 in year one, rising to $432,000 per year over a 30-year period (based on an annual escalation of 3 percent). In terms of operations and maintenance, we have factored in reasonable expenses, including:

- Fiber repairs: $50 per month per underground mile, starting in year 1
- Ticket processing and locates:[8] $150 per month per underground mile
- Network management allocation: $20,000 per year starting in year 1
- Administration allocation: $20,000 per year starting in year 1

[8] When an excavator files a permit request for planned construction in the City's rights-of-way (i.e., digging), the City will process a "ticket" and send an outside plant engineer to locate (i.e., mark) the City's conduit and fiber infrastructure in the vicinity. This process is essential for eliminating accidental damage to the City's infrastructure.

- Insurance costs: 0.60 percent of the OSP construction cost annually

The financing for the network can be accomplished through either a 20-year or 30-year bond. We estimate that the City's total financing requirement will be $10.2 million, based on the following assumptions:[9]

- Discount rate: 4.0 percent (used in the NPV analysis)
- Interest rate: 3.5 percent (interest charged on the bond)
- Debt service reserve: 5 percent[10]
- Bond issuance cost: 1 percent

4.3 Cost Savings Potential through Joint T&ES Project Coordination

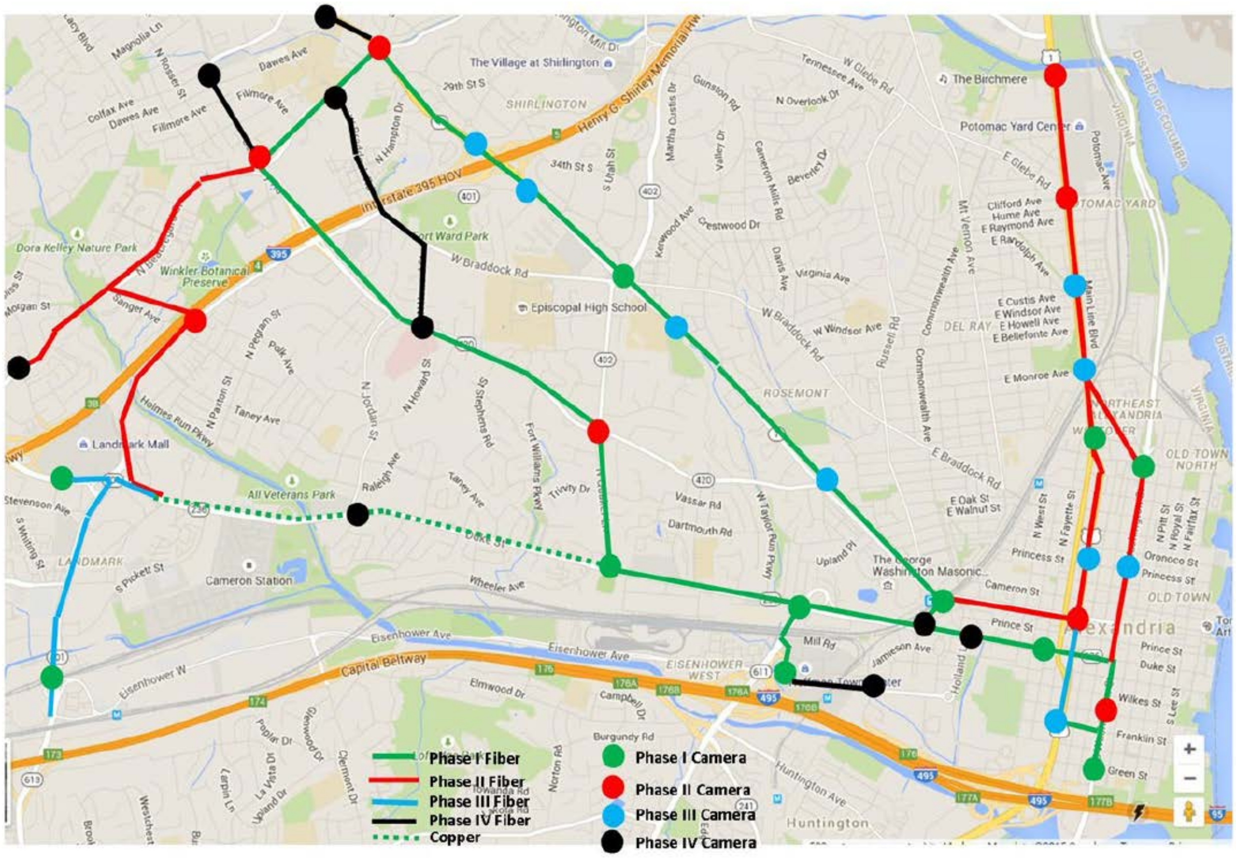
Significant fiber network construction cost savings potential exists through coordination with other internal City projects. Roadway resurfacing projects and sidewalk replacements, for example, can effectively eliminate the surface restoration costs that might otherwise be required for fiber construction if both efforts are well coordinated. It is difficult to quantify the potential cost saving opportunity across the wide range of potential projects without set schedules, and moreover, coordination may not always be prudent where timelines do not align, given that the expiration of the City's I-Net Fiber Use Agreement has created a somewhat time sensitive situation.

That said, an ongoing project led by the Transportation and Environmental Services (T&ES) to construct fiber optics to many of its traffic signal controllers and other intelligent transportation system (ITS) devices located along City roadways, including traffic surveillance cameras, may present a significant opportunity to cut costs in a straightforward manner. The City will soon be awarding a contract for construction of Phase 2 of this project, which is slated to construct fiber between many roadway intersections throughout the City (Figure 11), with many routes overlapping those of the City fiber network design proposed in this report. Although the federal grant programs under which this project is funded may place conditions on the usage of the particular fiber strands or fiber cables constructed using grant funds, these grant programs generally allow for (and encourage) cost efficiencies through joint-construction where clear demarcations in the costs and usage of the assets can be clearly delineated.

[9] The scope of work for this report does not include a review of the City's bonding capability or review of local or state bonding restrictions. A more detailed review and opinion from the City's accountants of bonding capability and restrictions is recommended, if bonding is pursued.

[10] Assets that are designated by a borrower to ensure full and timely payments to bond holders

Figure 11: Proposed T&ES Project Routes and Phases



Although a detailed analysis of this grant-funded project and its eligibility as a joint-build opportunity are beyond the scope of this analysis, we strongly encourage that the City explore this potential in greater detail. Approximately 1.5 miles of the ITS Phase 2 project involves new conduit installation along routes that overlap exactly (or approximately) with the proposed City fiber network design. If we assume that the City pays only the ***incremental*** costs for additional conduit and fiber along these routes—in other words, only those costs that would not otherwise be incurred but for the City's augmentation of the requirements of the ITS project for its other requirements—these Phase 2 routes alone could offer upwards of $200,000 in savings.

Additionally, there is significantly more overlap of the two projects in terms of future phases of the ITS project, as well as ITS Phase 2 project routes where new fiber is being installed in existing conduit that might be made more cost effective or further enhanced in terms of capacity through coordination with the City fiber network construction.

We caution that coordination with grant-funded programs may add timeline and cost risks due to the added layer of programmatic oversight - environmental compliance and approval requirements; reporting requirements related to performance progress, finances, and contractor wages; and scope change approval processes. Nonetheless, this significant City-led project warrants further investigation as a cost savings opportunity due to its similar scope and seemingly imminent timeframe to break ground.

4.4 Cost Savings Potential through Aerial Construction

Aerial, or “overhead,” construction involves the attachment of fiber optic cables and splice hardware to utility poles. In most cases, a steel messenger wire is run from pole to pole, to which the fiber cables are lashed with thin wires wound around both the messenger wire and fiber cable, so that the fiber cable does not actually support its own weight.

Aerial fiber is not susceptible to damage related to new underground, but is more susceptible to damage from other threats, in particular weather-related events, animal chewing, and automobile crashes. Resiliency of fiber infrastructure is generally considered to be relatively equivalent between aerial and underground, extreme geographic or weather factors notwithstanding, such as in regions prone to hurricanes.

Aerial construction can occur more rapidly and at substantially lower cost than any method of underground construction where utility poles are structurally sound and are not overly crowded with existing utilities. Where this is the case, material and labor costs for fiber cable placement are likely to range from about $5 to $7 per foot, compared to the $30-plus per foot expected for underground conduit and fiber placement. Also, where a directional boring crew may be able to place 300 to 500 feet of conduit per day, a single aerial crew can generally place upwards of 10,000 feet of cable.

Aerial fiber is generally less expensive to maintain, as well. A third party attacher, like the City, is generally charged an annual lease fee per pole, but these fees rarely meet or exceed the costs associated with utility locates for underground fiber infrastructure. Other operating costs related to repairs and general maintenance are equivalent or less for aerial infrastructure compared to underground. On the other hand, aerial construction is generally not as scalable in terms of increasing cable strand counts when compared to underground cable in conduit, so the implementation cost savings may come at the opportunity costs related to unknown capacity demands.

When utility poles are structurally overloaded or too crowed to support a new attachment while maintaining required physical clearances to ground and between different types of attachments (electric, communications, etc.), as dictated by code requirements and the pole owner’s own technical standards, “make-ready” construction must first occur before the new attachment can occur. Make-ready can vary in scope from relatively low-cost shifts in the vertical position of existing attachments to achieve appropriate clearances, to expensive pole replacements. Particularly where pole replacements are required, aerial construction costs can quickly exceed that of underground.

The extent to which aerial construction might provide savings can only be determined with a detailed engineering analysis. Thus, we examine aerial construction only as a potential cost savings mechanism, but base all business case analysis in the next section on completely underground construction. Based on a preliminary survey of the existing utility pole infrastructure, we believe aerial construction is a viable option along significant portions of the network routes (approximately 15.0 miles, or 42 percent), requiring relatively modest make-ready work (and few if any pole replacements). This equates to an estimated cost savings compared to completely underground construction of up to $1.1 million for the proposed routes, and potentially much more if the design was optimized to maximize the potential for aerial construction.

The potential for aerial construction is subject to the City granting itself a waiver of its undergrounding ordinance. [11] The City may deem the fiber project to warrant such a waiver on the basis that the project substantially benefits public safety, supports efficiency of government services, and promotes improved quality of life for residents, and as such the "general welfare of the city would not be furthered by compliance with the [undergrounding] requirements," as allowed by Title 5, Section 5-3-4(b). More specifically, the City may have grounds for such a waiver on the basis of one or more of the technical criteria defined in the code for granting such a waiver. In particular, the requirements of the undergrounding ordinance may be waived if:

- "the new or expanded overhead customer utility service, if placed underground, would significantly interfere with one or more existing city or private underground utilities;"[12] and / or
- "if the waiver were granted, there would be a reduction in the total number of overhead customer utility service lines serving the applicant's property."[13]

The scope of the project is sufficiently broad that it almost certainly will result in damages to existing utilities, regardless of the care given by contractors to avoid such damages, given the congestion of the existing right of way and the challenging nature of underground construction throughout the City (and in the downtown areas, in particular). Moreover, the project can be used to create a singularly unique communications infrastructure in the City, providing commercial operators access to dark fiber resources on an open access, non-discriminatory basis. Unlike all other fiber and communications lines on the poles today, the City's fiber is

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[11] Title 5, Chapter 3, Section 5-3-2 and 5-3-3 of the City Code requires most types of new utility infrastructure to be placed underground, but allows for waivers to be granted per Section 5-3-4, provided certain criteria are met.
[12] Title 5, Section 5-3-4, (a)(iii)c.
[13] Title 5, Section 5-3-4, (a)(iii)d.

likely to reduce the need for additional new attachments, and indeed, may even result in the abandonment and removal of certain legacy attachments no longer required by commercial operators.

5. Comparison of Costs for City-Owned Fiber and Leased Transport Services

The City currently pays a total of $506,400 per year to Comcast for dark fiber leases to 80 unique sites—an average of $528 per site per month. With the I-Net Fiber Use Agreement due to expire later this year, under which 76 of these connections are provided, the City will likely be required to transition to Comcast Managed Ethernet services; incur increased costs for continued use of the I-Net dark fiber; lease services or dark fiber from another provider; or construct its own fiber network.

While negotiations with Comcast for renewal of the Fiber Lease Agreement are still ongoing, we believe the status quo I-Net scenario is unlikely in the long term. Specifically, Comcast is unlikely to commit to a long-term (20- to 30-year) arrangement that allows the City to retain access to the dark fiber I-Net at pricing comparable to the current pricing. If a dark fiber I-Net is offered, we expect the term will be much more limited (perhaps no more than five years), and with no guarantee of renewal or price containment. Nonetheless, for sake of analysis across all potentially reasonable scenarios, we consider one in which Comcast renews the current Fiber Use Agreement indefinitely, with nominal annual increases in fiber lease pricing. In reality, we expect the City will be pushed into market-rate pricing for managed network services in the near-term or mid-term.

To benchmark potential rates for these services, we surveyed the costs of comparable transport services offered in other localities in the region. (These examples are provided in Appendix A.) We estimate that the rates offered by Comcast for the transport could range from $530 to $1,064 per month for 1 Gbps service to 69 I-Net sites, and $3,200 to $6,360 per month for 10 Gbps to the seven remaining I-Net sites—for a total annual cost of $708,000 to $1.42 million.

The City could alternatively build, own, and operate its own fiber network, and provide data transport services to its 80 I-Net sites over its own fiber. In the sections below, we analyze the capital and ongoing costs the City would incur to build and operate its own network, and compare different pricing and service scenarios to evaluate the business case for a City-owned network.

In our comparative analysis, we varied the cost of managed transport services and the level of service delivered to the City and ACPS sites (i.e., 1 Gbps or 10 Gbps). For each scenario, we assumed that the neither the monthly recurring cost (MRC) nor the level of service to each site would change over the 20-year and 30-year review periods (chosen to align with the likely terms of the City's bond), unless specifically indicated.

The rates we chose for our analysis are fees that were recently offered by Comcast for managed transport services through public, competitive bidding processes to the public school districts in comparable regional jurisdictions ("Comparable Comcast Pricing"), and to another local municipal government of comparable geographic size where Comcast offered the lowest pricing we could find ("Low Comcast Pricing"). Given that Comcast has existing fiber to each of the City and ACPS sites, we fully expect Comcast to be capable of offering the most competitive commercial service offerings to the City and ACPS, if so inclined, particularly given the limited availability of other fiber-based services within Alexandria. Even Verizon would likely need to build substantial amounts of fiber to provide comparable services, if only to construct the service drops from nearby fiber to feed the individual sites.

We then compare the total costs of each scenario to that of leased transport services, with respect to:

- Net Present Value (NPV); and
- Average monthly price per site

The different scenarios we considered are summarized as follows:

1. ***Scenario One – "Best Case" Comcast Dark Fiber I-Net:***
   Status quo dark fiber I-Net at $550 per site per month in year one (10 percent increase), with annual price increase of five percent thereafter
2. ***Scenario Two – Low Comcast pricing:***
   1 Gbps service at $530 per month per site to 73 sites; 10 Gbps service at $3,200 per month per site to seven core sites
3. ***Scenario Three – Low Comcast pricing with a 20 percent increase to MRC:***
   1 Gbps service at $636 per month per site to 73 sites; 10 Gbps service at $3,840 per month per site to seven core sites
4. ***Scenario Four – Low Comcast pricing with double the number of sites served at 10 Gbps:*** 1 Gbps service at $530 per month per site to 66 sites ; 10 Gbps service at $3,200 per month per site to 14 core sites
5. ***Scenario Five – Low Comcast pricing with a 20 percent increase to MRC and double the number of sites served at 10 Gbps:***
   1 Gbps service at $636 per month per site to 66 sites; 10 Gbps service at $3,840 per month per site to 14 core sites
6. ***Scenario Six – Comparable Comcast pricing, reduced by 5 percent every five years:***
   1 Gbps service at $1,064 per month per site (year 1) to 73 sites; 10 Gbps service at $6,360 per month per site (year 1) to seven core sites (this is the base case presented in the executive summary)

7. ***Scenario Seven – Comparable capacity at low Comcast pricing***
   10 Gbps service at $3,200 per month per site to all 80 sites

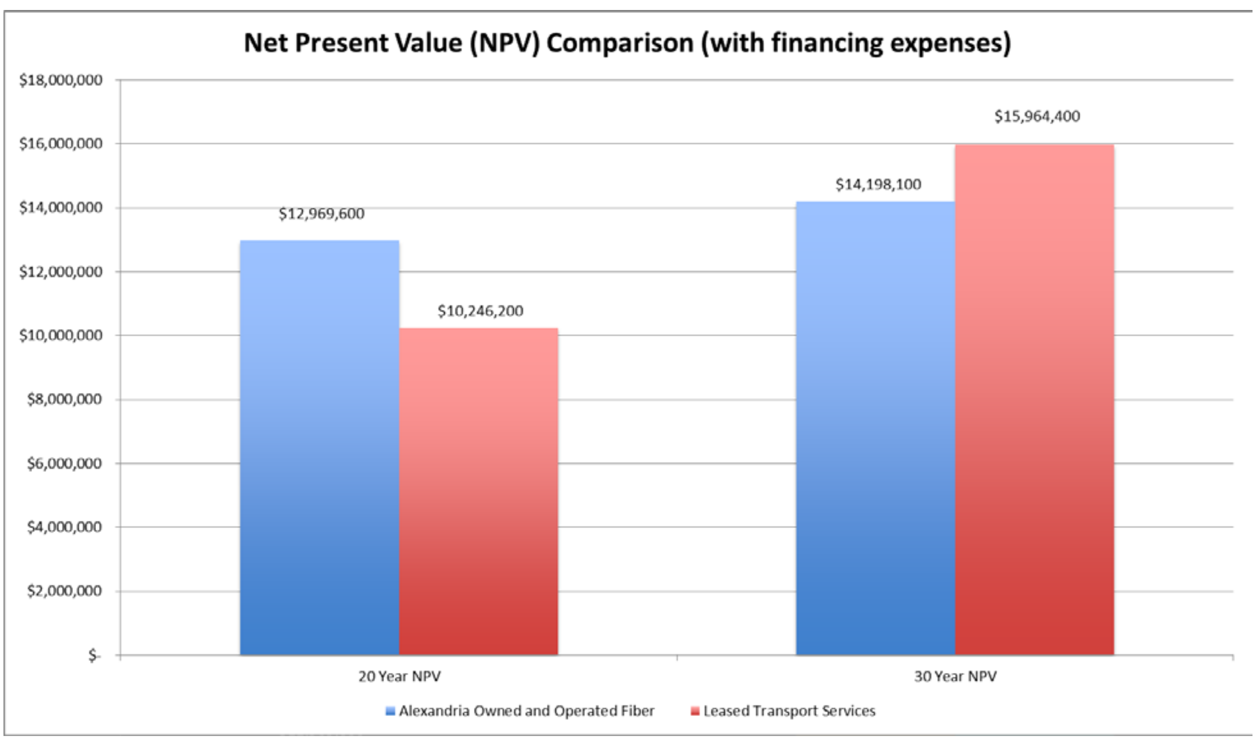
These scenarios, illustrated below, present the business case for a City fiber network on the basis of cost avoidance alone—relative to the likely range of leased service pricing—and do not take into account "off-the-balance-sheet" benefits offered by City-owned fiber discussed in previous sections, nor potential revenue streams enabled by City-owned fiber.

5.1 Scenario One: "Best Case" Comcast Dark Fiber I-Net

This scenario represents a best-case alternative to City-constructed fiber in terms of potential Comcast offerings, in which Comcast renews the I-Net Fiber Use Agreement indefinitely, allowing the City to continue to lease Comcast dark fiber. We assume a 10 percent price increase for the first year ($550 per site per month) and five percent increases each year thereafter. In this case, the NPV of the City-owned fiber network compared to that of the leased network is slightly more over a 20-year period, but actually lower over 30-year period as depicted in Figure 12.

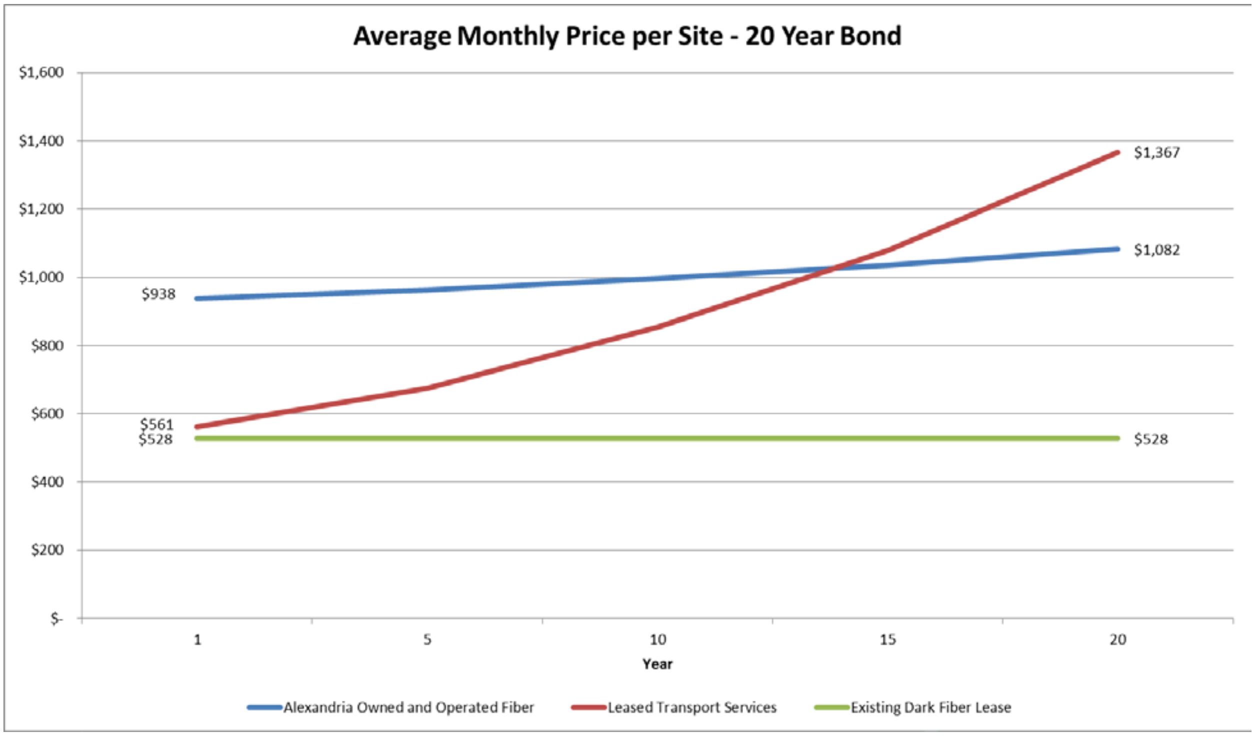
We note that, although two dark fiber solutions are being compared in this scenario, several factors beyond the financial analysis further tip the scale in favor of City-owned fiber, as detailed in the technical comparison offered in Section 3 and the revenue opportunities discussed in Section 6.

Figure 12: NPV of Scenario One



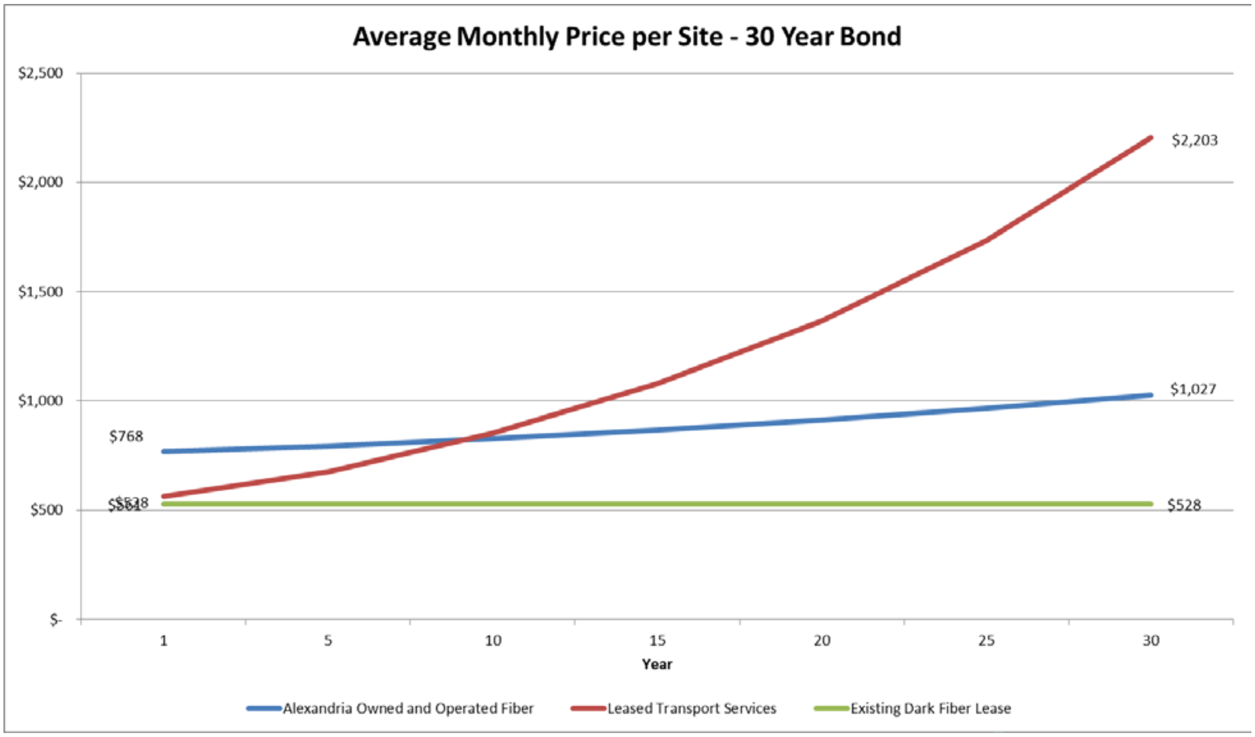
The average monthly cost per site for the City-owned network varies over the 20-year term as depicted in Figure 13.

Figure 13: Average Monthly Price per Site (20-Year Bond) in Scenario One



The average monthly cost per site for the City-owned network varies over the 30-year term as depicted in Figure 14.

Figure 14: Average Monthly Price per Site (30-Year Bond) in Scenario One

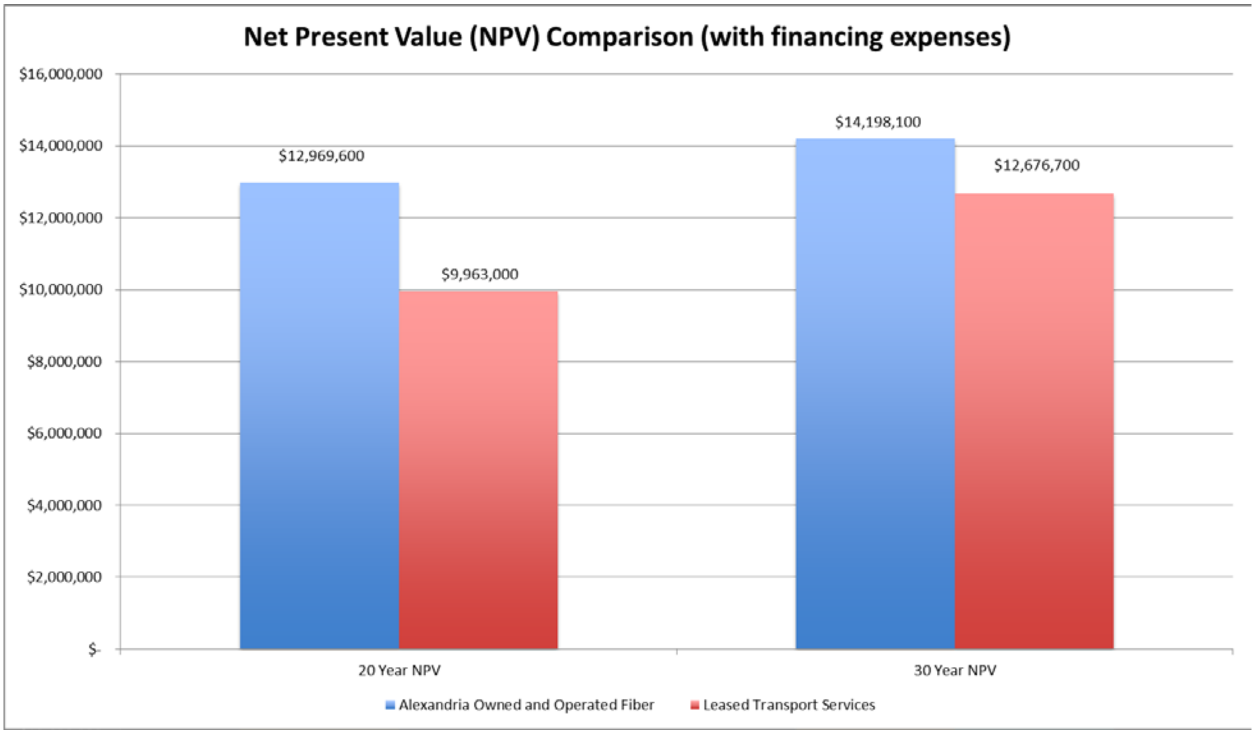


5.2 Scenario Two: Low Comcast Managed Service Pricing

In this scenario, we consider a best-case scenario for a "managed service" offering, consisting of 1 Gbps service at $530 per month per site to 73 sites and 10 Gbps service at $3,200 per month per site to seven core sites. The NPV of the City-owned fiber network compared to that of the leased network is somewhat higher over both a 20-year term and a 30-year period, as depicted in Figure 15.

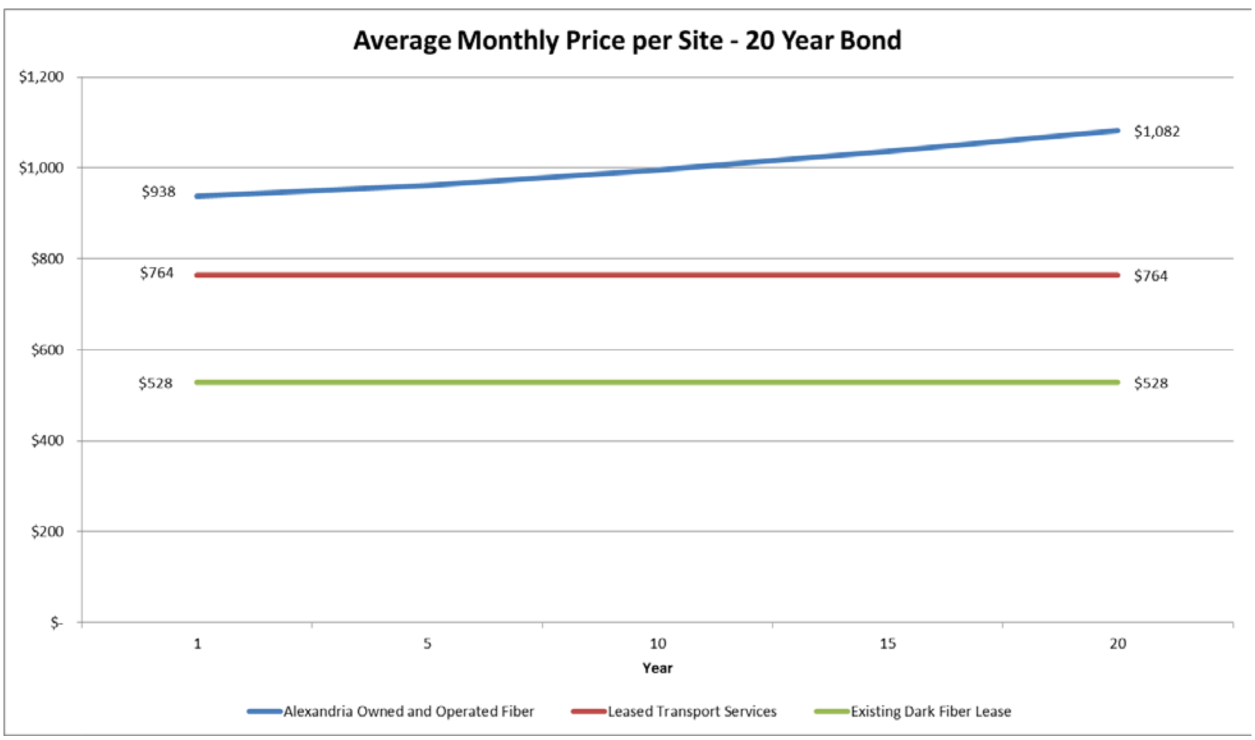
This scenario represents the low end of the spectrum in terms of managed service pricing that the City can expect when and if a dark fiber I-Net is no longer offered by Comcast. The leased service pricing reflected in this model is at the lower end of the expected range, and represents a compromise wherein the City accepts a lower capacity network in the form of a managed Ethernet service offering less scalability, less flexibility, and less control than the current I-Net fiber provides.

Figure 15: NPV of Scenario Two



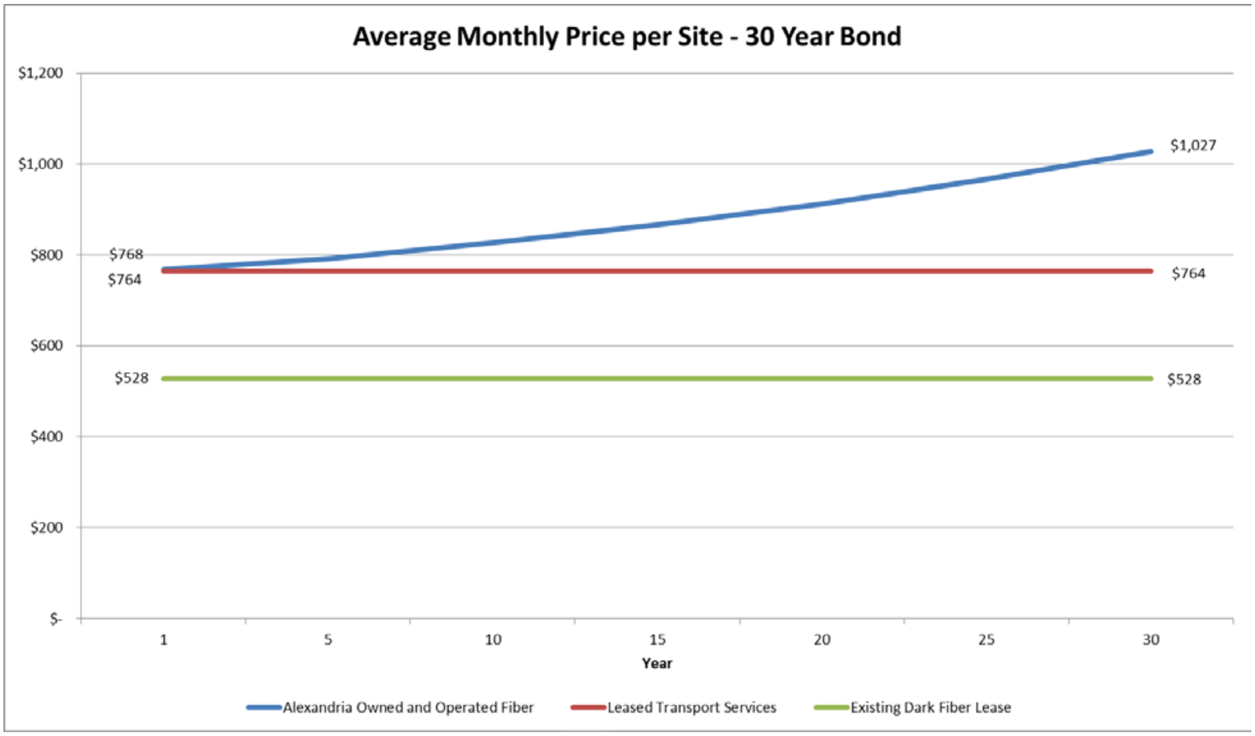
The average monthly cost per site for the City-owned network is the highest and varies over the 20-year term as depicted in Figure 16.

Figure 16: Average Monthly Price per Site (20-Year Bond) in Scenario Two



The average monthly cost per site for the City-owned network is the highest and varies over the 30-year term as depicted in Figure 17.

Figure 17: Average Monthly Price per Site (30-Year Bond) in Scenario Two

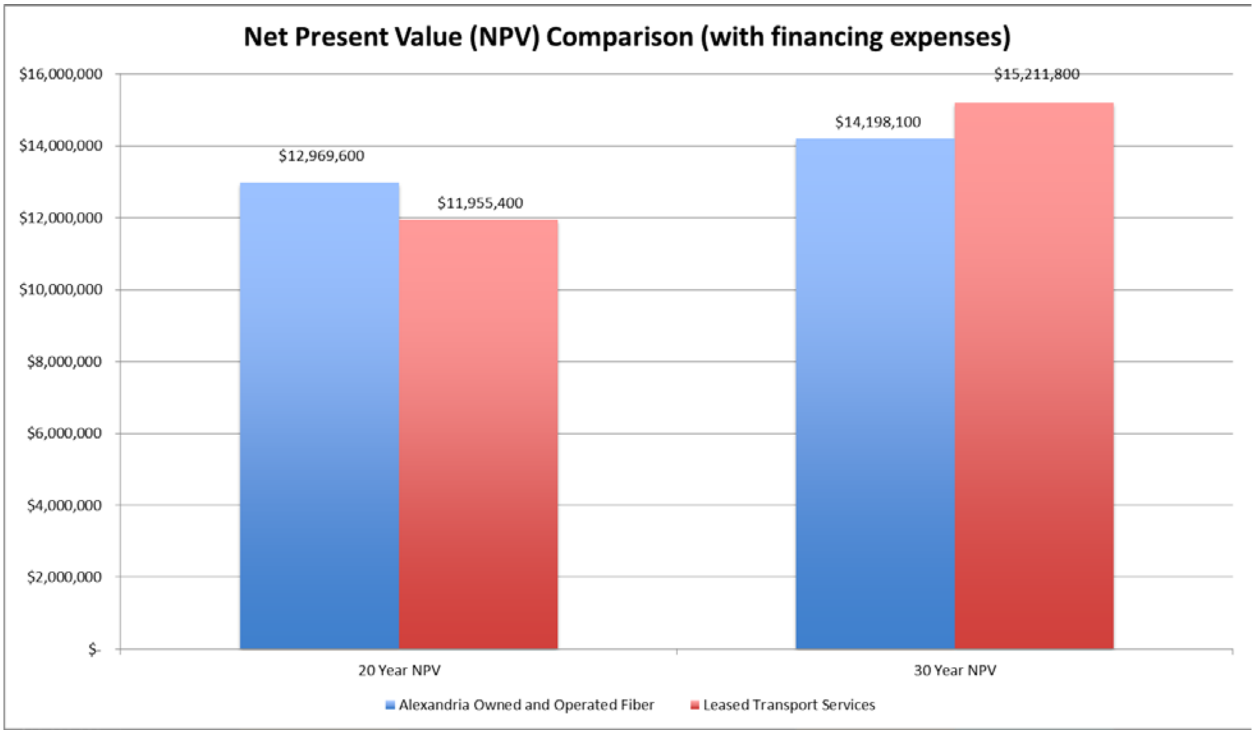


5.3 Scenario Three: Low Comcast Managed Service Pricing with 20 percent MRC Increase

In this scenario, we consider 1 Gbps service at $636 per month per site to73 sites, and 10 Gbps service at $3,840 per month per site to seven core sites. At these slightly increased and more realistic prices for the leased services, the NPV of the City-owned fiber network compared to that of the leased network is still slightly more over a 20-year period, but actually lower over 30-year period as depicted in Figure 18.

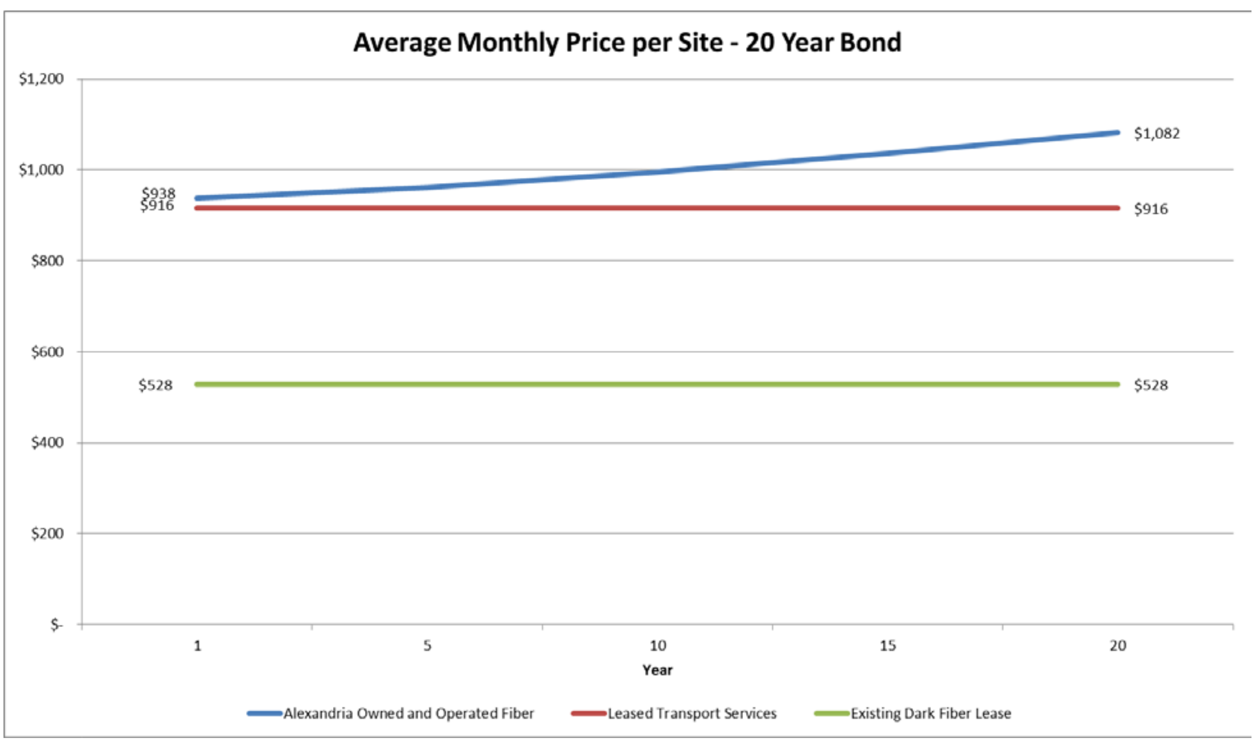
This scenario reflects more likely leased service pricing than in the previous, but still represents a scenario in which the City accepts the same lower capacity network in the form of a managed Ethernet service, offering less scalability, less flexibility, and less control than the current I-Net fiber.

Figure 18: NPV of Scenario Three



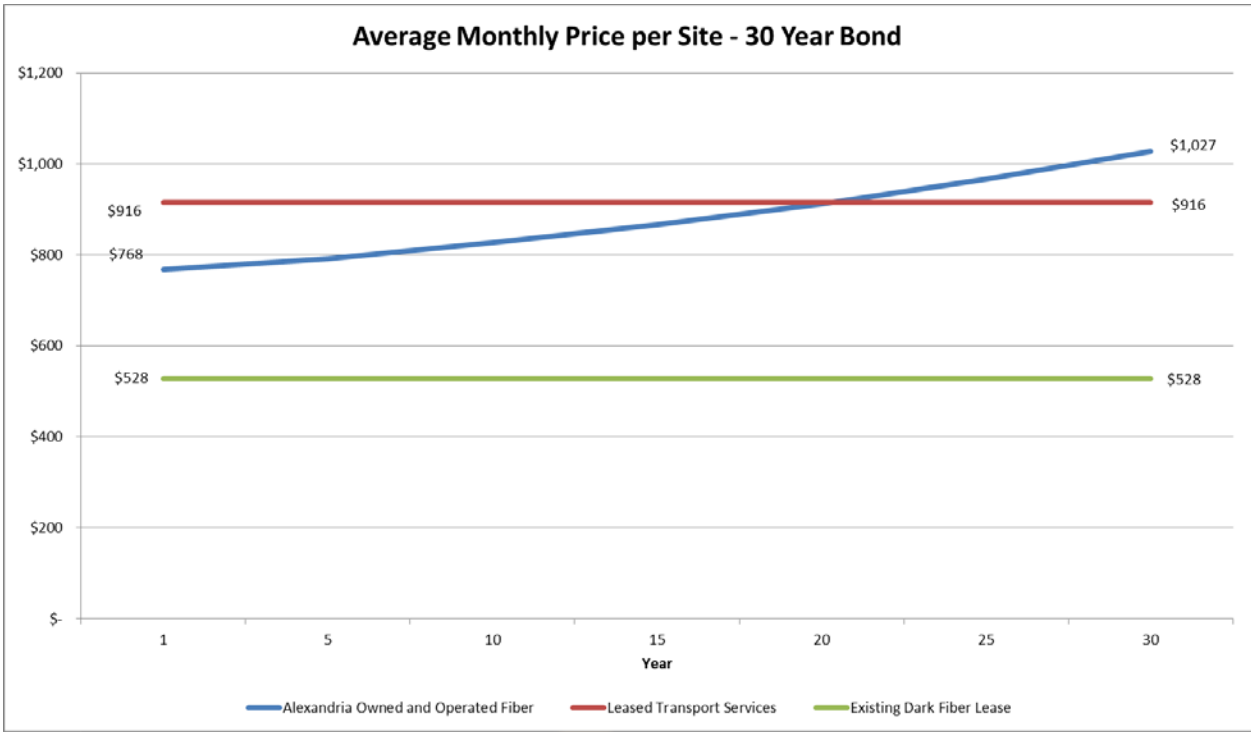
The average monthly cost per site for the City-owned network is the highest and varies over the 20-year term as depicted in Figure 19, consistently higher than for leased services.

Figure 19: Average Monthly Price per Site (20-Year Bond) in Scenario Three



The average monthly cost per site for the City-owned network varies over the 30-year term as depicted in Figure 20. It is lower than the leased transport services for nearly the first 20 years.

Figure 20: Average Monthly Price per Site (30-Year Bond) in Scenario Three

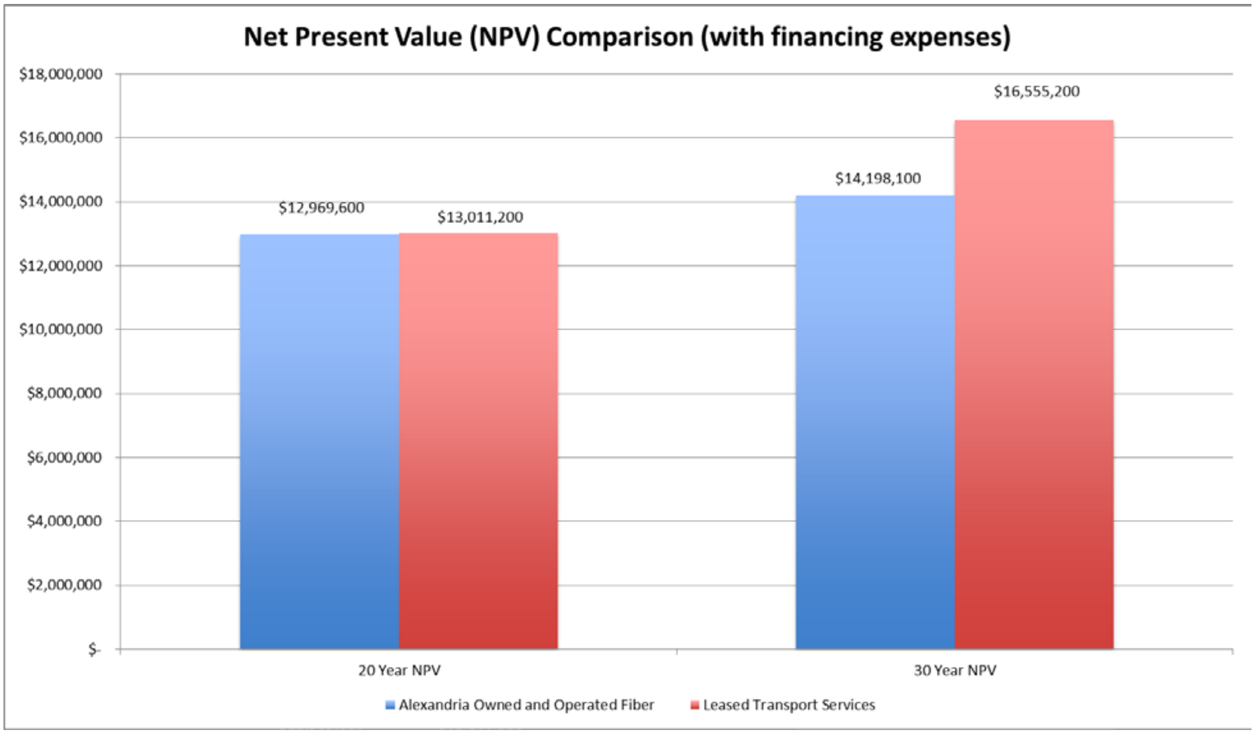


5.4 Scenario Four: Low Comcast Managed Service Pricing with Double the Number of Sites Served at 10 Gbps

In this scenario, we consider 1 Gbps service at $530 per month per site to 66 sites, and 10 Gbps service at $3,200 per month per site to 14 core sites. The NPV of the City-owned fiber network compared to that of the leased network is less over both a 20-year period and a 30-year period as depicted in Figure 21.

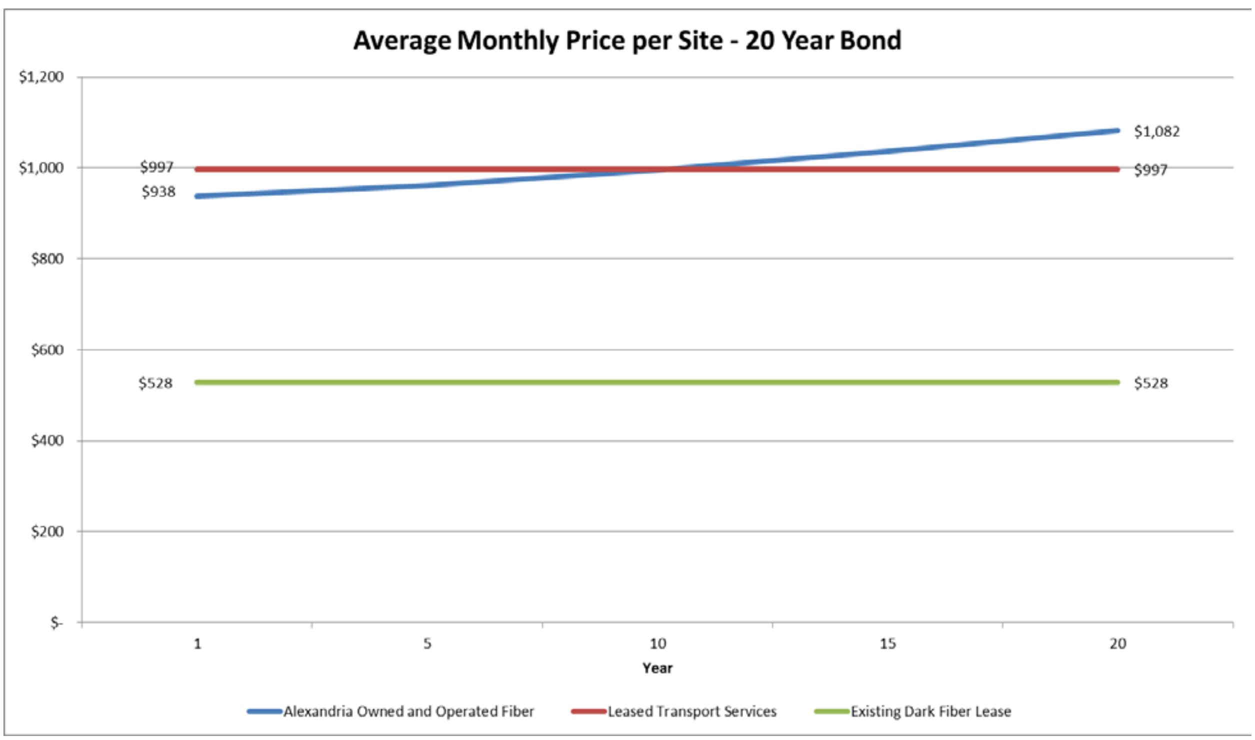
This scenario represents the same, lower-end leased pricing model presented in Scenario Two, but offers somewhat more capacity for a greater number of high-bandwidth consuming sites, still in the form of a managed Ethernet service, offering less scalability, less flexibility, and less control than the current I-Net fiber.

Figure 21: NPV of Scenario Four



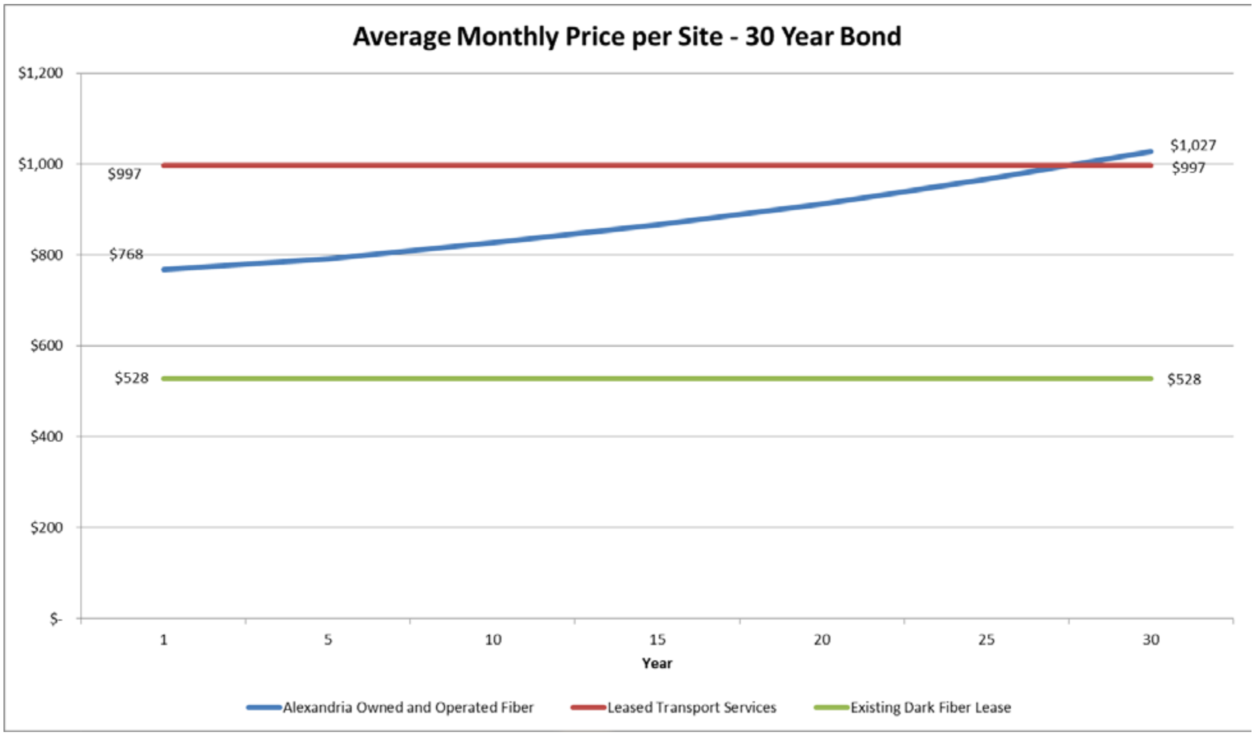
The average monthly cost per site for the City-owned network varies over the 20-year term as depicted in Figure 22.

Figure 22: Average Monthly Price per Site (20-Year Bond) in Scenario Four



The average monthly cost per site for the City-owned network is lower than the leased transport services for nearly the entire 30-year term as depicted in Figure 23.

Figure 23 Average Monthly Price per Site (30-Year Bond) in Scenario Four

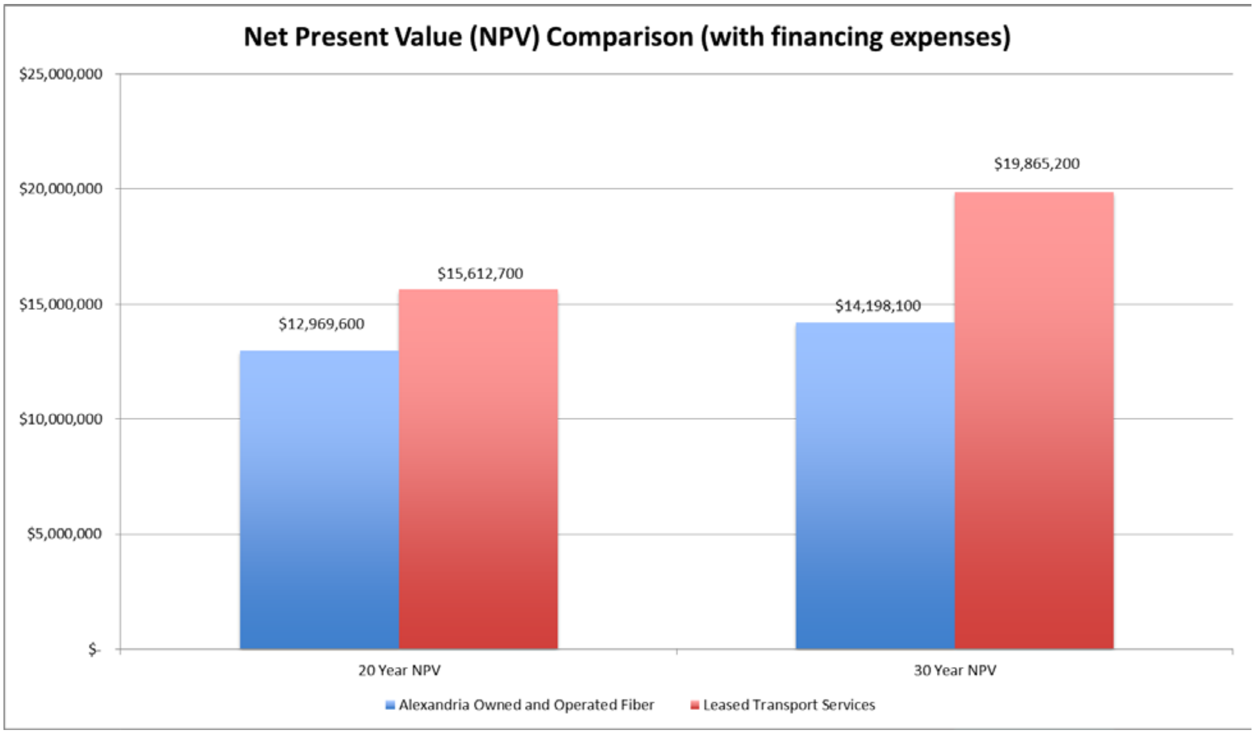


5.5 Scenario Five: Low Comcast Managed Service Pricing with 20 Percent MRC Increase and Double the Number of Sites Served at 10 Gbps

In this scenario, we consider 1 Gbps service at $636 per month per site to 66 sites, and 10 Gbps service at $3,840 per month per site to 14 core sites. The NPV of the City-owned fiber network compared to that of the leased network is significantly lower over both a 20-year and 30-year period as depicted in Figure 24.

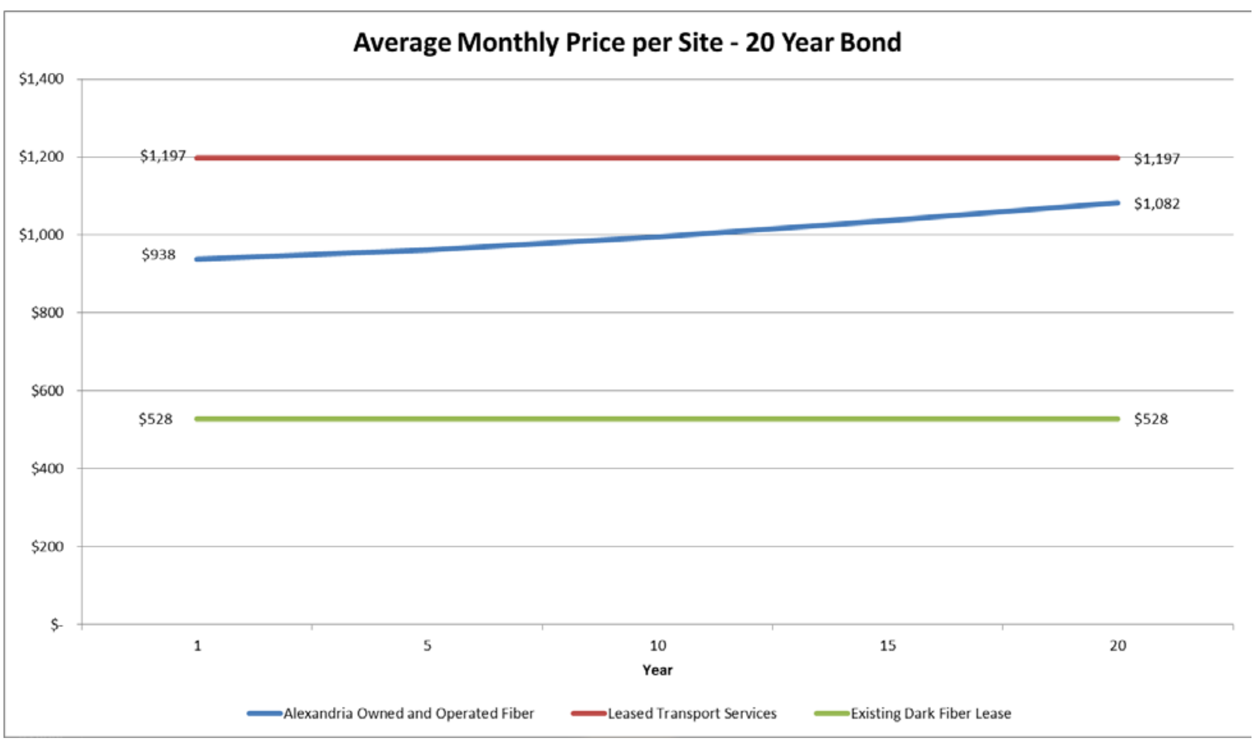
Compared to Scenario Two, this scenario combines the somewhat more realistic leased service pricing model in Scenario Three with the increased capacity offerings of Scenario Four.

Figure 24: NPV of Scenario Five



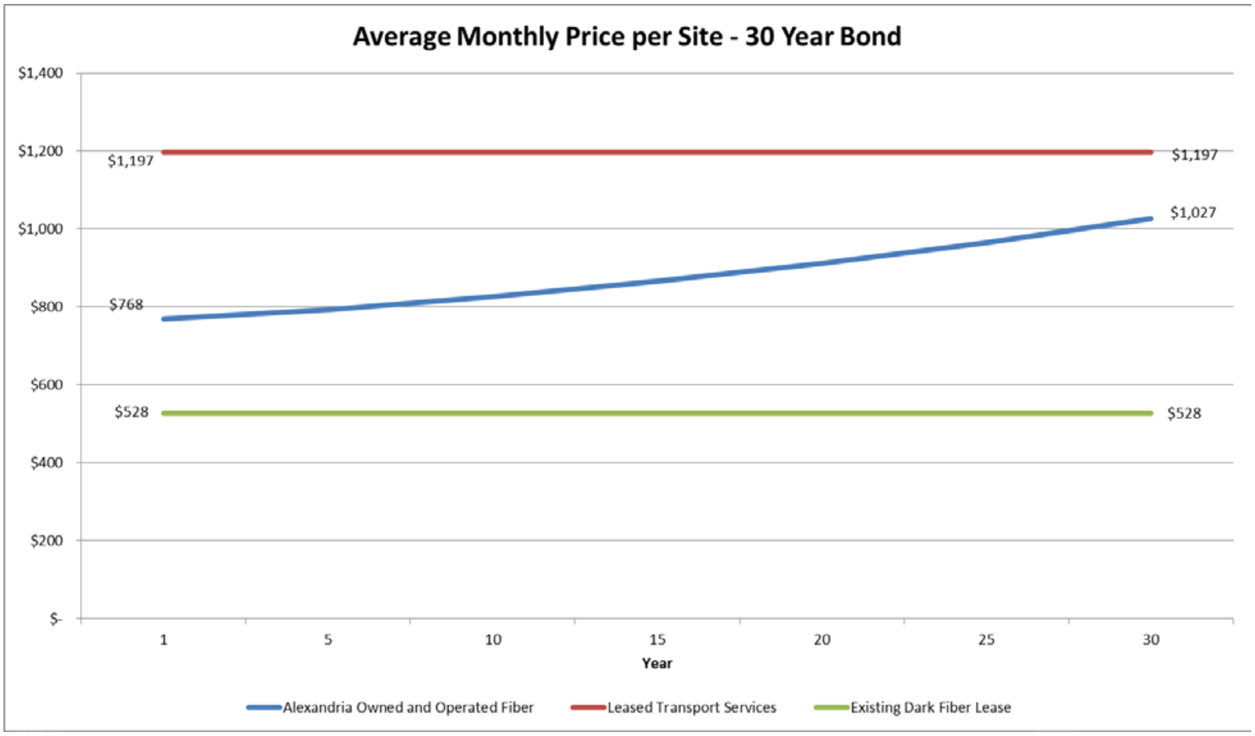
The average monthly cost per site for the City-owned network is much lower than the leased transport service and varies over the 20-year term as depicted in Figure 25.

Figure 25: Average Monthly Price per Site (20-Year Bond) in Scenario Five



The average monthly cost per site for the City-owned network is much lower than the leased transport service and varies over the 30-year term as depicted in Figure 26.

Figure 26 Average Monthly Price per Site (30-Year Bond) in Scenario Five



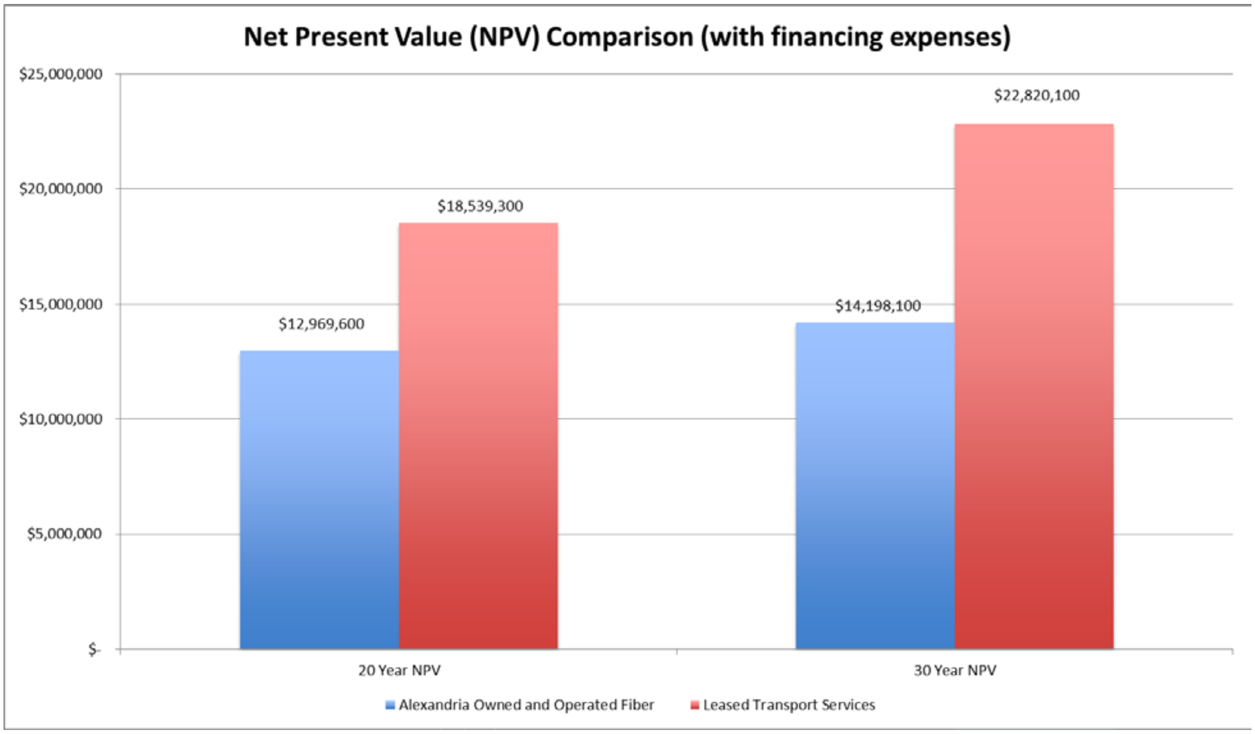
5.6 Scenario Six: Comparable Comcast Service Pricing with 5 Percent Decrease Every Five Years

Comcast recently offered managed Ethernet services to two large public school districts in the region in response to competitive bid processes, which we consider to be the best examples of discounted, market rate pricing. These bids were for networks of relatively similar scale to that of Alexandria's, and required service offerings ranging in capacity from 1 Gbps to 10 Gbps.

Consistent with this pricing data, we thus consider a scenario providing 1 Gbps service to 73 sites at $1,064 per month, and 10 Gbps service to seven core sites at $6,360 per month per connection. We also accounted for a 5 percent decrease in leased service pricing every five years. We believe this represents the most likely scenario for the City, if not in the near term (i.e. during the term of a renewed five year I-Net Fiber Use Agreement), then soon thereafter.

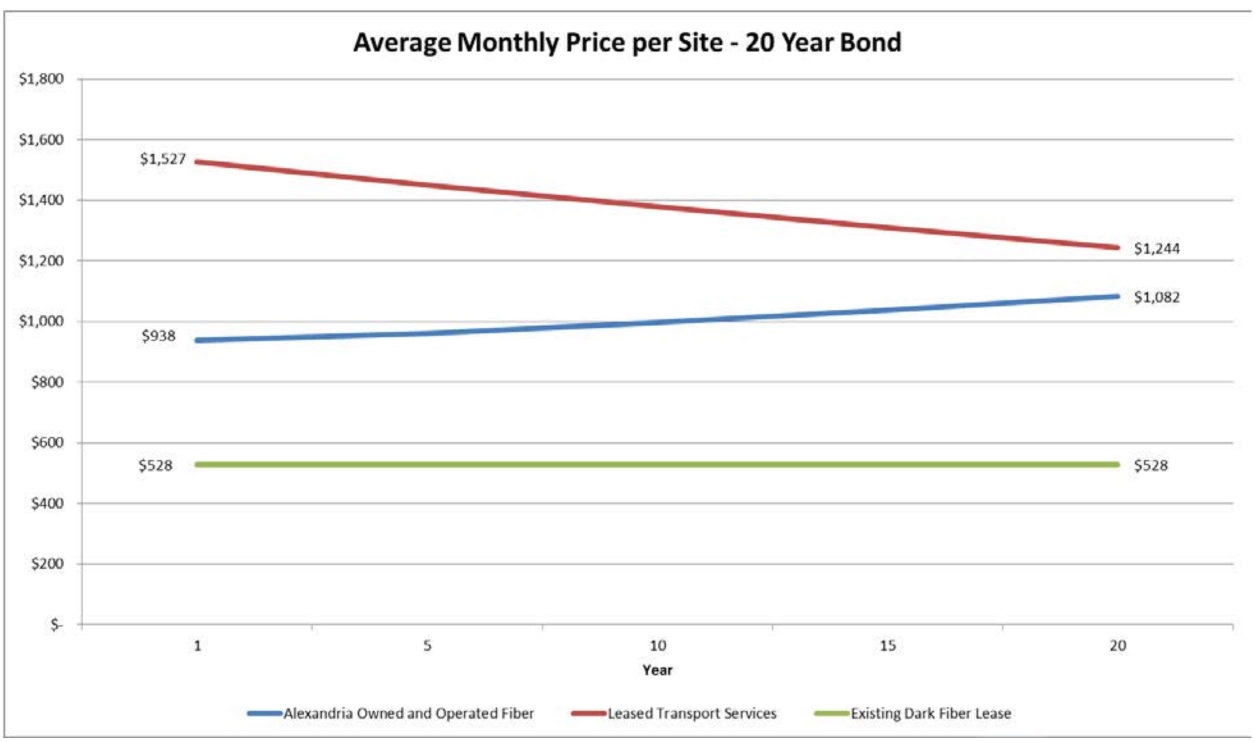
In this scenario, the NPV of the City-owned fiber network compared to that of the leased network is considerably lower over both a 20-year and 30-year period, as depicted in Figure 27.

Figure 27: NPV of Scenario Six (Base Case)



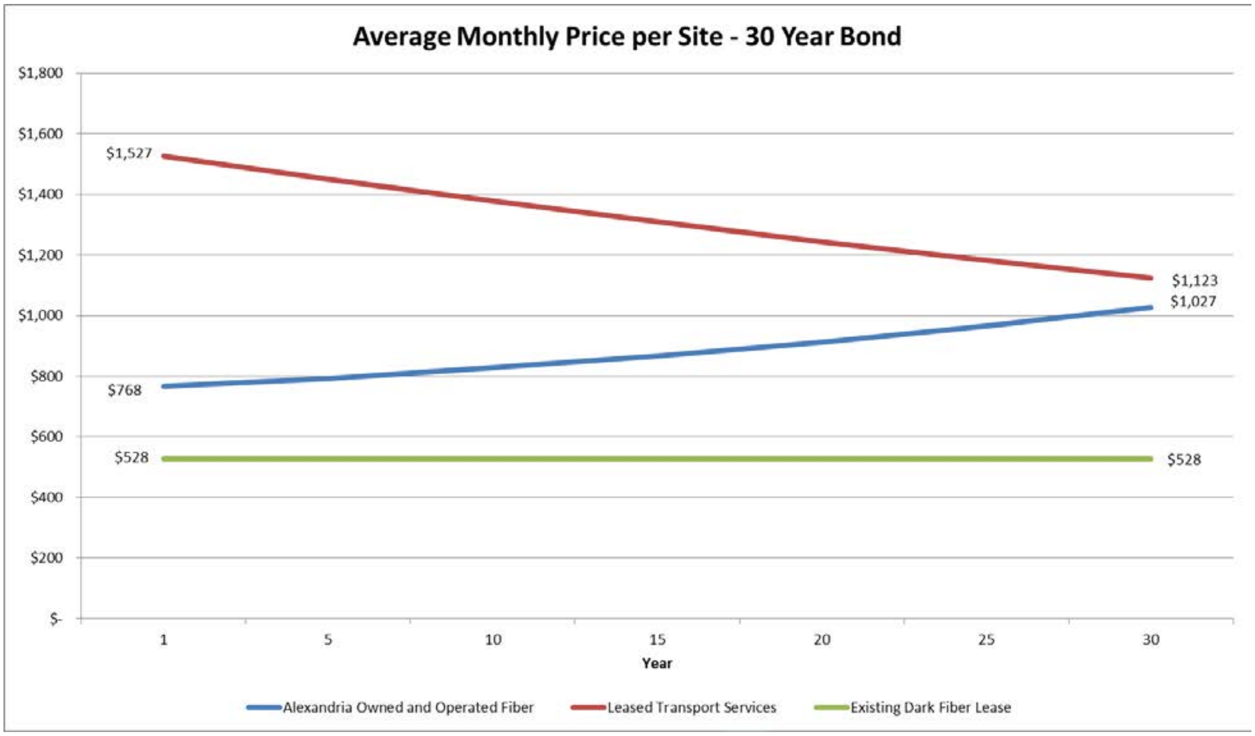
The average monthly cost per site for the City-owned network is lower than the cost of leased transport service with a variation over the 20-year term as depicted in Figure 28.

Figure 28: Average Monthly Price per Site (20-Year Bond) in Scenario Six (Base Case)



The average monthly cost per site for the City-owned network is lower than the cost of leased transport service with a variation over the 30-year term as depicted in Figure 29.

Figure 29: Average Monthly Price per Site (30-Year Bond) in Scenario Six (Base Case)



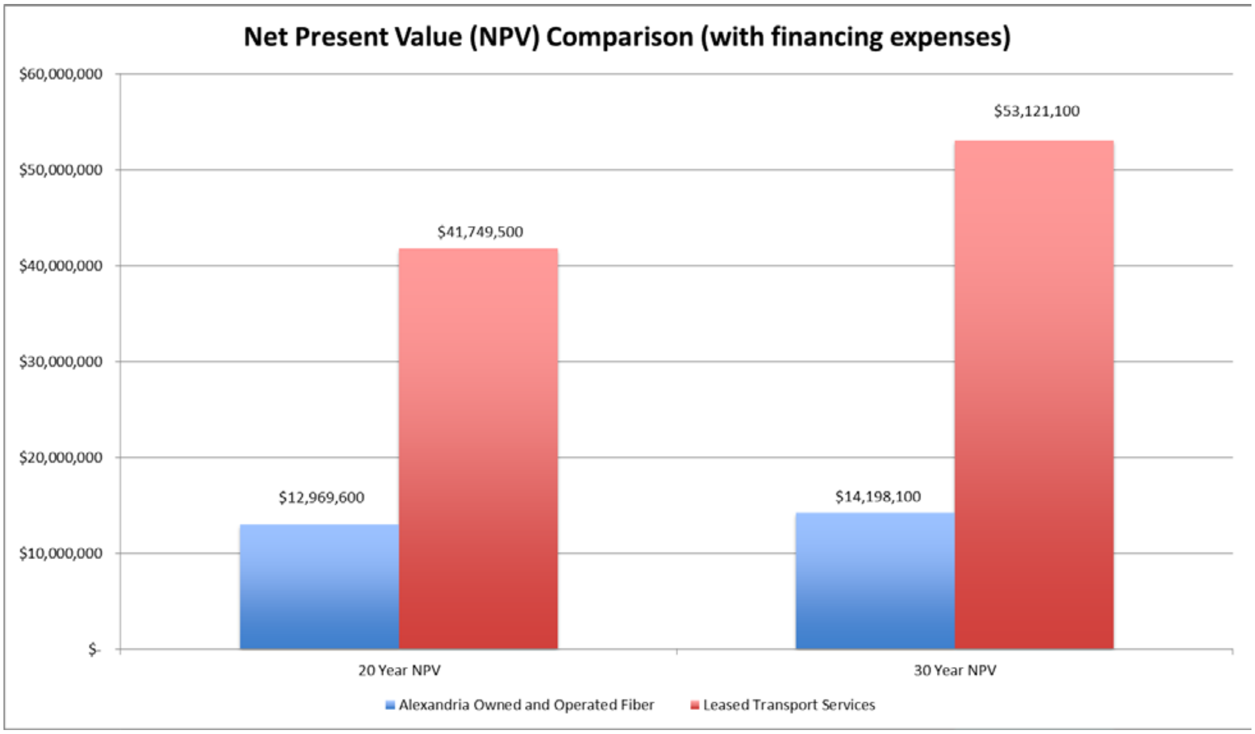
5.7 Senario Seven: City Fiber-Equivalent Capacity Service Pricing with 5 Percent Decrease Every Five Years

In this final scenario, we compare City-owned fiber to leased services at the low-end Comcast pricing, but at capacity levels equivalent to what the City would activate over its own fiber, consisting of 10 Gbps to all 80 sites at a monthly cost of $3,200 per site.

Although this level of leased network capacity would not likely be deemed worthwhile or affordable for a majority of the sites, this offers the best "apples-to-apples" functional comparison between City-owned dark fiber and lit managed services.

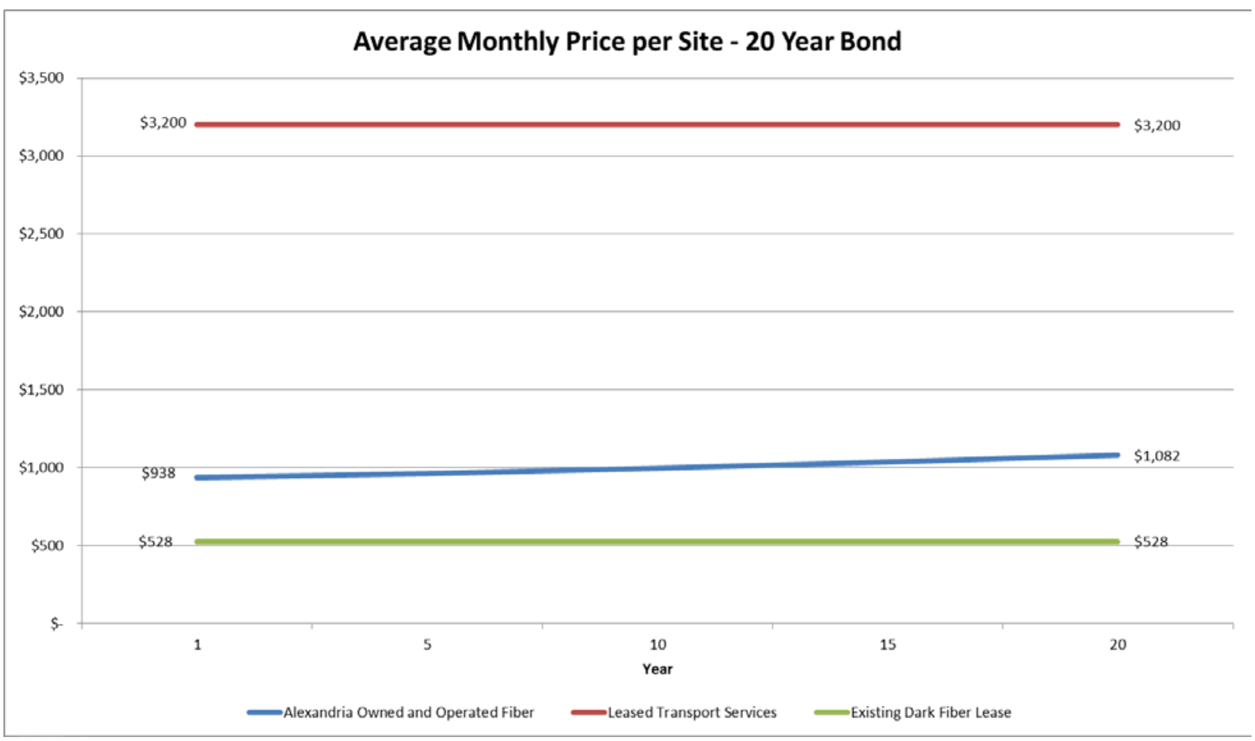
In this scenario, the NPV of the City-owned fiber network compared to that of the leased network is considerably lower over both a 20-year and 30-year period, as depicted in Figure 27.

Figure 30: NPV of Scenario Seven



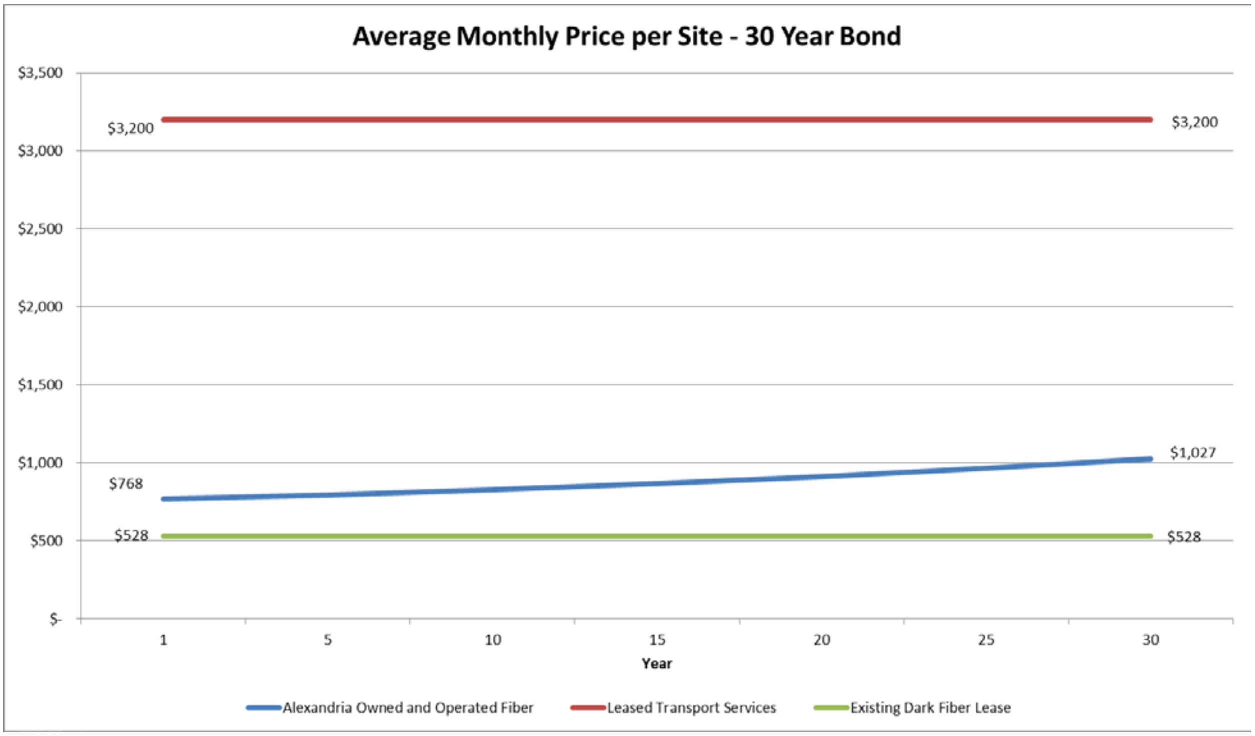
The average monthly cost per site for the City-owned network is lower than the cost of leased transport service with a variation over the 20-year term as depicted in Figure 28.

Figure 31: Average Monthly Price per Site (20-Year Bond) in Scenario Seven



The average monthly cost per site for the City-owned network is much lower than the cost of leased transport service and varies over the 30-year term as depicted in Figure 29.

Figure 32: Average Monthly Price per Site (30-Year Bond) in Scenario Seven



This may be the most accurate comparison when examining the ability of the network to meet demands in an unrestricted manner.

6. Opportunities to Monetize the City-Owned Fiber Network

The primary reason to develop a City-owned fiber network is to provide services to City buildings and community anchor institutions. In addition to serving the 80 sites currently connected with Comcast fiber, the fiber routes could be designed to connect to additional City locations, such as traffic signals. The City would retain ownership of the fiber assets and be positioned to provision services according to its evolving needs without being tied to a carrier's contract and pricing.

There are other potential benefits to the City owning and operating its own fiber—including opportunities to earn revenue (through leasing) and capitalize on funding opportunities such as the federal E-rate program for service to schools and libraries. In the sections below, we briefly outline these opportunities.

6.1 Leasing Dark Fiber

An important consideration that we have not accounted for in the above scenarios is the effect of potential revenues from dark fiber leases. For our analysis, the City's fiber network was designed with 288-count fiber backbone rings. This provides the City with a total of 10,295 fiber strand miles in the backbone ring, representing a significant source of potential revenues in the form of dark fiber leasing. The following sections briefly examine a few specific dark fiber lease scenarios. Appendix B provides a general overview of dark fiber leasing models.

6.1.1 Monthly Dark Fiber Leasing

If just 10 fiber strands on average over all fiber routes (3.3 percent of the total fiber strand miles) were leased to customers at $100 per strand mile per month (a reasonable target rate for short distance and/or short-term leases in an urban market), the monthly revenue generated would be $34,000. This revenue would subsidize the average cost per site per month by $425—reducing the average per month per site cost to $513 in year one of a 20-year term. (As noted in Section 1.1.2, we assume that O&M costs will rise 3 percent per year over the life of the network, so the average monthly cost will increase.)

If the City were able to lease fiber on a monthly basis across the entire network to one or more middle mile providers, such as Zayo or Level(3), we might expect a volume discount on the monthly rate—pricing the fiber at $75 per strand mile per month. Suppose the City was able to lease 12 strands of dark fiber to one carrier and six strands to the other over all fiber routes at a rate of $75 per strand mile per month, it would earn monthly revenue of $48,260 per month, or nearly $580,000 per year. This would reduce the average per month per site cost to $335 in year one of a 20-year term.

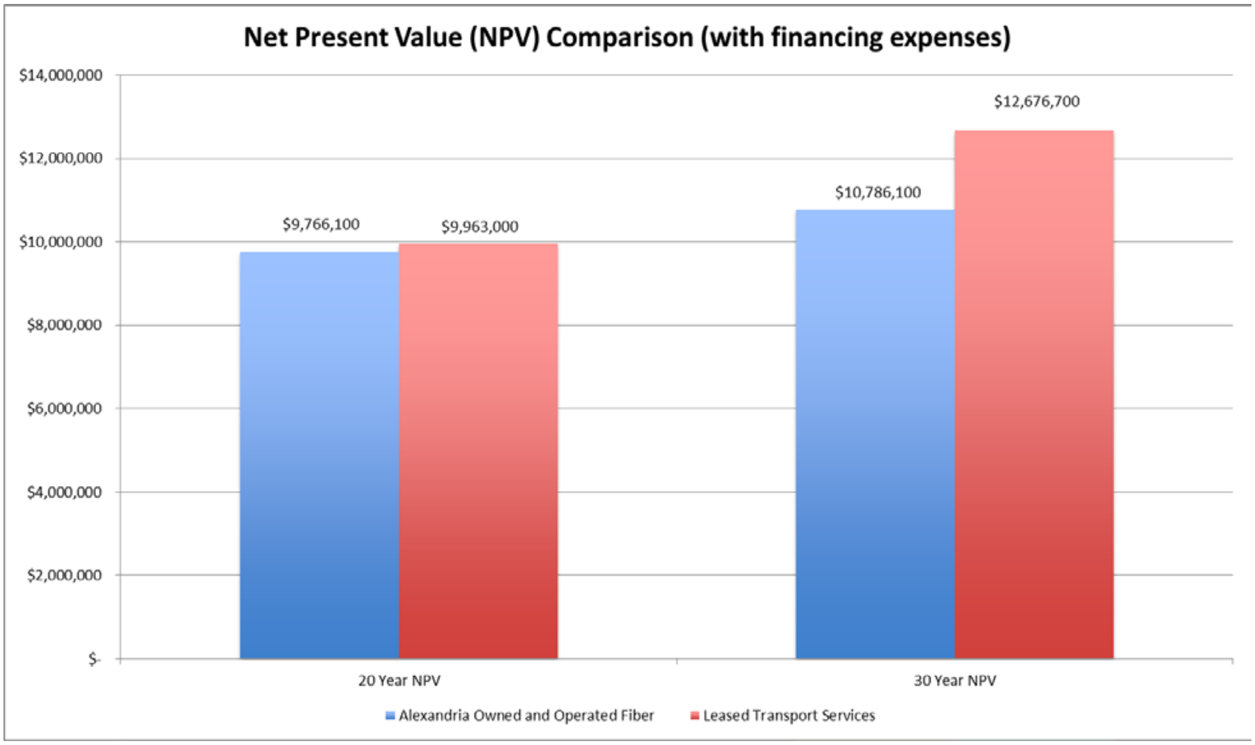
6.1.2 Long-Term IRUs to Offset Capital Construction Costs

When a commercial provider is seeking to establish a long-term presence in a new market or acquire long-haul connectivity between markets with a reduced upfront capital investment compared to constructing their own fiber, they frequently prefer a long-term indefensible right of use (IRU) agreement with an existing fiber owner. In the case of Alexandria, it is conceivable that multiple providers seeking to serve different market segments would look to the City for 20-year or 30-year IRUs to quickly establish a citywide footprint, and potentially to reach relatively untapped markets.

Pricing for dark fiber IRUs commonly involve an upfront payment, on the order of $2,000 or more per strand mile in major urban markets for a 20-year IRU, with a small annual maintenance fee paid throughout the term of the agreement. For sake of illustration, we consider a scenario in which the City leases 36 strands across its entire network to a last mile FTTP provider (i.e. Ting Internet) and 12 strands to a middle mile partner (i.e. Zayo). Even at a somewhat discounted rate of $1,500 per strand mile, plus a maintenance fee of approximately $250 per route mile, this would yield an upfront payment of almost $2.6 million and a maintenance fee of almost $17,900 in the first year. The sum of these IRU lease deals, including a 3 percent annual escalation of maintenance costs, would reduce the City's bonding requirement for its fiber network to less than $7.5 million.

In this case, the NPV of the City-owned fiber network is lower than that of the leased network over both a 20-year term and a 30-year period for even the "best-case" leased network pricing presented in Scenario Two (described in Section 5.2), as depicted in Figure 33.

Figure 33: NPV of "Scenario Two" with Potential Fiber Lease IRU Revenues



6.2 Providing E-Rate Services to Schools and Libraries

The federal E-rate program reimburses a substantial portion of schools' and libraries' Internet connectivity charges. If the City were to become the E-rate provider to Alexandria City Public Schools, the 80 percent federal subsidy for which ACPS is currently eligible would be paid to the City—and the entire cost of Wide Area Network (WAN) service would stay in the community. (As an additional benefit, the City may find it easier to enter the enterprise-grade services market if it can establish its credentials by successfully serving schools and libraries.)

For illustration purposes, if the City was awarded a contract as the WAN provider by ACPS as part of an E-rate-eligible bid process at the pricing described for Cost Comparison Scenario Six ("Market-Rate Comcast Managed Service Pricing," Section 5.6), the e-rate discount revenues could be as much as $367,000 annually.[14]

[14] We assume a total of 18 ACPS sites each receiving 1 Gbps connections at $1,064 per month, and 3 sites (School Board Administration and both High School campuses) each receiving 10 Gbps connections at $6,360 per month. Revenue calculations are based on the Alexandria E-Rate funding year 2015 discount level of 80 percent.

The E-rate bidding process is competitive—there is no guaranteed outcome. And the E-rate program strictly prohibits any collusion; the procurement process should be rigorously followed at all times.

6.3 Providing Dark Fiber Backhaul from Cellular Sites

In a carrier wireless network, cell towers have typically been connected (backhauled) to the wired telecommunications network through low-bandwidth circuits. As demand for mobile data access has grown, carriers are increasingly seeking fiber for backhaul—a trend that will continue to increase as carriers move toward fifth-generation (5G)[15] wireless technologies. The City may be able to construct relatively small extensions of its fiber routes to connect cellular sites (i.e., construct "fiber-to-the-tower," or FTTT), to provision backhaul from the cell sites to core network locations.

6.4 Forming Partnerships with Dominion Virginia Power

Electric utilities across the country are adopting "Smart Grid" technologies that rely on fiber and wireless infrastructure for two-way communication between the utility and its customers, as well as sensing within the utility system. The City may be able to support Dominion Virginia Power by providing fiber backhaul communications infrastructure for distribution automation (DA) and other Smart Grid applications.

[15] We anticipate that 5G rollouts will begin in the 2020 timeframe. It features greater capacity, smaller cells, and better traffic prioritization.

7. Recommendations and Next Steps

Based on the strong business case for a City fiber network, and recognizing that City-owned fiber provides the greatest flexibility to meet current needs and to respond to future requirements, we recommend that the City proceed with certain steps towards constructing a fiber network and seeking private partnerships supporting this direction.

Specifically, we recommend that the City:

1) ***Initiate planning and engineering of a City fiber network as soon as possible to minimize the amount of time the City may be required to entertain either a higher cost dark fiber or managed network service from Comcast***.

We suggest that the City engage Dominion Virginia Power to discuss utility pole attachment fees; establish a pole attachment agreement; discuss potential partnerships wherein the City might address Dominion's connectivity needs; and if viable, initiate pole make-ready analysis.

Furthermore, we recommend that the City begin detailed engineering and design efforts, to include field surveys of routes; investigate detailed permitting requirements and initiate required processes with permitting authorities; site surveys of network sites for fiber entrance planning; and detailed assessment of technical requirements for any candidate joint build opportunities with other City projects.

And finally, we recommend that the City simultaneously develop a fiber construction RFP to be released once engineering is substantially complete, both to validate construction costs and to allow the City to task construction as soon as final engineering and permitting is complete.

2) ***Develop and release an RFP soliciting public-private partnerships informed by the City's ongoing efforts to design a fiber network, and supported by its earnest intent to construct with or without private support.***

The RFP should seek proposals for partnership arrangements in which the City retains sufficient control of dark fiber assets to achieve its long-term internal connectivity objectives, as well as the flexibility to support economic development and other public-facing initiatives. Suitable partnership arrangement might include:

- Long-term dark fiber leases to a private partner in the form of an IRU with upfront capital payments to the City to offset construction costs, with or without exclusivity to providers operating in particular market segments (i.e. residential and/or small business FTTP, large business and enterprise data services, cellular backhaul provider, etc.);

- Joint fiber and/or conduit construction with shared construction costs, maintenance, and ownership, whether in the form of separate conduits and separate cables, or separate strands in a common cable sheath; and
- Long-term dark fiber lease by the private partner to the City.

Proposals should be evaluated based on criteria prioritizing long-term City control of fiber assets, positive impact to the projected financial bottom line for the City, and flexibility to achieve longer-term economic development objectives, including:

- Scale and timeframe of any resulting fiber lease to the private partner (i.e. all fiber routes or partial routes; number of fiber strands; length of term, etc.);
- Consistency with the proposed technical approach to meet the functions and technical design recommendations presented in Section 4.1;
- Total private capital contribution to offset fiber construction costs;
- Private partner commitments to facilitate open access to other providers;
- Private partner commitment to expand fiber and services to City businesses and residents; and
- Minimized or no limits placed on usage of fiber for non-governmental purposes imposed by the partner for any dark fiber leases to the City.

3) ***Update the fiber network construction business case financial analysis with direct cost inputs from future Comcast proposals and fiber construction bids to refine and validate the recommended strategy, as well as to serve as a tool to compare the financial impact on this strategy of potential proposals from private partners.***

With these more precise cost inputs and specific proposals for public-private partnerships, the City should refine the financial analysis for constructing and operating its own network compared to commercial service alternatives. Ultimately this will inform the private partner selection process, as well as help to define private partner negotiation parameters (fiber lease pricing, cost sharing requirements, etc.).

Appendix A: Lit Services Pricing in the Mid-Atlantic Region

Mid-Atlantic Broadband Cooperative (MBC) offers dedicated bandwidth from 10 Mbps to 10 Gbps in eastern Virginia. MBC has a flat-rate pricing model for all optical transport services, using SONET/TDM, Wavelength and Ethernet connections. MBC's standard contract term is 24 months; it offers a 10 percent discount for a 36-month contract and a 15 percent discount for a 60-month contract. Non-recurring costs (NRC) and monthly recurring costs (MRC) for sample Ethernet connectivity within the regional MBC footprint for on-net facilities or locations with minimal connectivity capital costs is provided in Table 5 below.

Table 5: Mid-Atlantic Broadband Regional Pricing

Connection	NRC	MRC (24-Month Term)	MRC (60-Month Term)
500 Mbps	$750	$4,500	$3,825
1 Gbps	$750	$7,000	$5,950

Pricing for sample bandwidths for connectivity from locations within the MBC regional network to an MBC long-haul market Point-of-presence (POP) is provided in Table 6 below. The prices do not include costs associated with cross-connects at the POP.

Table 6: Mid-Atlantic Broadband Reginal to Long-Haul POP Pricing

Connection	NRC	MRC (24-Month Term)	MRC (60-Month Term)
500 Mbps	$1,250	$4,750	$4,038
1 Gbps	$1,250	$6,000	$5,100
10 Gbps	$1,250	$14,500	$12,325

The State of Maryland's Department of Information Technology operates a statewide network called networkMaryland. The network offers maximum aggregate bandwidth to meet a variety of needs ranging from a monitored network connection to Layer 2 circuits and Internet services. Below is pricing for a monitored EVPL circuit (only available in certain locations), a Layer 2 circuit, and Internet services.[16]

[16] http://doit.maryland.gov/support/Documents/nwmd_gettingconnected/nwmd2016Rates.pdf

Table 7: networkMaryland Layer 2 Circuit

Connection	MRC	NRC
1,000 Mbps (1 Gbps)	$8,826	$500

Table 8: networkMaryland Internet Service

Bandwidth	MRC	Bandwidth Fee (per month per Mbps) – for reference only	NRC
500 Mbps	$4,455	$8.91	Subscriber must have a physical port connection before ordering Internet services
1,000 Mbps (1 Gbps)	$7,355	$7.36	

Zayo's pricing for a 10 Gbps and 1 Gbps point-to-point Ethernet line between two on-net enterprise locations in Alexandria and Arlington that are 11 miles apart is provided in the tables below.

Table 9: 10 Gbps Ethernet Transport Pricing in Alexandria

Term	12 Month	60 Month
Monthly Recurring Costs	$7,553	$5,513
Non-Recurring Costs	TBD	TBD

Table 10: 1 Gbps Ethernet Transport Pricing in Alexandria

Term	12 Month	60 Month
Monthly Recurring Costs	$3,206	$2,340
Non-Recurring Costs	TBD	TBD

Zayo's pricing for a 10 Gbps and 1 Gbps DIA between two on-net locations in Alexandria and Arlington is provided in the tables below.

Table 11: 10 Gbps DIA Pricing in Alexandria

Term	12 Month	60 Month
Monthly Recurring Costs	$28,393	$17,036
Non-Recurring Costs	TBD	TBD

Table 12: 1 Gbps DIA Pricing in Alexandria

Term	12 Month	60 Month
Monthly Recurring Costs	$5,968	$3,581
Non-Recurring Costs	TBD	TBD

Comcast provides DIA and Ethernet services such as Ethernet Private Line. EPL service is offered with 10 Mbps, 100 Mbps, 1 Gbps or 10 Gbps Ethernet User-to-Network Interfaces (UNI) and is available in speed increments from 1 Mbps to 10 Gbps.[17] Pricing proposed for 1 Gbps WAN services to 50 locations within Maryland was $1,250 monthly per location for a 60-month term. Pricing for 3 Gbps services to 20 locations was $3,000 monthly per location for a 60-month term. A 5 Gbps service to 12 locations was priced at $4,500 monthly per location for the same term. Pricing for 10 Gbps DIA was $14,700 monthly for a 60-month term.

Atlantech Online offers point-to-point, Ethernet and Internet services in Montgomery County, Maryland. The monthly bandwidth pricing (excluding the local loop) ranges from $8 per Mbps for 100 Mbps to $1 per Mbps for 100 Gbps. Local loop costs vary by location and competition.

Verizon's pricing for a 1 Gbps DIA service in Montgomery County, Maryland is $6,500 per month for a three-year term.

[17] http://business.comcast.com/ethernet/products/ethernet-private-line-technical-specifications

Appendix B: Dark Fiber Leasing Models and Sample Pricing

Most commonly, dark fiber is priced on a per strand, per mile basis for a set term. Usually, the lease price is for fibers on the existing fiber network, and the customer is responsible for the incremental cost to connect its facility to the closest access point on the existing fiber route. Colocation, splicing, make-ready, and rack space costs are generally assessed on top of the fiber pricing. Some leasing entities will also charge an up-front fee to cover administrative costs.

Dark Fiber Leasing Models

The following are a range of pricing structures found in both the private and public sectors.

1. **Incremental or proportional cost (either of construction or maintenance).** In this model, dark fiber is priced at the incremental or proportional cost of building or maintaining the leased fibers. These structures will result in the lowest pricing possible. In our experience, this model is used only where the provider is under some kind of duress or legal requirement.[18]

2. **Up-front payment plus maintenance.** Most commonly, dark fiber is leased as a 10- to 20-year (most often 20) Indefeasible Right of Use (IRU). The customer pays up front for the IRU and annually for maintenance.[19] The maintenance cost is calculated on route miles, not strand miles. The annual maintenance charge is the same per mile regardless of whether the lease is for one or 100 strands on the same route. The upfront payment covers the entire term of the fiber lease, while the maintenance and co-location portions of the contract are often renewable, typically on five-year or shorter terms (to allow for cost adjustments based on experience and inflation). The benefit of this model is the substantial inflow of funds early in the lease term—which can help bridge early-year cash shortfalls while an entity is beginning operations and developing new services. On the other hand, the model will not result in recurring annual revenues over the long term, beyond some of the cost of maintenance.

3. **Per annum or per month pricing.** This structure has the benefit of delivering to the fiber owner a steady annual income stream over time, but does not deliver a large up-front payment that could bridge a difficult budget year or finance new investment. On the other hand, this model is more achievable if the dark fiber lessee is not able to make a large up-

[18] For example, Minnesota Power was instructed to offer a dark fiber at a rate of $13.65 per mile per strand per month under a ruling from the Minnesota Public Utilities Commission on a transaction agreement between Minnesota Power and Enventis Telecom Inc. (a non-regulated subsidiary of Minnesota Power). The ruling bases the lease price of Minnesota Power's unused fiber assets using an incremental cost basis.

[19] One of the benefits of this model for the customer is the possibility that the IRU could be recognized as a financial lease that may allow the IRU to be treated as a capital expenditure.

front payment—but can pay for the fiber on a recurring annual or monthly basis. As a result, this model increases the number of potential dark fiber customers. Net pricing over the term of the lease tends to be higher than in the up-front payment model over the same total period of time. This model is often used for short-term leases, and can deliver very high revenues for a short time—a nice bonus, but not necessarily the basis for sustainability of a network.

Sample Dark Fiber Pricing

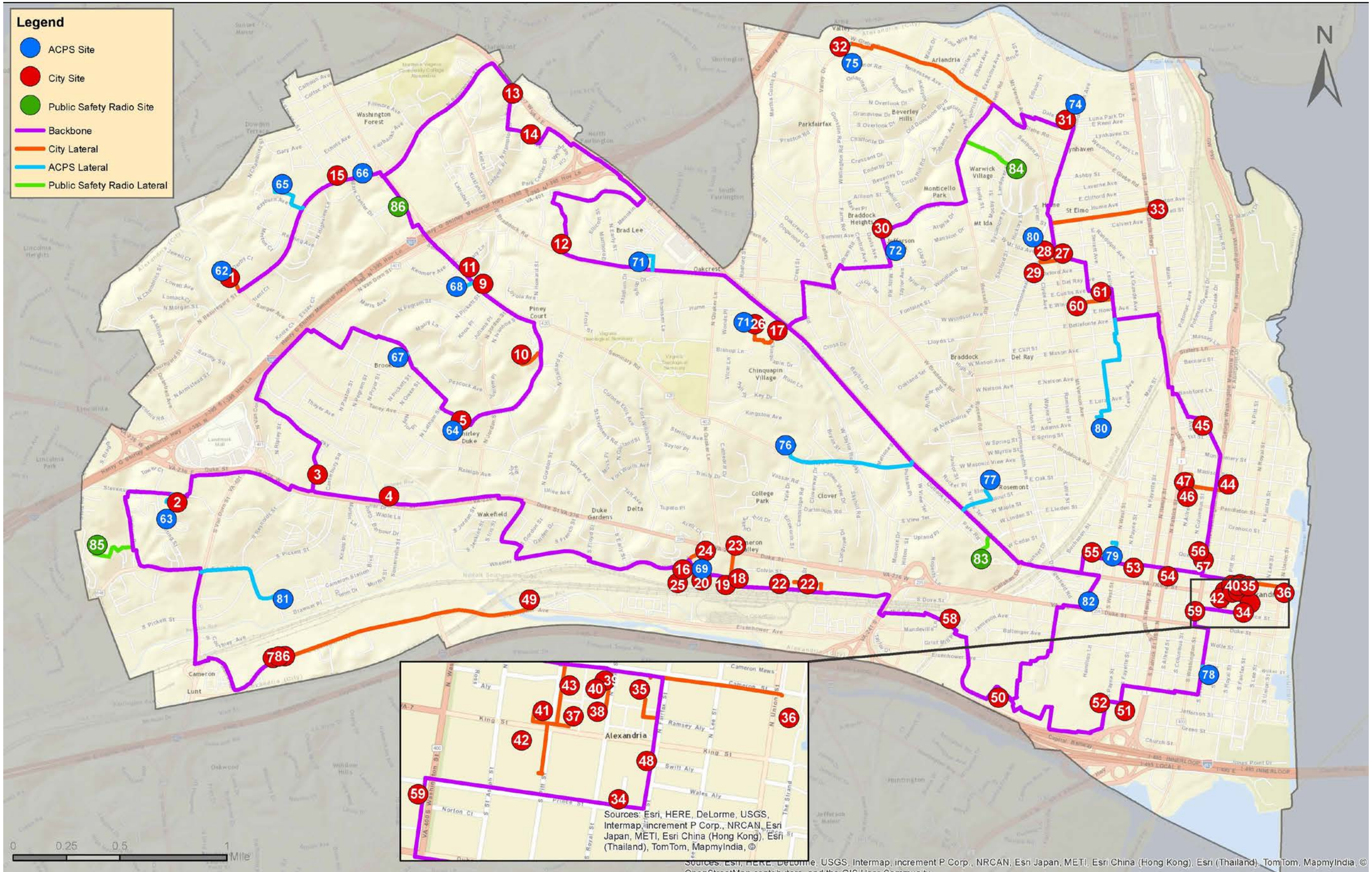
Metro-area prices are almost always considerably higher (on a per mile basis) than long-haul fiber, which is less costly to build. Within the metro-area category, urban routes will be priced significantly higher than routes in suburban and exurban areas, depending on the desirability of the urban market. Occasionally, an urban market will prove to be surprisingly cost-effective, usually because a glut of fiber has had the competitive impact of pushing pricing down.

Commercial pricing in major urban areas can range from $2,000 to $50,000 per mile per strand up-front for a 20-year term, depending on the provider and whether river crossings or similarly complex routing is necessary. On a per month, per mile basis, we have seen pricing range from to $20 to $2,500. In cases where the full cost for construction is included—as it frequently is in new commercial builds—the cost in our experience ranges from $350 to $6,000 per mile, per month per strand. We frequently see bids from commercial providers that include construction costs at 10 to 20 times the cost of the IRU itself, depending on the number of strands required. Dark fiber service connections to commercial customers typically have more than 40 percent of these revenues coming from value-added resellers.

The following are a range of prices, using a range of pricing structures, we have seen recently in the mid-Atlantic region.

- Maryland Broadband Cooperative, a rural cooperative, prices its dark fiber for members at $75 per fiber per mile per month for a 60-month lease. Maintenance charges are $10 per fiber per mile.
- Zayo offers point-to-point dark fiber between two on-net locations in Alexandria and Arlington that are 11 miles apart with an MRC ranging from $7,390 to $3,394 for a fiber pair depending on the duration of the term (12 months to 60 months).
- Carroll County in northern Maryland leases dark fiber at $30 per strand per month per mile.
- The Mid-Atlantic Broadband Cooperative serving Eastern Virginia offers IRUs in the range of $1,500 to $2,000 per strand per mile for 20-year term. The area served includes a mix of small urban, suburban, and rural areas

Appendix C-1: System Level Fiber Network Route Map



Appendix C-2: Fiber Network Site List

Site Number	Site Name	ADDRESS	NETWORK
1	Ramsey Recreation Center	5650 Sanger Road	City
2	Juvenile Detention Center	200 South Whiting Street	City
3	Fire Station 208	175 North Paxton	City
4	Beatley Library	5005 Duke Street	City
5	Patrick Henry Recreation Center	4643 Taney Avenue	City
6	Impound Lot	5249 Eisenhower Avenue	City
7	Firing Range	5261 Eisenhower Avenue	City
8	Fire Station 210	5255 Eisenhower Ave	City
9	Fire Station 206	4609 Seminary Road	City
10	Casey Clinic	1200 N. Howard Street	City
11	Burke Library	4701 Seminary Road	City
12	Ft Ward	4301 W Braddock Rd	City
13	Health Department 4480	4480 King Street	City
14	DCHS Aging/Vocational	4401 Ford Avenue	City
15	JobLink & CAC	1900 N. Beauregard Street	City
16	Police APD, Police Special Vehicle Facility	3600 Wheeler Avenue	City
17	Chinaquapin Recreation Center	3210 King Street	City
18	TES Traffic	116 S Quaker	City
19	TES Maintenance	133 South Quaker Lane	City
20	Fleet Services	3550 Wheeler Ave	City
21	Business Center	2914 Business Center Drive	City
22	DASH Bus	3000 Business Center Drive	City
23	Fire Station 207	3301 Duke Street	City
24	Gas Pumps	3400 Duke Street	City
25	Auxillary 1	3534 Wheeler Avenue	City
26	Teen Clinic @ TC Williams	3330 King Street	City
27	DHS	2525 Mount Vernon Avenue	City
28	Mount Vernon Recreation Center	2601 Commonwealth Avenue	City
29	Duncan Library	2501 Commonwealth Avenue	City
30	Fire Station 203	2801 Cameron Mills Road	City
31	Cora Kelly Recreation Center	25 West Reed Street	City
32	Barrett Recreation Center	1115 Martha Custis Drive	City
33	Fire Station 209	2800 Main Line Bv	City
34	Fire Station 201	317 Prince Street	City
35	City Hall	301 King Street	City
36	Torpedo Factory	105 N. Union Street	City
37	421 King Street	421 King Street	City

Site Number	Site Name	ADDRESS	NETWORK
38	General Svcs Dept Staff	110 N. Royal Street	City
39	Gadsby's Tavern	134 N. Royal Street	City
40	Tavern Square	132 N. Royal Street	City
41	Bankers Square	100 N. Pitt Street	City
42	Courthouse	520 King Street	City
43	ITS / NOC	123 N. Pitt Street	City
44	DCHS 720 (Community Services Board)	720 North Saint Asaph Street	City
45	Fire Station 204	900 Second Street	City
46	Black History Museum	902 Wythe Street	City
47	Charles Houston Recreation Center	905 Wythe Street	City
48	Apothecary Museum	107 South Fairfax Street	City
49	Animal Shelter	4101 Eisenhower Ave	City
50	Public Safety Center, Public Safety Visitors Center, Jail, and Magistrate	2003 Mill Road	City
51	Lee Center, Fire Training, and Police K9	1108 Jefferson Street	City
52	Print Shop / Archives	801 South Payne Street	City
53	Fire Station 205	1210 Cameron Street	City
54	MH Safe Haven	115 N. Patrick Street	City
55	Durant Recreation Center	1605 Cameron Street	City
56	Barrett Library	717 Queen Street	City
57	Lloyd House	220 North Washington Street	City
58	Substance Abuse Svcs	2355 Mill Road	City
59	Lyceum	201 S. Washington Street	City
60	Fire Station 202	213 East Windsor Street	City
61	Auxillary 2 (Del Ray)	311 East Custis Street	City
62	William Ramsey School	5700 Sanger Avenue	ACPS
63	Juvenile Detention Center School	200 South Whiting Street	ACPS
64	Patrick Henry School	4643 Taney Avenue	ACPS
65	John Adams School	5651 Rayburn Avenue	ACPS
66	School Board Administration	2000 N. Beauregard Street	ACPS
67	James Polk School	5000 Polk Avenue	ACPS
68	Francis Hammond School	4646 Seminary Road	ACPS
69	School Maintenance	3540 Wheeler Avenue	ACPS
70	T.C. Williams High School	3330 King Street	ACPS
71	Minnie Howard School	3801 West Braddock Road	ACPS
72	George Mason School	2601 Cameron Mills Road	ACPS
73	Mount Vernon School	2601 Commonwealth Avenue	ACPS
74	Cora Kelly School	3600 Commonwealth Avenue	ACPS

Site Number	Site Name	ADDRESS	NETWORK
75	Charles Barrett School	1115 Martha Custis Drive	ACPS
76	Douglas Macarthur School	1101 Janneys Lane	ACPS
77	Maury School	600 Russell Road	ACPS
78	Lyles-Crouch School	530 South Saint Asaph Street	ACPS
79	Jefferson-Houston School	1501 Cameron Street	ACPS
80	George Washington School	1005 Mount Vernon Avenue	ACPS
81	Samuel Tucker School	435 Ferdinand Day Drive	ACPS
82	Interim Education Program	216 S Peyton Street	ACPS
83	Masonic Temple	101 Callahan Drive	PSR
84	Aspen House	3201 Landover Street	PSR
85	Watergate Community	211 Yoakum Parkway	PSR
86	Mark Center	4900 Seminary Road	PSR

Appendix D: Fiber Construction Cost Estimates

Segment / Site Name	Address	Normal Underground Segment Mileage	Downtown Underground Segment Mileage	Total Underground Segment Mileage	Aerial Segment Mileage	Segment Mileage (Total)	Conduit/Fiber OSP Engineering Cost	Project Management / Quality Control	Conduit/Fiber OSP Construction Cost	Railroad and Interstate Crossing Costs	Splicing Cost	Termination and Testing Cost	Total Cost
Primary Ring - Southwest													
City Hall	301 King Street	0.04	-	0.04	0.00	0.04	$685	$262	$6,857	$0	$10,640	$21,920	$40,364
BB001	N/A	-	0.12	0.12	0.00	0.12	$2,205	$844	$49,907	$0	$0	$0	$52,957
Apothecary Museum	107 South Fairfax Street	-	0.00	0.00	0.00	0.00	$68	$26	$1,495	$0	$1,120	$3,020	$5,730
BB002	N/A	-	0.08	0.08	0.00	0.08	$1,414	$541	$32,006	$0	$0	$0	$33,961
Fire Station 201	317 Prince Street	-	0.00	0.00	0.00	0.00	$68	$26	$1,495	$0	$1,120	$3,020	$5,730
BB003	N/A	-	0.24	0.24	0.00	0.24	$4,256	$1,629	$96,327	$0	$0	$0	$102,213
Lyceum	201 S. Washington Street	0.01	-	0.01	0.00	0.01	$257	$98	$2,365	$0	$1,120	$3,020	$6,860
BB004	N/A	0.45	0.45	0.90	0.00	0.90	$16,347	$6,257	$266,952	$0	$0	$0	$289,556
Lee Center, Fire Training, and Police K9	1108 Jefferson Street	0.05	-	0.05	0.00	0.05	$856	$328	$7,884	$0	$1,120	$3,020	$13,208
BB005	N/A	0.07	-	0.07	0.00	0.07	$1,335	$511	$13,371	$0	$0	$0	$15,218
Print Shop / Archives	801 South Payne Street	0.05	-	0.05	0.00	0.05	$856	$328	$7,884	$0	$1,120	$3,020	$13,208
BB006	N/A	0.78	-	0.78	0.00	0.78	$14,166	$5,422	$141,839	$18,600	$0	$0	$180,027
Public Safety Center, Public Safety Visitors Center, Jail, and Magistrate	2003 Mill Road	0.03	-	0.03	0.00	0.03	$599	$229	$6,000	$0	$15,960	$32,880	$55,669
BB007	N/A	0.42	0.10	0.52	0.00	0.52	$9,410	$3,602	$117,982	$0	$0	$0	$130,994
Substance Abuse Services	2355 Mill Road	0.04	-	0.04	0.00	0.04	$685	$262	$6,307	$0	$1,120	$3,020	$11,394
BB008	N/A	0.89	0.09	0.98	0.00	0.98	$17,758	$6,797	$198,978	$18,600	$0	$0	$242,133
Business Center	2914 Business Center Drive	0.05	-	0.05	0.00	0.05	$856	$328	$7,884	$0	$1,120	$3,020	$13,208
BB009	N/A	0.12	-	0.12	0.00	0.12	$2,106	$806	$21,086	$0	$0	$0	$23,998
DASH Bus	3000 Business Center Drive	0.07	-	0.07	0.00	0.07	$1,284	$491	$11,826	$0	$1,120	$3,020	$17,741
BB010	N/A	0.23	-	0.23	0.00	0.23	$4,195	$1,605	$42,000	$0	$0	$0	$47,800
TES Traffic	116 S Quaker	0.02	-	0.02	0.00	0.02	$342	$131	$3,154	$0	$1,120	$3,020	$7,767
TES Maintenance	133 South Quaker Lane	0.01	-	0.01	0.00	0.01	$137	$52	$1,261	$0	$1,120	$3,020	$5,591
BB011	N/A	0.37	-	0.37	0.00	0.37	$6,626	$2,536	$66,343	$0	$0	$0	$75,504
Police APD, Police Special Vehicle Facility	3600 Wheeler Avenue	0.05	-	0.05	0.00	0.05	$942	$360	$9,429	$0	$10,640	$21,920	$43,291
Auxiliary 1	3534 Wheeler Avenue	-	-	0.00	0.00	0.00	$0	$0	$0	$0	$0	$0	$0
BB012	N/A	0.07	-	0.07	0.00	0.07	$1,219	$467	$12,206	$0	$0	$0	$13,891
Fleet Services	3550 Wheeler Ave	0.05	-	0.05	0.00	0.05	$925	$354	$8,515	$0	$1,120	$3,020	$13,933
BB013	N/A	1.71	-	1.71	0.00	1.71	$30,976	$11,856	$310,147	$18,600	$0	$0	$371,578
Beatley Library	5005 Duke Street	0.01	-	0.01	0.00	0.01	$240	$92	$2,207	$0	$1,120	$3,020	$6,679
BB014	N/A	0.45	-	0.45	0.00	0.45	$8,095	$3,098	$81,051	$0	$0	$0	$92,244
Fire Station 208	175 North Paxton	0.01	-	0.01	0.00	0.01	$240	$92	$2,207	$0	$1,120	$3,020	$6,679
BB015	N/A	1.99	-	1.99	0.00	1.99	$36,054	$13,799	$360,992	$0	$0	$0	$410,846
Patrick Henry Recreation Center	4643 Taney Avenue	0.01	-	0.01	0.00	0.01	$240	$92	$2,207	$0	$1,120	$3,020	$6,679
BB016	N/A	0.56	-	0.56	0.00	0.56	$10,173	$3,894	$101,862	$0	$0	$0	$115,930

Segment / Site Name	Address	Normal Underground Segment Mileage	Downtown Underground Segment Mileage	Total Underground Segment Mileage	Aerial Segment Mileage	Segment Mileage (Total)	Conduit/Fiber OSP Engineering Cost	Project Management / Quality Control	Conduit/Fiber OSP Construction Cost	Railroad and Interstate Crossing Costs	Splicing Cost	Termination and Testing Cost	Total Cost
Casey Clinic	1200 N. Howard Street	0.16	-	0.16	0.00	0.16	$2,842	$1,088	$26,174	$0	$1,120	$3,020	$34,244
BB017	N/A	0.45	-	0.45	0.00	0.45	$8,153	$3,121	$81,634	$0	$0	$0	$92,908
Fire Station 206	4609 Seminary Road	0.03	-	0.03	0.00	0.03	$548	$210	$5,046	$0	$1,120	$3,020	$9,943
Burke Library	4701 Seminary Road	0.03	-	0.03	0.00	0.03	$599	$229	$5,519	$0	$1,120	$3,020	$10,487
BB018	N/A	1.63	-	1.63	0.00	1.63	$29,510	$11,295	$295,473	$26,480	$0	$0	$362,758
Health Department 4480	4480 King Street	0.03	-	0.03	0.00	0.03	$599	$229	$6,000	$0	$10,640	$21,920	$39,389
BB019	N/A	0.29	-	0.29	0.00	0.29	$5,195	$1,988	$52,011	$0	$0	$0	$59,194
DCHS Aging/Vocational	4401 Ford Avenue	-	0.02	0.02	0.00	0.02	$445	$170	$9,717	$0	$1,120	$3,020	$14,472
Primary Ring - Northeast													
BB020	N/A	1.41	0.57	1.98	0.00	1.98	$35,848	$13,721	$488,566	$52,980	$0	$0	$591,115
Auxiliary 2 (Del Ray)	311 East Custis Street	0.00	-	0.00	0.00	0.00	$86	$33	$788	$0	$1,120	$3,020	$5,047
Fire Station 204	900 Second Street	0.06	-	0.06	0.00	0.06	$1,027	$393	$10,286	$0	$10,640	$21,920	$44,266
BB021	N/A	0.27	-	0.27	0.00	0.27	$4,945	$1,893	$49,508	$0	$0	$0	$56,345
DHS	2525 Mount Vernon Avenue	0.04	-	0.04	0.00	0.04	$633	$242	$6,343	$0	$10,640	$21,920	$39,779
Mount Vernon Recreation Center	2601 Commonwealth Avenue	0.03	-	0.03	0.00	0.03	$514	$197	$4,730	$0	$1,120	$3,020	$9,581
BB022	N/A	0.75	-	0.75	0.00	0.75	$13,474	$5,157	$134,914	$0	$0	$0	$153,545
Cora Kelly Recreation Center	25 West Reed Street	0.04	-	0.04	0.00	0.04	$685	$262	$6,307	$0	$1,120	$3,020	$11,394
BB023	N/A	1.28	0.10	1.38	0.00	1.38	$24,956	$9,552	$273,639	$0	$0	$0	$308,146
Fire Station 203	2801 Cameron Mills Road	0.01	-	0.01	0.00	0.01	$188	$72	$1,734	$0	$1,120	$3,020	$6,135
BB024	N/A	1.13	-	1.13	0.00	1.13	$20,467	$7,833	$204,925	$0	$0	$0	$233,225
Teen Clinic @ TC Williams	3330 King Street	0.20	-	0.20	0.00	0.20	$3,578	$1,370	$32,955	$0	$1,120	$3,020	$42,043
Chinaquapin Recreation Center	3210 King Street	0.07	-	0.07	0.00	0.07	$1,233	$472	$11,353	$0	$1,120	$3,020	$17,197
BB025	N/A	1.00	-	1.00	0.00	1.00	$18,077	$6,919	$180,993	$0	$0	$0	$205,989
Ft Ward	4301 W Braddock Rd	0.01	-	0.01	0.00	0.01	$171	$66	$1,577	$0	$1,120	$3,020	$5,954
BB026	N/A	1.52	-	1.52	0.00	1.52	$27,507	$10,528	$275,416	$26,480	$0	$0	$339,931
BB027	N/A	0.21	0.33	0.54	0.00	0.54	$9,834	$3,764	$174,086	$0	$0	$0	$187,684
Ring bisectors													
BB028	N/A	1.63	0.33	1.96	0.00	1.96	$35,386	$13,544	$429,925	$34,380	$0	$0	$513,234
Fire Station 205	1210 Cameron Street	-	0.04	0.04	0.00	0.04	$633	$242	$13,828	$0	$1,120	$3,020	$18,844
MH Safe Haven	115 N. Patrick Street	-	0.04	0.04	0.00	0.04	$808	$309	$17,640	$0	$1,120	$3,020	$22,897
Durant Recreation Center	1605 Cameron Street	0.04	-	0.04	0.00	0.04	$633	$242	$5,834	$0	$1,120	$3,020	$10,850
BB032	N/A	0.56	0.41	0.98	0.00	0.98	$17,649	$6,755	$270,690	$0	$5,320	$0	$300,413
Eisenhower spur													
BB029	N/A	0.74	-	0.74	0.00	0.74	$13,454	$5,149	$134,708	$0	$5,320	$0	$158,631
Juvenile Detention Center	200 South Whiting Street	0.00	-	0.00	0.00	0.00	$34	$13	$315	$0	$1,120	$3,020	$4,503
Juvenile Detention Center School	201 South Whiting Street	0.05	-	0.05	0.00	0.05	$925	$354	$8,515	$0	$0	$3,020	$12,813
BB030	N/A	1.88	-	1.88	0.00	1.88	$33,972	$13,003	$340,147	$52,980	$0	$0	$440,101
Firing Range	5261 Eisenhower Avenue	0.02	-	0.02	0.00	0.02	$342	$131	$3,154	$0	$1,120	$3,020	$7,767

Segment / Site Name	Address	Normal Underground Segment Mileage	Downtown Underground Segment Mileage	Total Underground Segment Mileage	Aerial Segment Mileage	Segment Mileage (Total)	Conduit/Fiber OSP Engineering Cost	Project Management / Quality Control	Conduit/Fiber OSP Construction Cost	Railroad and Interstate Crossing Costs	Splicing Cost	Termination and Testing Cost	Total Cost
Fire Station 210	5255 Eisenhower Ave	0.06	-	0.06	0.00	0.06	$1,062	$406	$9,776	$0	$0	$3,020	$14,264
Impound Lot	5249 Eisenhower Avenue	0.00	-	0.00	0.00	0.00	$34	$13	$315	$0	$1,120	$3,020	$4,503
Beauregard spur													
BB033	N/A	0.94	-	0.94	0.00	0.94	$17,060	$6,529	$170,811	$0	$5,320	$0	$199,720
JobLink & CAC	1900 N. Beauregard Street	0.05	-	0.05	0.00	0.05	$822	$315	$7,569	$0	$1,120	$3,020	$12,845
City Laterals													
Bankers Square	100 N. Pitt Street	-	0.11	0.11	0.00	0.11	$1,900	$727	$41,484	$0	$1,120	$3,020	$48,252
421 King Street	421 King Street	-	0.02	0.02	0.00	0.02	$342	$131	$7,475	$0	$1,120	$3,020	$12,088
ITS / NOC	123 N. Pitt Street	-	0.01	0.01	0.00	0.01	$137	$52	$2,990	$0	$1,120	$3,020	$7,319
General Svcs Dept Staff	110 N. Royal Street	-	0.05	0.05	0.00	0.05	$883	$338	$19,284	$0	$1,120	$3,020	$24,646
Gadsby's Tavern	134 N. Royal Street	-	0.01	0.01	0.00	0.01	$229	$88	$5,008	$0	$1,120	$3,020	$9,465
Tavern Square	132 N. Royal Street	-	0.01	0.01	0.00	0.01	$171	$66	$3,737	$0	$1,120	$3,020	$8,114
Courthouse	520 King Street	-	0.06	0.06	0.00	0.06	$1,113	$426	$24,292	$0	$1,120	$3,020	$29,971
Torpedo Factory	105 N. Union Street	-	0.14	0.14	0.00	0.14	$2,448	$937	$53,443	$0	$1,120	$3,020	$60,969
Fire Station 207	3301 Duke Street	0.16	-	0.16	0.00	0.16	$2,959	$1,132	$27,247	$0	$1,120	$3,020	$35,478
Gas Pumps	3400 Duke Street	0.09	-	0.09	0.00	0.09	$1,712	$655	$15,768	$0	$1,120	$3,020	$22,275
Animal Shelter	4101 Eisenhower Ave	1.23	-	1.23	0.00	1.23	$22,206	$8,499	$204,508	$18,600	$1,120	$3,020	$257,953
Ramsey Recreation Center	5650 Sanger Road	0.08	-	0.08	0.00	0.08	$1,507	$577	$13,876	$0	$1,120	$3,020	$20,099
Duncan Library	2501 Commonwealth Avenue	0.10	-	0.10	0.00	0.10	$1,866	$714	$17,187	$0	$1,120	$3,020	$23,907
Fire Station 209	2800 Main Line Bv	0.53	-	0.53	0.00	0.53	$9,588	$3,670	$88,299	$0	$1,120	$3,020	$105,697
Fire Station 202	213 East Windsor Street	0.17	-	0.17	0.00	0.17	$3,030	$1,160	$27,909	$0	$1,120	$3,020	$36,239
Black History Museum	920 Wythe Street	0.03	-	0.03	0.00	0.03	$623	$239	$5,739	$0	$1,120	$3,020	$10,741
Charles Houston Recreation Center	905 Wythe Street	0.20	-	0.20	0.00	0.20	$3,595	$1,376	$33,112	$0	$1,120	$3,020	$42,224
DCHS 720 (Community Services Board)	720 North Saint Asaph Street	0.09	-	0.09	0.00	0.09	$1,661	$636	$15,295	$0	$1,120	$3,020	$21,731
Lloyd House	220 North Washington Street	-	0.01	0.01	0.00	0.01	$120	$46	$2,616	$0	$1,120	$3,020	$6,922
Barrett Library	717 Queen Street	0.06	0.02	0.09	0.00	0.09	$1,558	$596	$19,534	$0	$1,120	$3,020	$25,828
Barrett Recreation Center	1115 Martha Custis Drive	0.79	-	0.79	0.00	0.79	$14,348	$5,491	$132,134	$0	$1,120	$3,020	$156,113
Public Safety Radio Laterals													
Watergate Community	211 Yoakum Pkwy	0.26	-	0.26	0.00	0.26	$4,636	$1,775	$42,699	$0	$1,120	$3,020	$53,250
Mark Center	4900 Seminary Rd	0.02	-	0.02	0.00	0.02	$394	$151	$3,627	$0	$1,120	$3,020	$8,311
Masonic Temple	101 Callahan Dr	0.12	-	0.12	0.00	0.12	$2,109	$807	$19,426	$0	$1,120	$3,020	$26,483
Aspen House	3201 Landover St	0.27	-	0.27	0.00	0.27	$4,869	$1,864	$44,844	$0	$1,120	$3,020	$55,716
School laterals													
Lyles-Crouch School	530 South Saint Asaph Street	0.09	-	0.09	0.00	0.09	$1,575	$603	$14,506	$0	$1,120	$3,020	$20,824
School Maintenance	3540 Wheeler Avenue	0.02	-	0.02	0.00	0.02	$394	$151	$3,627	$0	$1,120	$3,020	$8,311
Patrick Henry School	4643 Taney Avenue	0.09	-	0.09	0.00	0.09	$1,681	$644	$15,484	$0	$1,120	$3,020	$21,949
James Polk School	5000 Polk Avenue	0.03	-	0.03	0.00	0.03	$599	$229	$5,519	$0	$1,120	$3,020	$10,487
Samuel Tucker School	435 Ferdinand Day Drive	0.47	-	0.47	0.00	0.47	$8,540	$3,269	$78,650	$0	$1,120	$3,020	$94,598

Segment / Site Name	Address	Normal Underground Segment Mileage	Downtown Underground Segment Mileage	Total Underground Segment Mileage	Aerial Segment Mileage	Segment Mileage (Total)	Conduit/Fiber OSP Engineering Cost	Project Management / Quality Control	Conduit/Fiber OSP Construction Cost	Railroad and Interstate Crossing Costs	Splicing Cost	Termination and Testing Cost	Total Cost
William Ramsey School	5700 Sanger Avenue	0.09	-	0.09	0.00	0.09	$1,616	$619	$14,885	$0	$1,120	$3,020	$21,260
School Board Administration	2000 N. Beauregard Street	0.01	-	0.01	0.00	0.01	$188	$72	$1,734	$0	$1,120	$3,020	$6,135
John Adams School	5651 Rayburn Avenue	0.22	-	0.22	0.00	0.22	$3,952	$1,512	$36,392	$0	$1,120	$3,020	$45,996
Minnie Howard School	3801 West Braddock Road	0.14	-	0.14	0.00	0.14	$2,620	$1,003	$24,125	$0	$1,120	$3,020	$31,887
T.C. Williams High School	3330 King Street	-	-	0.00	0.00	0.00	$0	$0	$0	$0	$0	$3,020	$3,020
Douglas Macarthur School	1101 Janneys Lane	0.65	-	0.65	0.00	0.65	$11,814	$4,522	$108,798	$0	$1,120	$3,020	$129,273
Maury School	600 Russell Road	0.24	-	0.24	0.00	0.24	$4,335	$1,659	$39,924	$0	$1,120	$3,020	$50,058
George Washington School	1005 Mount Vernon Avenue	0.60	-	0.60	0.00	0.60	$10,780	$4,126	$99,274	$0	$1,120	$3,020	$118,319
George Mason School	2601 Cameron Mills Road	0.04	-	0.04	0.00	0.04	$723	$277	$6,654	$0	$1,120	$3,020	$11,793
Cora Kelly School	3600 Commonwealth Avenue	0.01	-	0.01	0.00	0.01	$257	$98	$2,365	$0	$1,120	$3,020	$6,860
Mount Vernon School	2601 Commonwealth Avenue	-	-	0.00	0.00	0.00	$0	$0	$0	$0	$1,120	$3,020	$4,140
Charles Barrett School	1115 Martha Custis Drive	0.03	-	0.03	0.00	0.03	$479	$183	$4,415	$0	$1,120	$3,020	$9,218
Interim Education Program	216 S. Peyton Street	-	0.01	0.01	0.00	0.01	$188	$72	$4,111	$0	$1,120	$3,020	$8,511
Francis Hammond School	4646 Seminary Road	0.04	-	0.04	0.00	0.04	$675	$258	$6,212	$0	$1,120	$3,020	$11,285
Jefferson-Houston School	1501 Cameron Street	0.13	-	0.13	0.00	0.13	$2,311	$885	$21,286	$0	$1,120	$3,020	$28,623
		32.36	3.38	35.75	0.00	35.75	$646,278	$247,359	$7,114,436	$267,700	$170,240	$381,060	$8,827,072

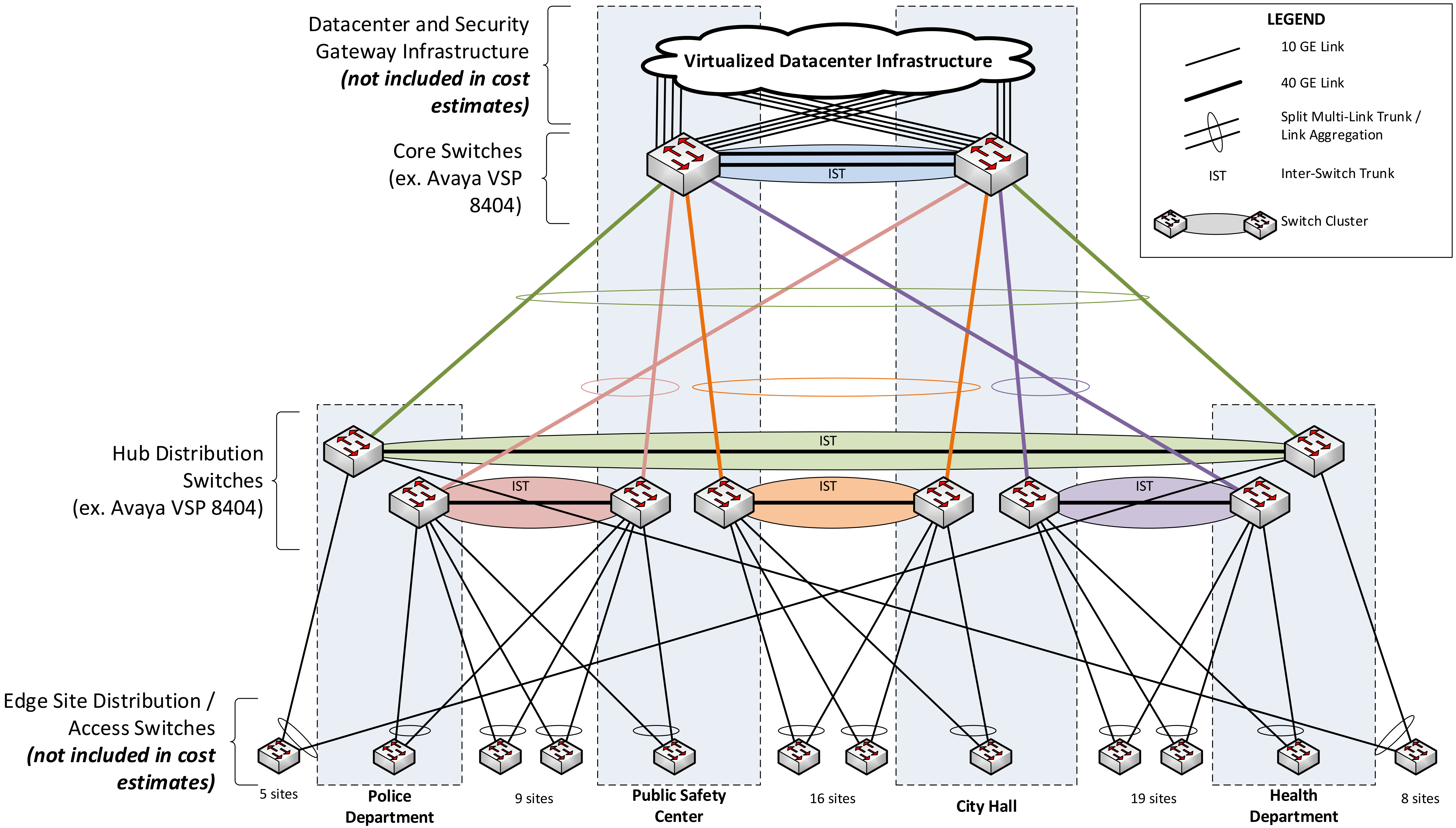
Appendix E: Network Equipment BOM (Candidate Avaya-based option)

City Core/Distribution Network Electronics

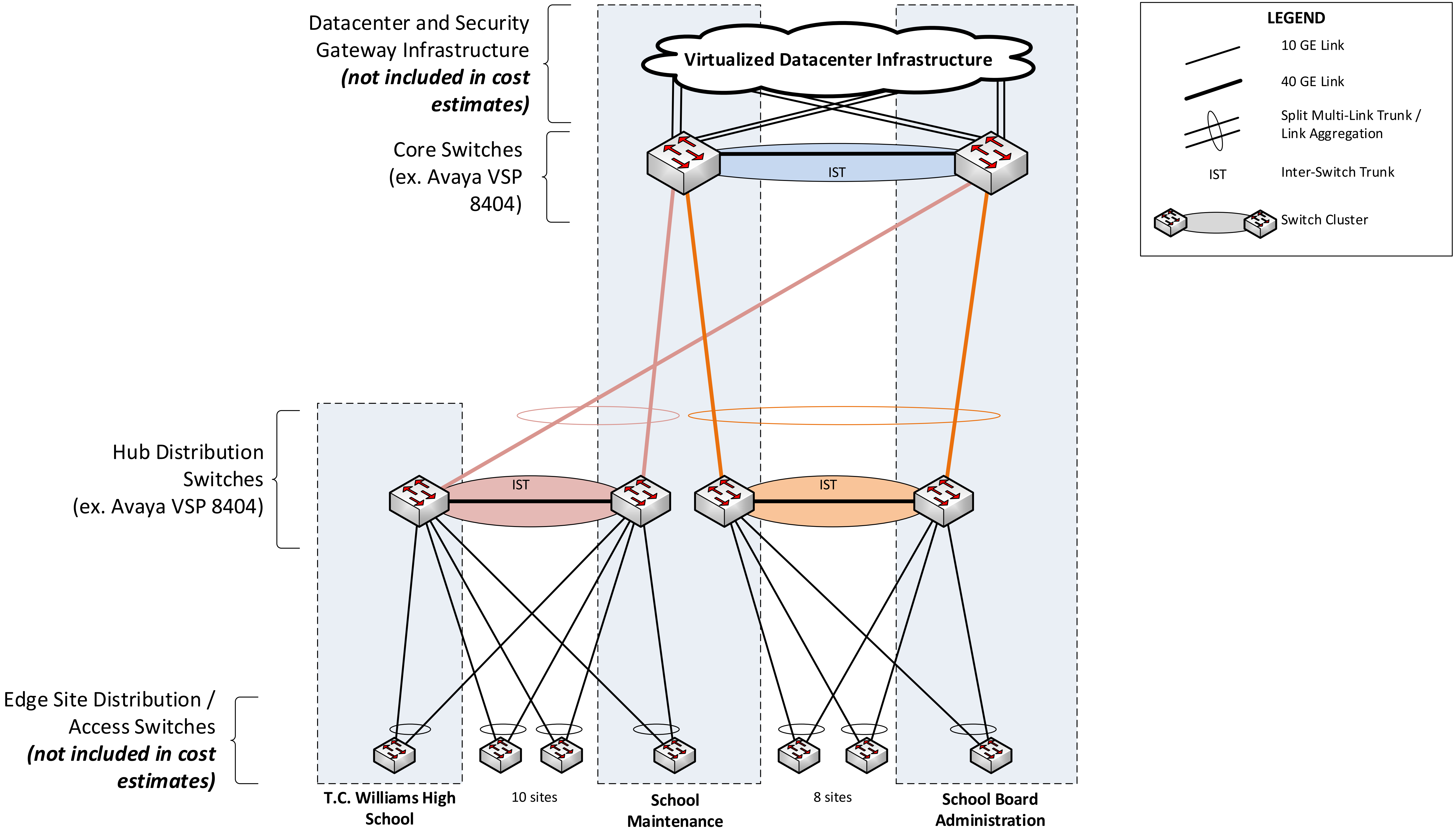
Part Number	Description	Unit List Price	Qty	Unit Net Price	Disc (%)	Extended Net Price
EC8400E01-E6	Virtual Services Platform 8404 4-slot Ethernet Switch, includes one 800W 100-240V AC Power Supply, four Fan Modules, and Base Software License	17,495.00	10	104,970.00	40%	62,982.00
EC8404005-E6	8418XSQ 16-port 10GBASE-SFP+ & 2-port 40GBASE-QSFP+ Combo Ethernet Switch Module	14,995.00	6	53,982.00	40%	32,389.20
EC8404001-E6	8424XS 24-port 10GBASE-SFP+ Ethernet Switch Module	14,995.00	4	35,988.00	40%	21,592.80
EC8404003-E6	8408QQ 8-port 40GBASE-QSFP+ Ethernet Switch Module for VSP 8400	14,995.00	4	35,988.00	40%	21,592.80
EC8005E01-E6	800W 100-240V AC Power Supply	795.00	10	4,770.00	40%	2,862.00
EC8011002-E6	VSP 8000 Slide Rack Mount Kit (300-900mm)	495.00	10	2,970.00	40%	1,782.00
AA1403017-E6	10GBASE-LRM SFP+, 220 m, MMF	590.00	24	8,496.00	40%	5,097.60
AA1403011-E6	10GBASE-LR/LW SFP+, 10 km, 1310 nm, SMF	2,495.00	110	164,670.00	40%	98,802.00
AA1403013-E6	10GBASE-ER/EW SFP+, 40 km, 1550 nm, SMF	5,995.00	13	46,761.00	40%	28,056.60
AA1404002-E6	40GBASE-ER4 QSFP+, 80 m, 1310 nm, MMF	2,495.00	8	11,976.00	40%	7,185.60
AA1404003-E6	40GBASE-ER4 QSFP+, 40 km, 1550 nm	11,095.00	18	119,826.00	40%	71,895.60
GH6300ETA	VSP 8000 8400CH - Avaya Express Delivered Managed Spares 24 x 7 4Hr Service - SLN ETA	5,874.00	10	49,929.00	15%	42,439.65
GH6300ET6	VSP 8000 8418 XSQ BD CU - Avaya Express Delivered Managed Spares 24 x 7 4Hr Service - SLN ET6	678.00	6	3,457.80	15%	2,939.13
GH6300ET3	VSP 8000 8424XS BD - Avaya Express Delivered Managed Spares 24 x 7 4Hr Service - SLN ET3	678.00	4	2,305.20	15%	1,959.42
GH6300ET5	VSP 8000 8408QQ BD - Avaya Express Delivered Managed Spares 24 x 7 4Hr Service - SLN ET5	678.00	4	2,305.20	15%	1,959.42
					Installation and Integration:	100,883.96
					Total:	**504,419.78**

ACPS Core/Distribution Network Electronics						
Part Number	**Description**	**Unit List Price**	**Qty**	**Unit Net Price**	**Disc (%)**	**Extended Net Price**
EC8400E01-E6	Virtual Services Platform 8404 4-slot Ethernet Switch, includes one 800W 100-240V AC Power Supply, four Fan Modules, and Base Software License	17,495.00	6	62,982.00	40%	37,789.20
EC8404005-E6	8418XSQ 16-port 10GBASE-SFP+ & 2-port 40GBASE-QSFP+ Combo Ethernet Switch Module	14,995.00	8	71,976.00	40%	43,185.60
EC8005E01-E6	800W 100-240V AC Power Supply	795.00	6	2,862.00	40%	1,717.20
380176	VSP 8000 Series Premier Software License: enables L3 VSN	7,495.00	0	0.00	40%	0.00
EC8011002-E6	VSP 8000 Slide Rack Mount Kit (300-900mm)	495.00	8	2,376.00	40%	1,425.60
AA1403017-E6	10GBASE-LRM SFP+, 220 m, MMF	590.00	20	7,080.00	40%	4,248.00
AA1403011-E6	10GBASE-LR/LW SFP+, 10 km, 1310 nm, SMF	2,495.00	38	56,886.00	40%	34,131.60
AA1403013-E6	10GBASE-ER/EW SFP+, 40 km, 1550 nm, SMF	5,995.00	5	17,985.00	40%	10,791.00
AA1404002-E6	40GBASE-ER4 QSFP+, 80 m, 1310 nm, MMF	2,495.00	6	8,982.00	40%	5,389.20
AA1404003-E6	40GBASE-ER4 QSFP+, 40 km, 1550 nm	11,095.00	8	53,256.00	40%	31,953.60
GH6300ETA	VSP 8000 8400CH - Avaya Express Delivered Managed Spares 24 x 7 4Hr Service - SLN ETA	5,874.00	6	29,957.40	15%	25,463.79
GH6300ET6	VSP 8000 8418 XSQ BD CU - Avaya Express Delivered Managed Spares 24 x 7 4Hr Service - SLN ET6	678.00	8	4,610.40	15%	3,918.84
					Installation and Integration:	50,003.41
					Total:	**250,017.04**

Appendix F-1: Proposed City Network Backbone Electronics Architecture



Appendix F-2: Proposed ACPS Network Backbone Electronics Architecture


Datacenter and Security Gateway Infrastructure
(not included in cost estimates)
Core Switches (ex. Avaya VSP 8404)
Hub Distribution Switches (ex. Avaya VSP 8404)
Edge Site Distribution / Access Switches
(not included in cost estimates)
Virtualized Datacenter Infrastructure
IST
IST
IST
T.C. Williams High School
10 sites
School Maintenance
8 sites
School Board Administration
LEGEND
10 GE Link
40 GE Link
Split Multi-Link Trunk / Link Aggregation
IST
Inter-Switch Trunk
Switch Cluster