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City of Madison Fiber-to-the-Premises Feasibility Analysis

Prepared for City of Madison
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1 Executive Summary

1.1 Project Background

The City of Madison is among the localities that seek to bring ultra-high-speed broadband connectivity to their communities. The City recognizes fiber-based connectivity—particularly fiber-to-the-premises (FTTP) deployment designed to serve every business and resident in the community—as an important foundation for taking full advantage of the power of broadband. A ubiquitous FTTP buildout ensures that, no matter who the retail service provider is, every resident and business has the opportunity to access the power of a fiber-based network infrastructure. This is especially true if the City prioritizes some form of open access, which is a common goal for many localities.

There are several possible approaches to deploying broadband in a community; the City aims to determine which of these options—if any—makes sense for Madison's residents and businesses. Accordingly, the City engaged CTC Technology & Energy (CTC) to explore whether the City can feasibly[1] pursue deployment of a citywide ultra-high-speed fiber-based broadband network, either directly or through a public–private partnership. This report also aims to assist the City in distilling its goals and focusing on realistic solutions to meet the community's connectivity needs.[2]

This report and the supplemental market research described in Section 1.2 represent the City's compliance with Wisconsin state law, which requires any municipality that seeks to offer broadband services to conduct a cost-benefit analysis.[3]

1.2 Methodology

This report was researched and prepared in early 2016 by CTC, with ongoing input from City staff. In addition to drawing on our extensive industry experience, our analysis is guided by our conversations and interviews with a range of City staff and stakeholders about the City's objectives and desired outcomes.

Over the course of the engagement, CTC performed the following general tasks:

1. Reviewed and inventoried the City's key physical infrastructure, including the Metropolitan Unified Fiber Network (MUFN);

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[1] While CTC cannot provide legal counsel and this report does not contain legal guidance, the City has engaged legal counsel to expand on CTC's findings from a legal standpoint.

[2] Appendix A outlines common community goals and objectives to help guide the City's decision-making.

[3] David L. Lovell, "Statutory Limitation on Municipal Offering of Broadband Service," *Wisconsin Legislative Council*, last modified October 3, 2014, https://c.ymcdn.com/sites/www.weda.org/resource/resmgr/Fall_PP/Lovell_Outline_10-3.pdf.

2. Conducted interviews with representatives of City departments, stakeholders, and utility owners;
3. Researched the region's available broadband services and costs (see Section 3);
4. Conducted onsite and desk surveys of City infrastructure;
5. Evaluated potential public–private partnership business models based on current developments in the broadband industry; and
6. Developed pro forma financial statements for the City based on a dark fiber lease model, where the City would own and operate a fiber network, and grant access to it through dark fiber leasing.

In addition to those tasks, at the City's request, CTC prepared a high-level network design and cost estimate for deploying a gigabit FTTP network. The cost estimate (Section 7) provides data relevant to assessing the financial viability of network deployment, and offers guidance in developing business models for a potential City construction effort (including the full range of models for public–private partnerships). This estimate also provides key inputs to financial modeling to determine the approximate revenue levels necessary for the City to service any debt incurred in building the network.

1.3 Residential Market Research Identified Unmet Demand

The City also commissioned CTC to carry out residential market research to supplement the findings of this report, and to help gauge the community's interest in broadband. The City was prudent to reach out directly to the community in order to cast the widest net possible in understanding citizens' needs and desires, and to give residents a voice.

To develop a set of questions tailored for Madison residents, CTC sought feedback from City staff and stakeholders on the survey questionnaire. We adjusted question language and placement consistent with City recommendations, while being mindful of best practices for conducting market research. The resulting questionnaire is attached to this report as Appendix C.

The survey, which was mailed to approximately 3,700 randomly selected Madison residents in early May 2016, was designed to identify issues related to residential demand, and to identify differences among users based on income level, education level, and other differentiating factors.[4]

[4] Individual information about respondents is not reported separately; rather, it helps ensure that the responses are a representative sample of the citizens of the City of Madison.

The survey found that Madison residents are highly connected: 95 percent of respondents have some form of Internet connection (89 percent of residents have home Internet service and 77 percent have a cellular telephone with Internet access). However, the survey also points to service gaps and unmet needs in the residential market. For example, survey responses indicate that:

- Older, low-income, and less-educated respondents are less likely than their counterparts to have some form of Internet access at their home.
- Reliability of respondents' Internet connections ranks as the most important aspect of their Internet service, followed by connection speed and price paid. Residents are generally satisfied with the speed and reliability of their Internet service.
- Respondents would be willing to switch to a very high-speed Internet connection, especially at monthly prices lower than $50 or for a one-time hookup fee at or below $250.
- More than one-half of respondents' employers allow telework, and more than one-fourth of responding households have a member who already teleworks.
- About six in 10 respondents believe that the City should install a state-of-the-art communications network and either offer services or allow private companies to offer services to the public.

We also conclude that small and medium businesses in Madison are not being served at the level they need. Small businesses often buy residential services as an affordable, if not wholly sufficient, solution; if robust broadband is not available throughout the City for residents, there are likely even more gaps for small businesses. And residential services are not sufficient for many small businesses—meaning that there likely are businesses that need more than residential service, but cannot afford enterprise-grade broadband.

1.4 The City's Core Objectives Are Equity, Ubiquity, Competition, Consumer Choice, and Control

The City has been engaged in the issue of broadband access for some time. In 2013, the City created the "Digital Technology Committee" to advise the Mayor and Common Council on how the City currently uses and can improve upon its use of digital technology.[5] One of the Committee's focuses is the "digital divide," which is the disparity between those who have access to modern information and communications technology and those who do not. "Access" encompasses not only the presence of service in an existing area, but also whether it is affordable to potential subscribers. The City is sensitive to the need for a wide range of options

[5] https://www.cityofmadison.com/cityhall/legislativeinformation/roster/102250.cfm, accessed March 2016.

that can serve its diverse population, including those who may have traditionally been unable to purchase service.

Bringing access to traditionally underserved populations is only one key driver for the City's broadband initiative. The City also understands that filling broadband service gaps is important to support robust economic development efforts, particularly for small and medium-sized businesses whose needs are not met with residential-grade service offerings but that cannot afford traditional business-class service.

Based on our discussions with City staff and our understanding of community goals, we recognize the following objectives as the baseline for the City's broadband initiative:

- Equity – Alignment with Racial Equity and Social Justice (RESJ) and digital divide goals
- Ubiquity – Service is deployed to the entire City
- Competition in the marketplace – Enabling multiple providers to compete
- Consumer choice – Citizens can purchase service from various providers
- Control – The City has a long-term stake in the asset

In our view, the benefits of equity, ubiquity, competition, and consumer choice are likely to arise from this initiative, as are additional benefits (such as City control) depending on the model the City adopts. Some of these benefits are summarized below.

1.4.1 Ubiquitous FTTP Deployment Will Create Consumer Choice and Competition

When a new, high-speed Internet service provider (ISP) enters a market, consumers tend to experience an increase in available services and a decrease in the cost of some services. As the new entrant begins to offer services, incumbent providers typically respond by upgrading their infrastructure to enable higher tiers of service and decreasing the price that customers pay. The impact is especially pronounced when the new entrant, or a public sector partner, builds a new FTTP network, capable of delivering speeds beyond what most incumbent cable and telecommunication networks currently provide.

For instance, in most of the markets where Google has announced plans to launch Google Fiber service, consumers benefit from Google's additional service offerings, as well as from upgraded service and significant price reductions from incumbent telecom and cable carriers. A recent *Consumerist* report notes that in markets where Google has announced plans to build fiber, AT&T offers customers 1 Gigabit per second (Gbps) service starting at $70 per month. In markets without competition from Google, AT&T charges customers $80 per month for 300 Mbps service.[6]

The threat of a new entrant is often enough to spur incumbents to make new investment or lower prices. Where competition emerges, the competitive reaction intensifies, and incumbent companies lower prices and improve services. Indeed, in the various markets where Google Fiber has announced that it will—or may—build new fiber networks, the incumbent phone and cable companies have responded by upgrading their own facilities, increasing speeds, and reducing pricing. This reaction frequently emerges in cities that build municipal networks also. For example, in Chattanooga, Tennessee, Comcast fought hard to prevent the public electric utility from offering Internet service. Unable to block the new entrant, Comcast has been forced to compete. The cable company last year announced that Chattanooga would be one of the first cities to receive its 2 Gbps FTTP service.[7]

1.4.2 New Broadband Competition Will Create Benefits for Equity

Residents who do not use broadband are typically confronted with one or more of the following issues:

1. Lack of access to service
2. Inability to afford service
3. Lack of knowledge of how to use computers, devices, or broadband

With those causes in mind, new broadband competition can have a significant positive impact on efforts to close the digital divide. The City's initiative to bring a competitive FTTP provider to Madison addresses the second, and often most pressing concern—affordability—by introducing robust competition into the market.

Broadband competition will serve to lower some prices. We believe that a new provider (whether a public or private entity) will offer some low-cost products. Even if the new provider does not offer low-cost products, incumbents are likely to lower their pricing on some products in response to the new competition. We have seen this in other markets, and have no reason to doubt that the same scenario will play out in Madison.

To be clear, this does not mean that the high-end symmetrical Gigabit products will necessarily be available at low prices, or affordable to every resident. It may be that only lower bandwidth

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[6] Chris Morran, "ATT Touts Lower Prices for Gigabit Internet," *Consumerist*, last modified September 15, 2015, http://consumerist.com/2015/09/30/att-touts-lower-prices-for-gigabit-internet-still-charges-40-more-if-google-fiber-isnt-around/.

[7] Jon Brodkin, "Comcast brings fiber to city that it sued 7 years ago to stop fiber roll out," *ArsTechnica,* last modified April 30, 2015, http://arstechnica.com/business/2015/04/comcast-brings-fiber-to-city-that-it-sued-7-years-ago-to-stop-fiber-rollout/.

products are available at low prices. For example, in some markets we have seen the incumbent telephone companies compete for price-sensitive customers by offering low-price, low-bandwidth services.

But a more robust market environment will lead to competitive pricing that benefits low-income consumers in ways that simply do not happen in monopoly and duopoly environments.

We expect this FTTP initiative, regardless of the partner that the City selects or the partnership approach that the City takes, to result in real benefits for low-income residents of Madison. Further, we note that in any partnership arrangement, the City would have the option to subsidize service for low-income residents.

1.4.3 Meeting the Need for Broadband Services to Small and Medium Businesses in Madison Will Promote Economic Vitality and Innovation

Based on our market analysis (Section 3), our knowledge of local broadband markets in general, and our conversations with City staff, we believe that there is likely a significant gap with respect to very high-end competitive broadband services for small and medium-sized businesses. Larger business and institutions appear relatively well served by the incumbents and the competitive providers that are already present in the market—but as is the case in many markets, small and medium-sized businesses likely struggle to get affordable high-end services.

There likely is a gap, too, when it comes to home-based businesses and teleworkers. Many teleworkers are sophisticated telecommunications users—and they need services that have greater reliability and capacity than the consumer-based broadband connections they have from the phone and cable companies that currently serve Madison.

These gaps represent both a real need in the community, and a significant business opportunity for private sector retail service providers. A growing body of evidence demonstrates that high-speed fiber connections facilitate an innovation ecosystem and enable small businesses and start-ups to thrive.

Blazing fast Internet connections provide entrepreneurs, freelancers and small-business owners with a variety of new tools that allow them to compete as never before. A growing portion of the US workforce can do much of their work from wherever they find a robust Internet connection. While a basic broadband connection is sufficient for certain tasks, gigabit speeds enable richer collaboration tools, such as vivid telepresence.[8] As bandwidth-hungry collaboration tools continue to improve, the physical location of people becomes less

[8] http://www.pewinternet.org/2014/10/09/killer-apps-in-the-gigabit-age/

important.[9] Small business owners and entrepreneurs with access to abundant bandwidth can draw on talent from across the globe, forming short-lived teams that complete specific tasks without ever needing to meet in person. Although contractors and freelancers are generally free to roam as they please, they will gravitate to areas with abundant bandwidth that can provide a quality connection to their clients.

Higher speed connections have the potential to improve the flow of goods and services in every sector of the economy. Many entrepreneurs with a desire to create new services based on high capacity connections have flocked to the first few Gig Cities to build and test their products.[10] Although a robust two-way connection has the potential to improve everything from how we exercise[11] to how we react to weather emergencies,[12] there are a number of emerging fields that are entirely dependent on extremely high speed connections. Virtual and augmented reality and precise 3D modeling require data flows far beyond the average home or small business connection speed today. The new businesses that emerge in these sectors will undoubtedly be based in localities that have abundant, affordable bandwidth.

Big bandwidth will be particularly important for the entrepreneurs that seek to create value through the analysis of large data sets. As sensors proliferate and the cost of memory plummets, more data is being collected than ever before in history. In the past, only large companies would be able to afford the computing power necessary to make sense of such huge data sets, but now any savvy statistician with a laptop and a gigabit internet connection can run an analysis in minutes. Big data stands to improve productivity and efficiency in every sector of the economy,[13] but the companies and individuals that will conduct the analysis will be located in areas with abundant bandwidth.

Innovation is possible everywhere, but individuals living in a place with affordable high speed connections have a natural advantage coming up with a new idea or when trying to turn a prototype into a product. Abundant bandwidth gives people the freedom to tinker and figure out how symmetrical high-speed connections can improve our daily lives. As William Gibson once said, "The future is already here, it's just not evenly distributed." People living in the first

[9] According to the New Jersey Institute of Technology, 45 percent of U.S. employees already work from home at least part of the time. http://betanews.com/2015/09/11/the-rise-of-telecommuting-45-percent-of-us-employees-work-from-home/

[10] http://www.nlc.org/Documents/Find%20City%20Solutions/City-Solutions-and-Applied-Research/Innovation%20Districts%20Report.pdf
http://siliconprairienews.com/2014/04/three-years-after-announcement-kansas-city-is-still-figuring-out-fiber/

[11] https://www.nsf.gov/mobile/discoveries/disc_summ.jsp?cntn_id=134550&org=NSF

[12] https://www.us-ignite.org/globalcityteams/actioncluster/zJiQHYzzoXrZJthAHwcN5F/

[13] http://www.mckinsey.com/business-functions/business-technology/our-insights/big-data-the-next-frontier-for-innovation

few cities with super high speed broadband have the chance to create the future for everyone else.

1.5 Building Ubiquitous FTTP in Madison Would Cost at Least $143.5 Million

We developed a conceptual, high-level FTTP design that reflects the City's goals and is open to a variety of architecture options. From this design, we present two cost estimate examples:

1. The cost to deploy *only* the FTTP outside plant (OSP) infrastructure.[14] This is the total capital cost for the City to build a dark FTTP network for lease to a private partner. This is the City's projected OSP cost in a "dark FTTP partnership."[15]

2. The cost to deploy FTTP OSP infrastructure, network electronics, service drops to the consumer, and CPEs.

We provide two versions for each of these estimates: all-underground construction, and a combination of underground and aerial construction (Table 1).

Table 1: Projected Cost Estimates Summary

FTTP Cost Estimates		
	Dark FTTP (No Electronics, Service Drops, or CPEs)	**Fiber, Network Electronics, Service Drops, and CPEs[16]**
Aerial and Underground Construction	$143.5 million	$194 million
All Underground Construction	$149.1 million	$212 million

These estimates represent the total capital costs—which would be incurred by the City, or the City and its partner(s)—to build an FTTP network to support a ubiquitous 1 Gigabit per second (Gbps) data-only service.

1.5.1 Dark FTTP Cost Estimate – No Network Electronics, Service Drops, or CPEs

The dark FTTP partnership cost estimate assumes that the City constructs and owns the FTTP infrastructure up to a demarcation point at the optical tap near each residence and business, and leases the dark fiber backbone and distribution fiber (the fiber in an FTTP network that

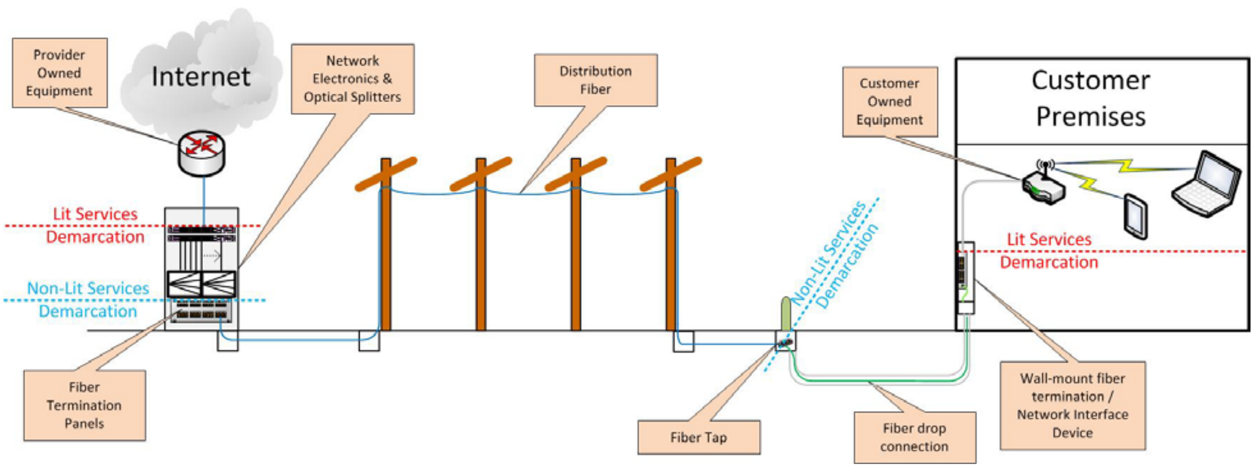
[14] This is the physical portion of a network (also called "layer 1") that is constructed on utility poles (aerial) or in conduit (underground).

[15] See Section 6.4 for more information about the dark FTTP partnership model, where the City would construct, own, operate, and maintain the dark fiber network, and provide access to its partner(s) to "light" the network and offer service over it.

[16] The estimated total cost assumes a 35 percent penetration rate or "take rate," meaning that 35 percent of the residents and businesses passed by the fiber would subscribe to the service.

connects the hub sites to the fiber distribution cabinets)[17] to a private partner. The private partner would be responsible for all network electronics, fiber drops to subscribers, and CPEs—as well as network sales, marketing, and operations.

Figure 1: Demarcation Between City and Partner Network Elements



1.5.1.1 Combination of Aerial and Underground Construction (Dark FTTP Partnership)

Assuming a combination of aerial and underground construction, the citywide dark FTTP network deployment will cost more than $143 million, inclusive of OSP construction labor, materials, engineering, permitting, and pole attachment licensing. Again, this estimate *does not* include any electronics, subscriber equipment, drops, or CPEs. Section 1.5.2 and Section 7 show estimated costs for fiber, network electronics, drops, and CPES, and include all underground construction, as well as a combination of aerial and underground.

[17] The FDC houses the fiber connections between the distribution fiber and the access fiber. FDCs, which can also house network electronics and optical splitters, can sit on a curb, be mounted on a pole, or reside in a building. Access fiber is the fiber in an FTTP network that goes from the FDCs to the optical taps that are located outside of homes and businesses in the ROW.

Table 2: Breakdown of Estimated Dark FTTP Cost – Combination of Aerial and Underground Construction

Cost Component	Total Estimated Cost
OSP Engineering	$14.7 million
Quality Control/Quality Assurance	5.4 million
General OSP Construction Cost	99.3 million
Special Crossings	0
Backbone and Distribution Plant Splicing	5 million
Backbone Hub, Termination, and Testing	11.4 million
FTTP Lateral Installations	7.7 million
Total Estimated Cost:	$143.5 million

1.5.1.2 All Underground Construction (Dark FTTP Partnership)

Assuming that all construction is underground, the citywide dark FTTP network deployment will cost more than $149 million, inclusive of outside plant (OSP) construction labor, materials, engineering, permitting, and pole attachment licensing. Again, this estimate *does not* include any electronics, subscriber equipment, or drops—and it includes no aerial fiber.

The projected cost to construct all underground is only about $5.6 million more than the cost for a combination of aerial and underground fiber. This difference is notably minimal; underground construction costs can sometimes be much higher than aerial, but our projections indicate that it would not add a major financial burden if the City opts to construct the dark FTTP network entirely underground.

Table 3: Breakdown of Estimated Dark FTTP Cost – All Underground Construction

Cost Component	Total Estimated Cost
OSP Engineering	$14.7 million
Quality Control/Quality Assurance	5.4 million
General OSP Construction Cost	104.9 million
Special Crossings	0
Backbone and Distribution Plant Splicing	5 million
Backbone Hub, Termination, and Testing	11.4 million
FTTP Lateral Installations	7.7 million
Total Estimated Cost:	$149.1 million

1.5.2 FTTP Cost Estimate for Fiber, Network Electronics, Service Drops, and CPEs

This variation of the cost estimate assumes that the City constructs and owns the FTTP infrastructure, all network electronics, service drops, and CPEs. This is typical of a retail service model, where the locality is the network owner, the network operator, and the retail service provider.

1.5.2.1 Combination of Aerial and Underground Construction (Fiber, Network Electronics, Drops, and CPEs)

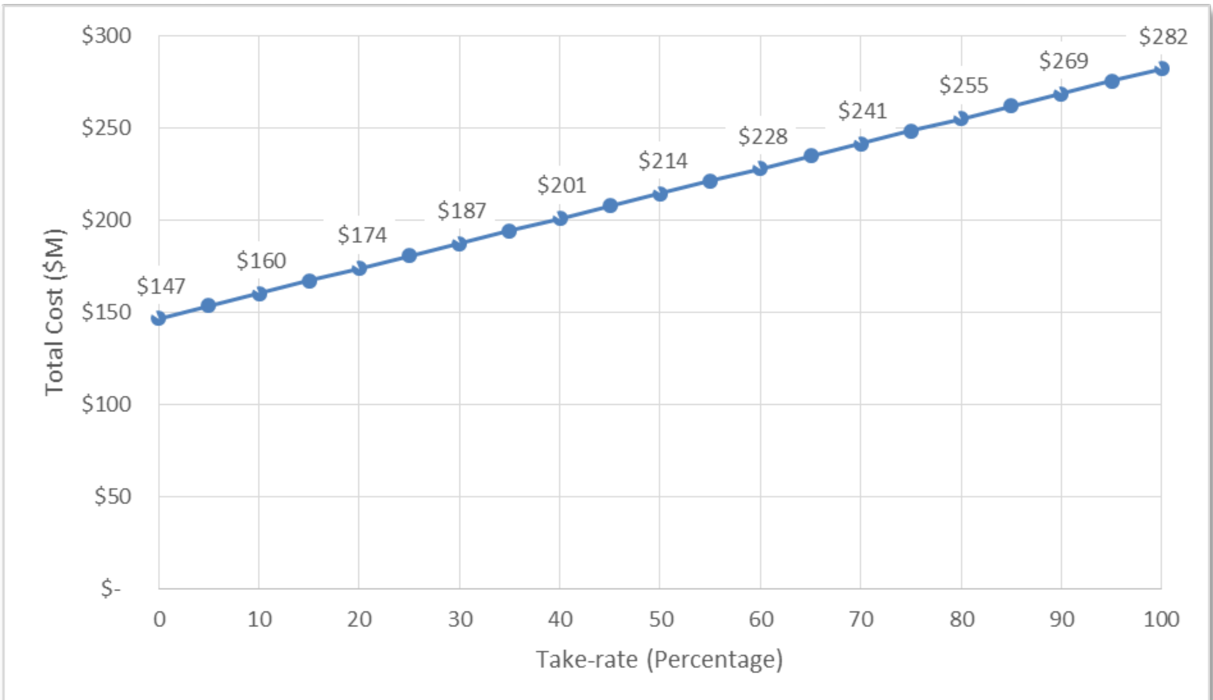
Assuming a combination of aerial and underground construction, the citywide FTTP network deployment will cost more than $194 million. This estimate includes OSP construction labor, materials, engineering, permitting, pole attachment licensing, network electronics, drop installation, CPEs, and testing. The estimated total cost assumes a 35 percent penetration rate or “take rate,” meaning that 35 percent of the residents and businesses passed by the fiber would subscribe to the service.

Table 4: Breakdown of Estimated Total Cost

Cost Component	Total Estimated Cost
OSP	$136 million
Central Network Electronics	8 million
FTTP Service Drop and Lateral Installations	28 million
CPE	22 million
Total Estimated Cost:	$194 million

The total cost will vary based in part on the actual take rate because adding subscribers adds costs, to connect the subscribers’ home or business to the network at the curb. Figure 2 shows the change in total estimated cost as the take rate increases.

Figure 2: Total Estimated Cost versus Take Rate



1.5.2.2 All Underground Construction (Fiber, Network Electronics, Drops, and CPEs)

The City's existing middle mile fiber that supports the Metropolitan Unified Fiber Network (MUFN) is constructed entirely underground for reliability reasons and to avoid negotiating pole access with the utility owners.[18] As part of our FTTP analysis, we developed a cost estimate assuming that the entire FTTP network were to be constructed underground. An all-underground network would cost more than $212 million. The following is a breakdown of the all-underground cost estimate.

Table 5: Breakdown of Estimated Total Cost with Electronics for an All Underground Network

Cost Component	Total Estimated Cost
OSP	$141 million
Central Network Electronics	8 million
FTTP Service Drop and Lateral Installations	41 million
CPE	22 million
Total Estimated Cost:	$212 million

[18] We note that Madison Gas and Electric (MG&E) is a local pole owner that has so far been collaborative with the City and CTC during the preparation of this analysis.

The cost increase is due to the added cost of constructing the outside plant as well as the increased costs for underground fiber drops, which are significantly more expensive than aerial drops.

1.5.3 MUFN Decreases FTTP Construction Costs

The cost estimate assumes the use of MUFN to provide:

1. Fiber optic connectivity between hub sites and distribution hub sites;
2. Space at existing City facilities to be used as core and distribution sites; and
3. Access to multiple Internet points of presence (POPs) for network connectivity.

The use of MUFN as a backbone would significantly reduce the cost and complexity of deploying an FTTP network because the network already extends to all areas of the City. A detailed engineering design may determine that enhancements to MUFN are necessary to support citywide FTTP; however, the estimate presented in this report assumes that no additional costs are required to enable MUFN to support the FTTP network.

Our FTTP cost estimates assume that the use of MUFN may reduce the total cost of OSP construction by approximately 10 percent, which is reflected in our projections.

Additional savings may also be available through the use of existing conduit in the downtown areas. While this conduit was generally designed to support a middle mile network, it may provide cost savings by eliminating or reducing underground construction along certain routes. A more detailed cost savings would be determined during the engineering of the network.

1.6 Madison Would Require Lease Payments of at Least $15 per Passing per Month to Cover Its Costs

Our financial analysis assumes that the City will construct, own, and maintain the dark fiber network over which one or more private partners will provide lit retail service to end users. In this dark FTTP partnership model,[19] the financial responsibility for deploying core electronics to "light" the network falls to the private partner.

The financial analysis represents a minimum requirement for the City of Madison to break even each year, excluding any potential revenue from other dark fiber lease opportunities that may be available to the City.

Using the $149.1 million all-underground cost estimate for the fiber outside plant (OSP), and in order for the City to maintain positive cash flow, the City's private partner will need to pay a

[19] We also assume the partner is responsible for CPEs, and installing the drop cable to the customer. This model assumes that maintenance and replenishments for electronics are the partner's responsibility.

minimum fee of $15 per passing per month. This payment assumes there are no upfront or balloon payments. Based on an assumption that the City will deploy a ubiquitous FTTP network, the financial model applies the fee to all residential and business premises in the City. The model keeps the $15 per passing fee constant, although the City and its partner should negotiate periodic increases on the portion of the fee covering operational and maintenance costs.

The financial analysis for the base case scenario is as follows:

Table 6: Base Case Financial Analysis

Income Statement	1	5	10	15	20
Total Revenues	$ 88,550	$ 17,710,020	$ 17,710,020	$ 17,710,020	$ 17,710,020
Total Cash Expenses	(856,190)	(2,316,120)	(2,316,120)	(2,316,120)	(2,316,120)
Depreciation	(2,274,200)	(7,494,600)	(7,494,600)	(7,494,600)	(7,494,600)
Interest Expense	(2,430,000)	(7,754,950)	(6,023,970)	(3,866,860)	(1,178,750)
Taxes	-	-	-	-	-
Net Income	$ (5,471,840)	$ 144,350	$ 1,875,330	$ 4,032,440	$ 6,720,550
Cash Flow Statement	**1**	**5**	**10**	**15**	**20**
Unrestricted Cash Balance	$ 209,360	$ 613,770	$ 3,410,190	$ 6,207,970	$ 9,006,860
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	2,430,000	-	-	-	-
Debt Service Reserve	2,700,000	9,325,000	9,325,000	9,325,000	9,325,000
Total Cash Balance	$ 5,339,360	$ 10,084,900	$ 12,931,870	$ 15,779,960	$ 18,629,160

We have provided the City with a complete financial model in Excel format. Because the Excel spreadsheets can be manipulated to show the impact of changing assumptions (much as we have done in the scenarios in Section 8.6 below), it will be an important tool for the City to use as it negotiates with a private partner.

1.7 Recommendations

We outline here several recommendations for the City as it moves forward in consideration of an FTTP deployment.

1.7.1 Consider Adopting a Partnership Model in Which the City Owns the Dark Fiber Network

There are three basic types of partnerships emerging today:

- **Private investment, public facilitation**: The model focuses not on a public sector investment, but on modest measures the public sector can take to enable or encourage greater private sector investment.
- **Private execution, public investment:** This model, which involves a substantial amount of public investment, is a variation on the traditional municipal ownership model for broadband infrastructure—but with private rather than public sector execution.

- **Shared investment and risk:** In this model, localities and private partners find creative ways to share the capital, operating, and maintenance costs of a broadband network. The evolving structure of this model, referred to as a "Dark FTTP Partnership" is described further below.

We believe that the model most applicable to the City is the "dark FTTP partnership" which is a "shared investment and risk" approach. In the "dark FTTP partnership," the City constructs and owns the fiber network, the private partner "lights" the fiber with electronics, and the private partner directly serves the end user. This is the model currently underway in the City of Westminster, MD with its private partner Ting Internet;[20] a similar model was recently announced by the City of Huntsville, AL with its private partner, Google Fiber.[21]

Retaining ownership of the fiber OSP assets is important to mitigate risk; owning assets is a way for communities to retain some control of the network, and to have some say in when, where, and how it is built. This includes a scenario where a community pursues a partnership with a private provider; a good way to balance risk and reward is for the City to maintain ownership and control of the assets while it assigns operational responsibilities, including the capital investment for network and consumer electronics, to a private partner. This enables both parties to perform functions that highlight their strengths while not having to expend resources and energy attempting to carry out tasks for which they are ill-equipped.

There is risk to the City in this model because it requires a substantial capital investment to build (or expand) and maintain the fiber network, but it also gives the City a degree of control because the City owns the network. In the event that the partnership fails for any reason, the City owns its assets and can take over control of the network directly or by engaging a different partner. Especially given the likelihood that the City-owned MUFN will be used as backbone fiber in the overall FTTP deployment, the City can pursue a partnership model where it retains ownership of the fiber assets. Such a model will enable the City to make use of its existing fiber assets, and retain some degree of control.

1.7.2 At the Appropriate Time, Publish a Dark Fiber Rate Card to Promote Fiber Leasing

If the City enters into a dark FTTP partnership, its private partner(s) will likely want access to significant dark fiber via an IRU or lease agreement, which means the City will need to establish dark fiber lease rates. There will likely be lease rates for access to MUFN fiber (because the

[20] Wiley Hayes, "Westminster, Md. Partners with Private Sector to Broaden Fiber-Optic Network," *GovTech*, last modified October 26, 2015, http://www.govtech.com/dc/articles/Westminster-Md-Partners-with-Private-Sector-to-Broaden-Fiber-Optic-Network.html.

[21] Frederic Lardinois, "Google Fiber Is Coming To Huntsville, Alabama," *Tech Crunch*, last modified February 22, 2016, http://techcrunch.com/2016/02/22/google-fiber-is-coming-to-huntsville-alabama/.

existing rates for access to MUFN fiber may not be applicable to a partnership) and separate rates for access to any new fiber that is constructed as part of the FTTP deployment.[22]

The City currently does not directly lease fiber to any commercial partners. A commercial entity that seeks to lease dark fiber does so through the City's agreements with the Wisconsin Independent Network (WIN) and SupraNet. As part of these agreements, commercial partners are charged for access to dark fiber per the rate sheet shown below. (These rates are only an example, and may not apply as the City moves forward with FTTP deployment.)

Table 7: Current MUFN Dark Fiber Lease Fees

Zone	Topology	Monthly Fee per Pair
1 to 1	Point-to-Point	$350
1 to 2	Point-to-Point	$350
1 to 3	Point-to-Point	$350
2 to 2	Point-to-Point	$350
3 to 3	Point-to-Point	$350
2 to 3	Point-to-Point	$700
1 to 1	Ring	$700
1 to 2	Ring	$700
1 to 3	Ring	$700
2 to 2	Ring	$700
3 to 3	Ring	$700
2 to 3	Ring	$1,100

The numbers in this rate sheet apply only to commercial entities that seek to access the City's dark fiber network, and not to the City's "partners" in the MUFN consortium. The City charges MUFN members the operations costs that the City incurs to perform locates and general maintenance of the fiber network.

By publishing dark fiber lease rates and entering into a partnership arrangement that makes use of City-owned dark fiber at competitive rates, the City will not be competing with the private sector, but enabling it. The City will be reducing barriers to market entry for private providers so that they can offer innovative and new services to Madison residents and businesses, consistent with the City's vision for its community.

1.7.3 Target a 1 Gigabit Per Second (Gbps) Service Offering to Meet the Emerging Broadband Benchmark

The Federal Communications Commission's (FCC) definition of broadband has evolved, especially in recent years. The unchanged core definition is that broadband is high-speed

[22] The City should determine with its counsel the legality of separate lease rates under Wisconsin law.

Internet access that is always on. It is faster than traditional dial-up access, and was most recently defined in early 2015 as being at least 25 Megabits per second (Mbps) download speed and 3 Mbps upload speed. What this means is that when a user receives (downloads) data, the speed must be at least 25 Mbps; and when a user sends (uploads) data, the speed must be at least 3 Mbps.

It is important to note that the FCC's minimum broadband speeds are much slower than the evolving industry standard. The industry began to shift when Google Fiber began offering 1 Gigabit per second (Gbps) service for $70 per month in Kansas City in 2012,[23] lending a household name to a concept select localities and utilities were also working to bring to fruition. Since then, Comcast has begun offering 2 Gbps service in select markets[24]—and in late 2015, the City of Salisbury, NC and Chattanooga's Electric Power Board (EPB) each announced that they will offer 10 Gbps service.[25,26]

In stark contrast to the FCC's most recent definition of broadband, the industry benchmark is 1 Gbps to all homes and businesses as cities throughout the nation find ways to deploy gigabit-capable networks and offer affordable 1 Gbps service. Symmetry between upload and download speeds also sets networks apart. Traditionally, download speeds are emphasized when selling services to consumers, as download speeds typically exceed upload speeds. A symmetrical service offers upload speeds that match or are very close to download speeds. Further, there is an expectation of unfettered access and no caps or restrictions.

In light of the practical definition of broadband within the industry, and the likelihood that Madison's residents and businesses will desire access to 1 Gbps service, we encourage the City to prioritize offering a simple, straightforward 1 Gbps service.

However, we caution the City that offering 1 Gbps service as it rolls out its FTTP initiative can actually serve to *further* the digital divide. If much of the community has the means to purchase 1 Gbps service, but low-income customers are only able to afford 10 Mbps service, this effectively creates the same divide that the City is attempting to bridge with its pilot program. This is not an impossible hurdle—the City might subsidize access to 1 Gbps for its most vulnerable populations, such as those who are part of the City's broadband pilot program (see

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[23] Cyrus Farivar, "Google Fiber to arrive this fall; $70 for gigabit service," *ArsTechnica*, last modified July 26, 2012, http://arstechnica.com/business/2012/07/google-fiber-launches-in-kansas-city/.

[24] Fergal Gallagher, "Why Comcast's New 2-Gigabit Broadband Service Won't Worry Google Much," *Tech Times,* last modified April 2 2015, http://www.techtimes.com/articles/43818/20150402/comcasts-new-2gb-broadband-service-twice-fast-google-fiber.htm.

[25] Klint Finley, "Chattanooga Is Offering Internet Faster Than Google Fiber," *Wired*, last modified October 15, 2015, http://www.wired.com/2015/10/chattanooga-is-offering-internet-faster-than-google-fiber/.

[26] Claire Zillman, "Want 10 Gbps Internet? Move to this city," *Fortune*, last modified September 3, 2015, http://fortune.com/2015/09/03/gigabit-internet-municipal/.

Section 2.2.2). But the City should be mindful of this unintended consequence of deploying a citywide ultra-high speed network that seeks to provide 1 Gbps service to all its residents.

1.7.4 Continue to Coordinate and Collaborate with Madison Gas and Electric

In some cases, there is little room for collaboration or even cooperation between the locality and the regional investor-owned utility (IOU). Collaboration with a local utility might mean obtaining access to its utility poles or underground conduit, or any existing fiber infrastructure it may have. It can also mean sharing the cost to deploy new infrastructure that may benefit both the locality and the utility.

As part of this analysis, CTC engineers and City staff met with representatives from Madison Gas and Electric (MG&E) to determine the degree to which the utility may be willing to work with the City toward the goal of deploying an FTTP network. It was our experience that MG&E is amenable to the City's initiative, and is willing to collaborate with the City. If the City aims to construct its network entirely underground, it may be especially beneficial to coordinate with MG&E for access to any conduit the utility may own in areas where deploying fiber will be especially difficult, such as areas with a great deal of concrete or right-of-way (ROW) [27] congestion.

We encourage the City to continue open communication and collaboration with MG&E, and to explore any opportunities for symbiosis. The City may be able to assist MG&E in meeting some of its own connectivity goals, and the two entities may be able to enter a partnership of sorts where the two potentially can jointly build some infrastructure as opportunities arise. There are other utilities in the area that may be helpful from a part

1.7.5 Consider Exploring a Procurement Process to Further Evaluate Partnership Opportunities

If the City moves forward with deploying a network, it may be prudent to conduct a procurement process to gauge private sector interest in partnering with Madison.

After review of the City's needs and discussion with the Mayor and staff, we believe the model that best meets the City's objectives is a partnership in which the City owns and maintains the fiber, while the private entity lights the network and offers service over it. There are a handful of private companies in the industry today that are willing to work with localities to deploy this model, and we encourage the City to open discussions with one or more of these vendors, depending on what it is legally able to do.

It may be that the City can directly enter exclusive negotiations with a private partner based on the release of an updated dark fiber leasing rate sheet. That is, the City may be able to publish

[27] The ROW is land reserved for the public good such as utility construction; it typically abuts public roadways.

its dark fiber lease rates and then execute a contract with a partner based on the partner's acceptance of those rates. Alternatively, the City may need to go through a publicized procurement process, such as a request for information (RFI) or request for proposals (RFP), that allows multiple vendors to respond to the City's articulated needs, and enables negotiation with a partner through a process of elimination. The exact avenue the City takes will be driven by the procurement rules to which the City is bound; these should be reviewed by the City's legal counsel.

1.7.6 Prioritize the Continuation of Service to Customers in Pilot Service Areas if Feasible

As we note in Section 2.2.2, the City is in the process of carrying out a pilot program aimed at bringing affordable broadband service to low-income neighborhoods. The pilot is in its infancy, and is expected to last two years. The City will likely want to find a way to continue providing service to pilot customers beyond the pilot period, whether through a temporary partnership (such as an extension of the City's contract with ResTech) or as part of the overall FTTP deployment.

Some incumbent providers often "cherry pick" in communities by upgrading their infrastructure only in areas where they are certain they will be able to recover their cost of infrastructure investment. This typically means that affluent or middle-class neighborhoods have a greater likelihood of being served by incumbent providers than low-income areas. If the City is covering a portion of the cost to bring last-mile service to these areas, this could reduce the overall cost of an eventual citywide FTTP deployment, which may be attractive to a private sector partner.

2 The City's Goals and Priorities

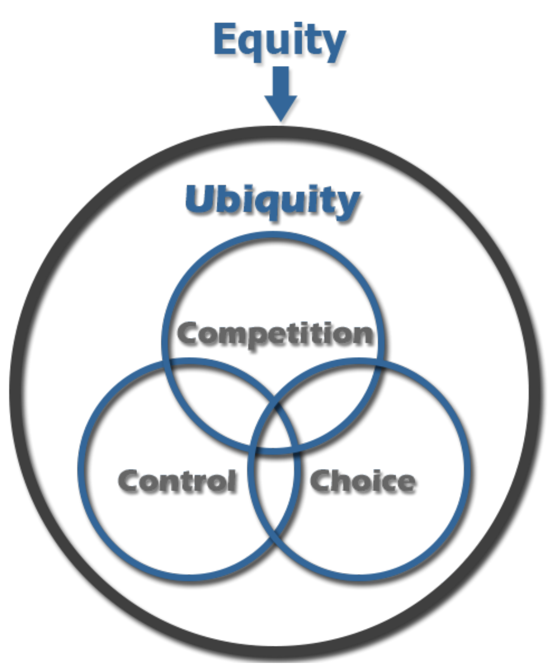
2.1 The City's Core Objectives

Based on our discussions with City staff and our understanding of community goals, we recognize the following objectives as the baseline for the City's broadband initiative:

- Equity – Alignment with Racial Equity and Social Justice (RESJ) and digital divide goals
- Ubiquity – Service is deployed to the entire City
- Competition in the marketplace – Enabling multiple providers to compete
- Consumer choice – Citizens can purchase service from various providers
- Control – The City has a long-term stake in the asset

As we note in Appendix A, ubiquity—which refers to designing and building the network so that it connects every residence, business, and institution in the community—is consistent with and upholds the City's equity initiatives. Incumbent providers have often built only to the most affluent areas of a community where they are sure to see a return on investment (ROI), a practice known as "cherry picking," and the City aims to ensure that none of its residents, businesses, or community anchor institutions (CAIs) is excluded from access to broadband service. Prioritizing ubiquity aligns with the City's other core goals. Ubiquity is a means to achieve equity, and is foundational to the City's broadband initiative.

Figure 3: Equity Informs Ubiquity, Which Aligns with Choice, Competition, and Control



Competition in the marketplace and consumer choice are complementary objectives, and are often sought through a pursuit for open access. That is, many communities prioritize open access as an essential, nonnegotiable objective—but at the core of the pursuit for open access is a desire for competition and consumer choice. We have noted that it may not be necessary to focus on open access in the traditional sense, and by seeking creative ways to foster competition in the marketplace, the City potentially increase consumer choice.

Control of the assets is another important City objective, and one that will be a fundamental aspect of any partnership agreement. It is important for the City to understand what "ownership" really looks like, and what it considers important assets over which it would like to retain control. For example, we believe the City is well-suited to pursue a dark FTTP partnership model where it owns the dark fiber assets but not the network electronics.

2.2 Promoting Equity

2.2.1 Addressing Areas of Need

The City is committed to ensuring that all of its residents have access to the information and services necessary to enjoy a high quality of life, and it is enacting programs to reach vulnerable populations. For example, the City implemented the Racial Equity and Social Justice (RESJ) initiative in 2013 to prioritize inclusion throughout the City for people of color. The RESJ initiative focuses on equity in municipal operations, policies, procedures, and spending—as well as within the community. Its goal is to minimize racial and economic exclusion from important municipal decision-making processes by facilitating change within the City at a fundamental level.

The Neighborhood Resource Teams (NRT) program is another important City initiative. The NRT program, which builds on the RESJ initiative, fosters communication between the City and the community it serves; different teams of City staff serve portions of the community ranging from 500 to 2,000 citizens. The NRTs work with other public, private, and governmental organizations within the community to meet the needs of the populations they serve, and to work collaboratively toward bettering a wide range of aspects of citizens' lives. Everything from public health issues to access to educational resources might be addressed by the NRTs and partnering organizations within the community, based on input from citizens about the needs they perceive in their neighborhoods.

It is beyond the scope of this report to provide extensive guidance on addressing the City's unique digital divide. However, we note that the City's broadband pilot project (see Section 2.2.2) works in conjunction with other City programs to addresses technical, legislative, and social issues. Broadband supports a range of programs and issues, and touches nearly every facet of modern living—and lack of access to it can severely hinder citizens' ability to participate in many aspects of contemporary life.

2.2.2 Bridging the Digital Divide with Pilot Fiber Project

The Common Council approved funds in late 2014 during its annual budget process for a two-year pilot program aimed at bringing broadband Internet service to residential customers in four low-income areas in the City.[28] The following spring, the City issued a request for proposal (RFP), which led to an eventual contract with ResTech Services, LLC.[29]

The pilot is an initiative of Mayor Soglin designed to serve vulnerable populations who may never previously have had access to broadband service—either because there was no service available in their area, or because they could not afford it. The pilot program will offer 10 Megabits per second (Mbps) service at $9.99 per month. The four pilot areas are:

- Allied
- Brentwood
- Darbo-Worthington
- Kennedy Heights

Three of the four areas (Allied, Brentwood, and Darbo-Worthington) are designated NRT neighborhoods. Each of these neighborhoods include multi-dwelling units (MDUs) ranging in size from two units to over 100 units.

While the pilot program was initially envisioned as a wireless deployment, the City broadened its RFP to allow for alternative technologies. ResTech proposed an FTTP approach that would enable it to offer retail services to pilot customers by expanding the City's MUFN network infrastructure into the pilot areas. The contract with ResTech was finalized in early 2016 with the expectation that construction would be underway once weather permitted in the spring.

The pilot was originally intended to produce data to inform a cost-benefit analysis, which could potentially be used to pursue citywide broadband deployment. The initial plans would have produced a cost-benefit analysis at the end of the two-year pilot program, which may be late 2018. After the initial stages of the pilot program were underway, Mayor Soglin determined that the City may want to take on a citywide FTTP initiative sooner than originally anticipated, and tasked the Digital Technology Committee with exploring this possibility. The Digital

[28] "City of Madison - File #40237," *City of Madison*, accessed February 16, 2016, https://madison.legistar.com/LegislationDetail.aspx?ID=2473855&GUID=356DEBE5-18B0-44BC-835A-381CCED09BFE.

[29] CTC provided Appendix B, "Best Practices for FTTP Deployment in Underserved Areas," to the City to help shape some portions of its contract with ResTech; that appendix is based on experience with the BTOP project in Champaign-Urbana, Illinois, which brought last-mile service to some underserved portions of the cities.

Technology Committee formed the Citywide Broadband Subcommittee, which engaged CTC to develop a cost-benefit analysis for ubiquitous FTTP deployment.

There is little data from the pilot program at this stage, and we believe that even final data may not be useful to extrapolate to a citywide deployment to shed light on issues like market demand. However, the pilot is a microcosm of an overall citywide FTTP deployment, and can potentially allow small-scale testing of engineering specifications by using a similar financial model where a private vendor provides lit services over City-owned infrastructure.

Further, the pilot can provide helpful word-of-mouth marketing for the City's "brand." Although the City will not be the retail provider, any partnership will likely be perceived as a City project. (This also means that the City will likely be held accountable for any perceived shortcomings or failures.) Through the pilot, the City has an opportunity to create a stable foundation as a trustworthy and competent steward, which may be helpful to get community buy-in for a larger project.

2.3 Understanding Competition and Open Access

A desire for increased competition in the marketplace is often at the root of the goals that drive a public entity to seek ways to expand access to ultra-high speed broadband connectivity. This can potentially be achieved through "open access," which has traditionally meant one infrastructure that is available to multiple providers to offer service. Open access networks are meant to enable numerous providers to deliver service over the network—thus fostering competition—and to give consumers greater choice and flexibility in picking a provider.

Open access is most easily achieved if a community builds and owns a network itself, because it is then in a position to set terms for private lessees of its fiber that could include open access. But some forms of open access may be possible even under the pure private investment model.

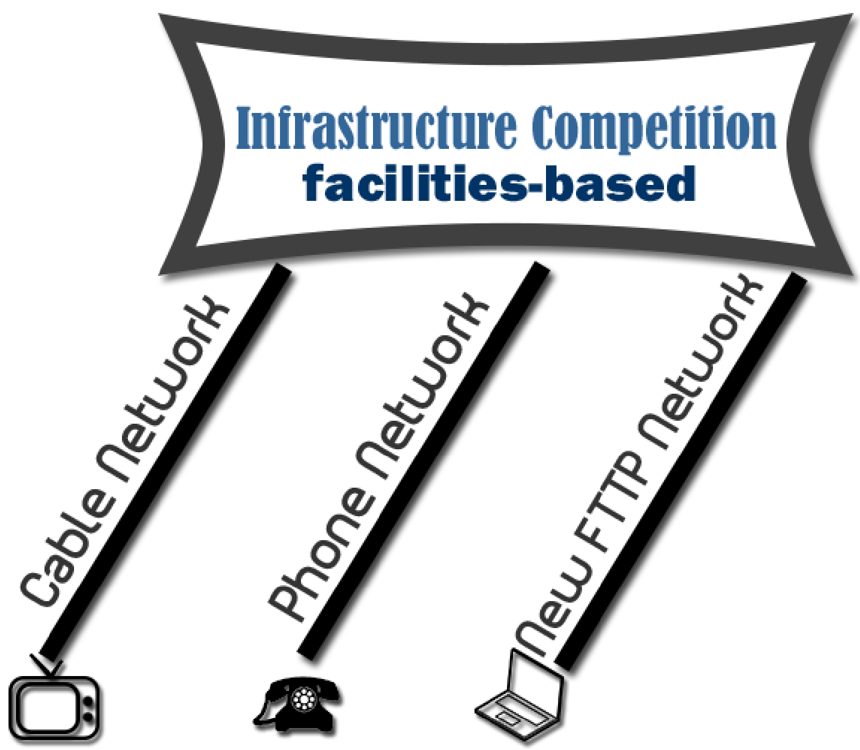
It's essential to note that creating the *potential* for open access does not mean that actual competition will emerge over that platform, particularly over the short to medium term, given the economics of broadband competition—but the potential exists.

There may be other ways for the City to achieve its open access goals, too. That is, the City may find that it can concede on providing infrastructure-based open access if it can ensure that the community's goals with respect to *competition* are met. Indeed, the primary goal of developing an open access network is to level the provider playing field to reduce monopolistic and oligopolistic practices by incumbents, and to give consumers greater choice in service providers. Pursuit of a traditional open access model may not be necessary for to achieve better competition. Rather, competition over the data pipe (known as Over the Top competition) and over multiple network infrastructures (known as facilities-based competition) can serve to enable real competition, thus reducing the need to provide access to physical infrastructure in order to promote and support competition.

2.3.1 Facilities-Based Competition

While it is frequently derided by open access advocates and is not economically efficient, we suggest that the City not discount the benefits of achieving competition through facilities-based competition. In this scenario, competition is achieved when multiple separate entities develop their own separate networks and physical pathways to reach the customer. Most private providers are usually not interested in granting access to their expensive infrastructure for companies that will then compete with them over it, so each of these networks is likely to host only one Internet Service Provider—the network owner.

Figure 4: Facilities-based Infrastructure Competition



This approach is not efficient because it requires a large capital expenditure by each network owner and, frankly, robust competition over separate facilities has not emerged for the most part in the United States, unless one considers the modest duopoly-competition between phone and cable companies to constitute "competition."

But the past five years have brought new competitive networks and new competitors into the broadband market, led by a range of municipalities and by Google Fiber. For cities that have had the benefit of a third provider in the market (whether public or private), facilities-based competition has begun to work, particularly as the incumbents have started to react to competition by investing, upgrading, and improving services and prices.

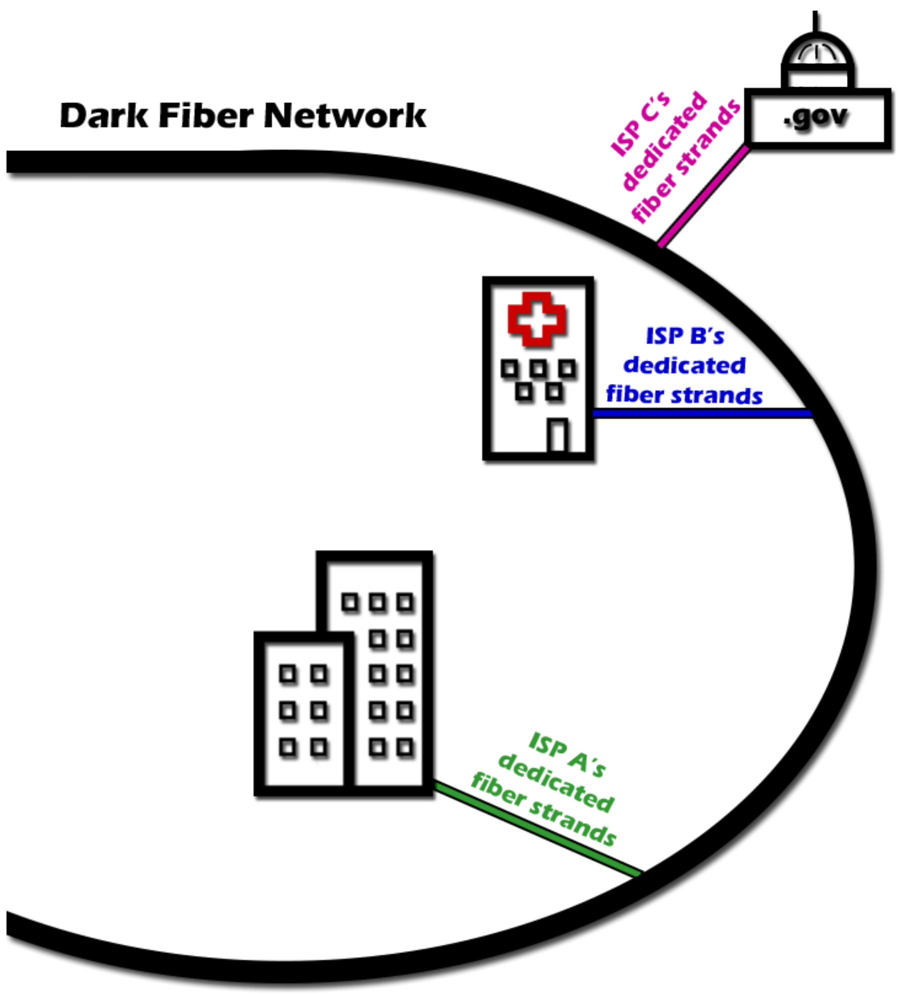
As a result, we believe that Madison is likely to see the substantial benefits of competition from the development of a FTTP network, even if open access over that network does not emerge.

2.3.2 Competition at the Dark Fiber Level

Dark fiber open access enables private providers to offer services without having to construct their own infrastructure. Instead, ISPs can enter into dark fiber lease or indefeasible right of use (IRU) agreements with the network owner, and the ISPs can then offer retail data, video, and voice services over the network.

In a dark fiber model, there is one fiber network infrastructure, and one or more ISPs pay the network owner for access to dedicated fiber strands that the ISPs can use at their discretion (Figure 5).

Figure 5: Competition Over a Dark Fiber Network



This model requires each ISP to "light" the dark fiber by investing in network electronics to provide service over the network. While the cost to install electronics is a lower upfront capital investment than paying to deploy and maintain fiber, electronics costs are still a significant expense for an ISP. This is especially true given that the equipment the ISP owns must be replaced, multiple times over the lifetime of the dark fiber. Equipment may be refreshed every five, seven, or 10 years—and possibly more frequently, depending on advances in technology.

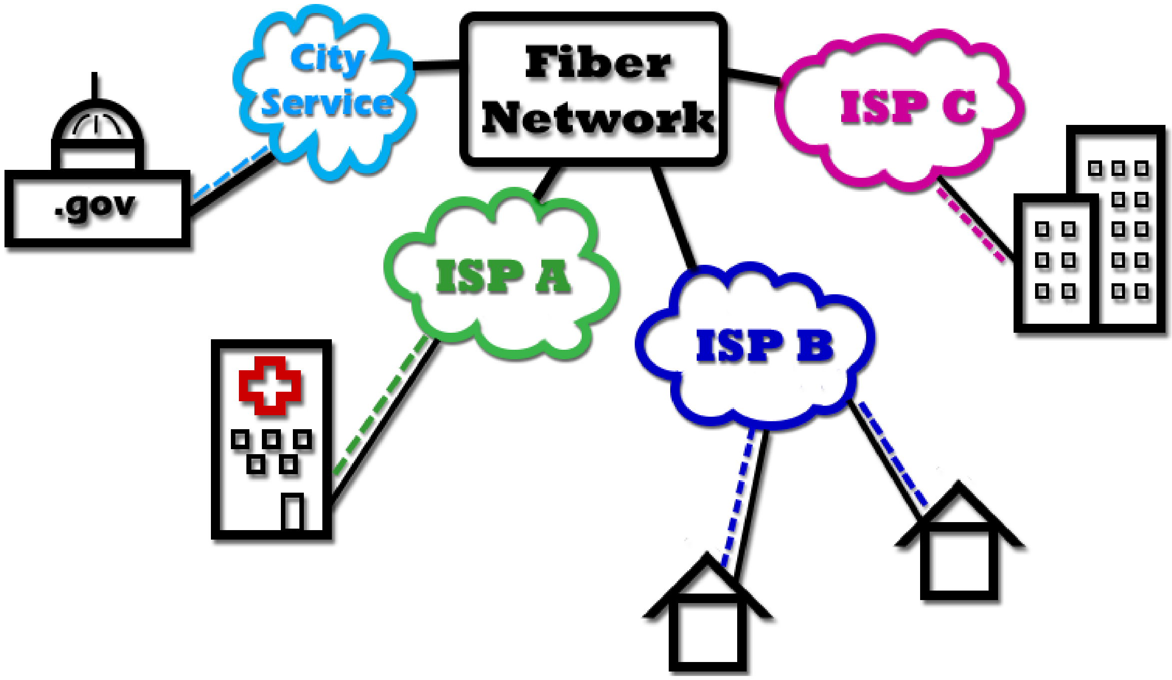
And the ISPs will face many other significant costs to compete in the market, even with access to ubiquitous dark fiber. For example, none of the traditional costs for billing, collections, marketing, and sales are removed by dark fiber access. Nor are costs for customer service. Further, this model may also require the ISP to pay some portion of the cost to install a fiber drop from the dark fiber network at the curb to the home or business of a potential customer it wishes to serve.

As a result, the ISP still has considerable costs to enter the market, thus making multiple-ISP competition at the dark fiber layer more challenging, particularly given that the market has a finite size and that each additional competitor is competing for the same set of customers currently served by the existing providers. For these reasons, we are not optimistic about the potential for multiple-ISP competition over dark fiber, at least in the short- to medium-term. In the long run, the market is likely to change dramatically, however, and dark fiber open access could enable all kinds of new innovators to offer competitive services.

2.3.3 Competition at the "Lit" Services Level

Another option to enable competition is to allow ISPs to compete over a "lit" fiber network—this lowers the barriers to market entry by removing the cost of fiber, electronics, and maintenance, thus allowing more ISPs to compete in the marketplace. In this scenario, the network owner lights the fiber and ISPs compete at the virtual network layer instead of at the physical layer (Figure 6).

Figure 6: Competition Over a Lit Network



In this model, consumers could hypothetically choose which service provider they want to engage by simply clicking a button on a Web interface from the comfort of their homes. The idea is that many ISPs will be able to compete to be a consumer's chosen service provider, and the ISPs can enter the market without having to make large investments in fiber infrastructure or network electronics.

The underpinnings of the traditional open access model are a desire for competition and consumer choice. A lit services model can support both.

That said, it's important to note that even if the barriers to entry are reduced through this model, there is no guarantee that many new competitors will emerge in the near-term. Indeed, it may not make sense for smaller ISPs to operate in a market where there are several other competitors and where customer acquisition and retention costs are correspondingly high.

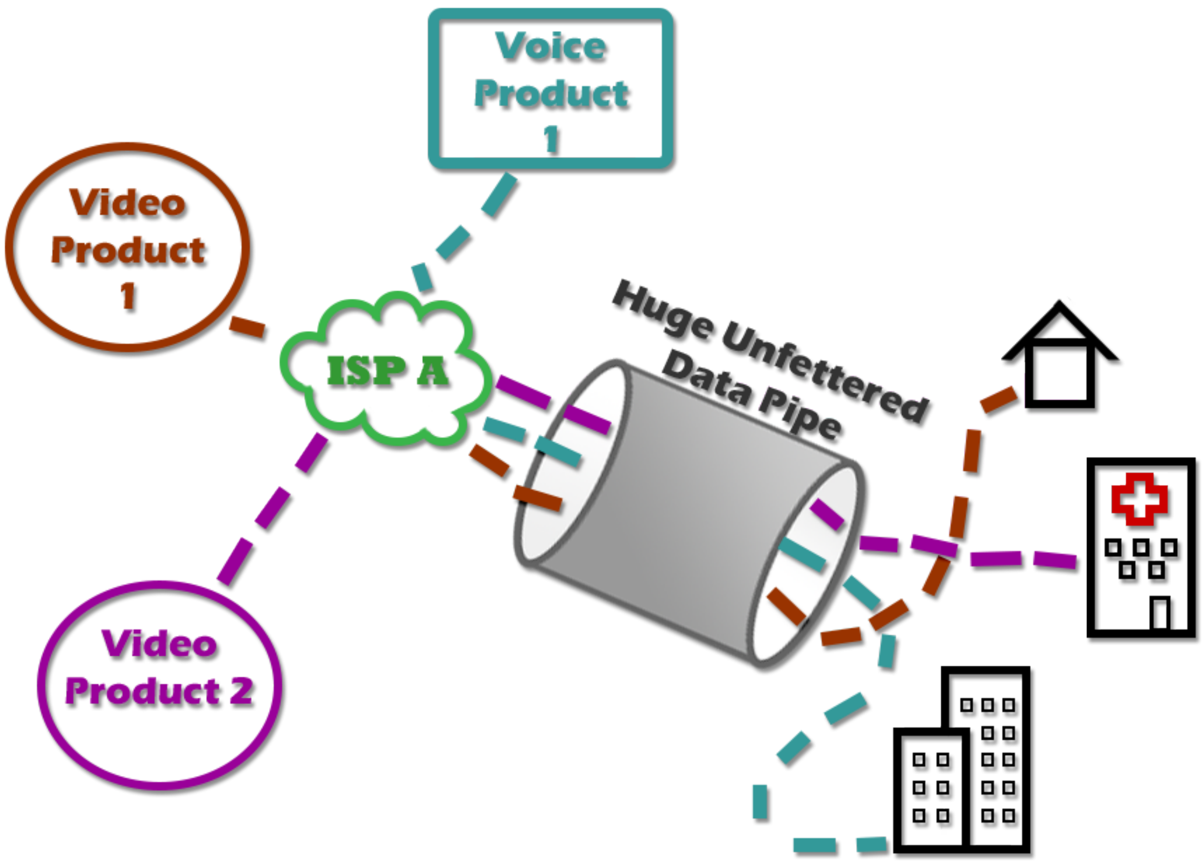
2.3.4 Over-the-Top Content Offers Service-Level Competition and a Variation on Open Access

Another way to potentially achieve the City's open access goals is to enable multiple over-the-top (OTT) providers to offer various services over a high-capacity data network. OTT content (typically video and voice) is delivered over the Internet by a third-party application or service that utilizes a robust, (ideally unfettered) data connection.

OTT content delivery is particularly effective over ultra-high-speed fiber optic broadband networks that are provisioned for affordable data service at 1 Gbps speeds and beyond, operated by service providers that do not put constraints on consumers' access to data. Such high-capacity networks can support a variety of OTT applications to meet consumers' needs. Consumers are likely to pursue alternatives to conventional video and voice services as additional and increasingly varied content becomes available OTT, and as access to high-speed data connections becomes more prominent and affordable.

A large, unfettered data connection can thus serve to meet the competition goals typically associated with open access networks.

Figure 7: Over-the-top Competition



As OTT programming and applications become increasingly prevalent, the need for traditional open access, which relies on access to infrastructure—and all the operational details and costs associated with it—is reduced. The City may find that it can achieve its open access goals of promoting competition and consumer choice through alternative means. If the City builds a ubiquitous network, and then partners with a private entity to manage operations and provide an unfettered data service, this introduces a new competitor into the market and drives competition at the applications layer.

2.3.5 Evolving Over-the-Top Providers

The concept of OTT or "value added" services took hold in the voice market first, as consumers sought alternatives to traditional landline service without being locked into long cell phone contracts—Voice over Internet Protocol (VoIP) providers offered a middle ground. VoIP providers like Vonage emerged in the early 2000s and continued to increase in popularity along with consumers' desire for greater choice. Prior to becoming the videoconferencing-focused service it is today, Skype started with voice service that allowed consumers to make inexpensive or free calls domestically and internationally with their computer, a data connection, and a headset.[30]

Different OTT services have begun to emerge and evolve rapidly in the video market as consumers increasingly ditch cable service in favor of streaming video,[31] and providers clamor to compete with each other in response.[32] There are numerous established services and applications that will likely continue to promote change in the cable industry and drive an increase in consumers' desire for greater choice and control over how they access content. Standalone media-streaming boxes like Apple TV and Roku have enabled consumers to stream content with applications such as YouTube, Netflix, and Hulu without a cable subscription since 2008.[33,34] These "cord-cutters" cancel their cable subscriptions in favor of accessing their favorite content via applications and services streamed over the Internet—OTT content.

Since the debut of Apple TV and Roku, similar devices like the Amazon Fire TV stick and Google Chromecast have entered the market, allowing consumers greater choice. Further, consumers can now purchase smart TVs, which come with preinstalled platforms that support streaming applications and require no additional hardware. With only an Internet connection, consumers can stream movies, music, news, TV shows, movies, and even play games.

Some streaming video services strive to emulate cable television—without the hefty price tag, long contracts, and notoriously subpar customer service that traditional cable providers are

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[30] Doug Aamoth, "A Brief History of Skype," *Time*, last modified May 10, 2011, http://techland.time.com/2011/05/10/a-brief-history-of-skype/.

[3131] http://www.consumerreports.org/cro/tvservices/more-people-are-cutting-the-pay-tv-cord, accessed April 2016.

[32] http://techcrunch.com/2016/05/02/hulu-to-compete-with-sling-tv-via-new-cable-tv-like-service/, accessed May 2016.

[33] http://www.apple.com/pr/library/2008/01/15Apple-Introduces-New-Apple-TV-Software-Lowers-Price-to-229.html, accessed January 2016.

[34] http://rokumodels.com/roku-models/first-generation-roku/, accessed January 2016.

known for.[35] Other services specialize in one type of content, like only offering documentaries or movies. The OTT video market has exploded in recent years as consumers continue to seek alternatives to traditional video services, and content providers nimbly adapt to consumer demand. Providers like Amazon, Hulu, and Netflix have continued to tailor their approach through efforts like creating original content to supplement traditional content offerings.[36] Such content easily rivals traditional television programming; some OTT provider original series have been nominated or won Critics' Choice, Emmy, Golden Globe, People's Choice, Screen Actors Guild, and other awards. Even tech giant Apple may begin producing original content.[37]

In 2015 alone, several companies began offering standalone streaming or providing access to content through new streaming services. HBO and Showtime both began offering access to their content through directly streaming via subscription service in 2015.[38,39] In addition to an ability to easily access sports programming, a desire for premium programming like HBO and Showtime has been a stubborn barrier to customers who want to eliminate their cable subscriptions (and to competitors that want to disrupt the market). Often, consumers would happily give up enormous cable bills in favor of more streamlined, inexpensive services—but they do not take the leap because they want specific programming that is only available with a cable subscription. It is significant when content powerhouses like HBO and Showtime take such an industry-disrupting leap.

Also in 2015, Verizon FiOS announced an "a la carte" offering called Custom TV, which allows consumers to choose from bundled packages that more appropriately reflect their programming desires and include less unwanted channels.[40] While this is not a true OTT application, it demonstrates a recognition within the incumbent market that consumers are dissatisfied with traditional content delivery and are seeking alternate choices.

As we noted, sports programming is a major barrier for many consumers who wish to cancel their cable subscription. DISH Network launched an OTT service in early 2015 called Sling TV that offers sports programming on channels such as ESPN, as well as other programming and popular TV channels. The service, called Sling TV, is streamed over the Internet.[41] Like other

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[35] http://www.fool.com/investing/general/2015/06/03/comcast-time-warner-cable-still-rank-worst-in-cust.aspx, accessed January 2016.

[36] http://www.huffingtonpost.com/2014/01/18/netflix-hulu-amazon-prime-originals_n_4591418.html, accessed January 2016.

[37] http://gizmodo.com/the-apple-original-content-rumor-is-back-1727863339, accessed January 2016.

[38] http://www.pcworld.com/article/2894534/hbo-announces-hbo-now-standalone-streaming-service-with-discounted-apple-tv.html, accessed January 2016.

[39] http://money.cnn.com/2015/07/07/media/showtime-streaming/, accessed January 2016.

[40] http://arstechnica.com/business/2015/04/verizons-new-custom-tv-is-small-step-toward-a-la-carte-pricing/, accessed January 2016.

[41] http://www.nytimes.com/2015/01/06/business/media/dish-network-announces-web-based-pay-tv-offering.html, accessed January 2016.

streaming services, Sling TV does not require additional hardware to access OTT content, including sports programming. Sling TV currently is priced at $20 per month with no time commitments, but it has experienced hiccups as its offerings are subject to limitations and restrictions that are reminiscent of traditional cable.[42] Traditional cable content providers' attempts at OTT service have seen varying degrees of success, but it is significant in the industry for these providers to even acknowledge the need for these services.

Companies that hope to compete in the video market will likely find that they must adjust their business models, marketing strategies, and understanding of consumer demands and desires. Perhaps one of the most significant illustrations of this is that, for the first time ever, Comcast's broadband subscribers outnumbered its cable subscribers in 2015—an unprecedented and major shift in the industry.[43] The City can essentially "court" OTT providers and promote these applications by requiring a public–private partnership's data-only offering to provide unfettered access. The City has already laid out unfettered access to data as a base requirement for any partnership agreement it enters. This can help the City achieve its goals of consumer choice and competition in the market without the need for traditional infrastructure-based open access.

[42] http://www.pcworld.com/article/2909572/sling-tv-channel-guide-all-the-programming-and-all-the-restrictions-all-in-one-chart.html, accessed February 2016.

[43] Emily Steel, "Internet Customers Surpass Cable Subscribers at Comcast," *The New York Times,* last modified May 4, 2015, http://www.nytimes.com/2015/05/05/business/media/comcasts-earnings-rise-10-driven-by-high-speed-internet.html?_r=0.

3 Market Analysis: Assessment of the Local Broadband Marketplace

As part of our analysis for the City of Madison, CTC assessed the current market for enterprise and residential or small business services.[44] This analysis outlines various types of service in the City, and corresponding pricing and contract terms where applicable.

Not every service described here is available in every part of the City to all potential customers—especially small and medium businesses. This competitive assessment is intended to outline the breadth of services that may be available to users in the City, but it does not identify specific service boundaries for each provider.

For enterprise users, the analysis summarizes dark fiber and lit services availability and pricing. For the residential and small business market, this analysis describes available cable, digital subscriber line (DSL), satellite, and wireless services.

3.1 Enterprise Market

In this section, we provide an overview of competitive providers for dark fiber and lit services for enterprise customers in the City.

During the course of our research, we identified 10 service providers in the Madison area that offer a range of services, from dark fiber connectivity to data transport services, with speeds that range from 1 Megabit per second (Mbps) to 100 Gigabits per second (Gbps). Individual providers tailor these services to customers' requirements like speed or class of service. Greater proximity to the provider's existing network infrastructure results in lower service pricing. Providers prefer to offer transport services between locations on their network (on-net). For off-net locations, providers provision Multiprotocol Label Switching (MPLS) based services.

A current trend that we expect to continue is the consolidation of competitors through mergers and acquisitions. Madison-area competitors are discussed in detail in the following sections.

3.1.1 Dark Fiber Services

There are two service providers in the City with dark fiber availability: Level 3 Communications and Zayo Group.

Level 3 has dark fiber routes in Madison, as depicted in Figure 8. Services are offered only to select customers based on the provider's application requirements. Dark fiber pricing varies individually, based on distance from the provider's fiber ring. Even a few tenths of a mile distance from Level 3's fiber ring can result in significant price differences for dark fiber connectivity, due to additional construction costs.

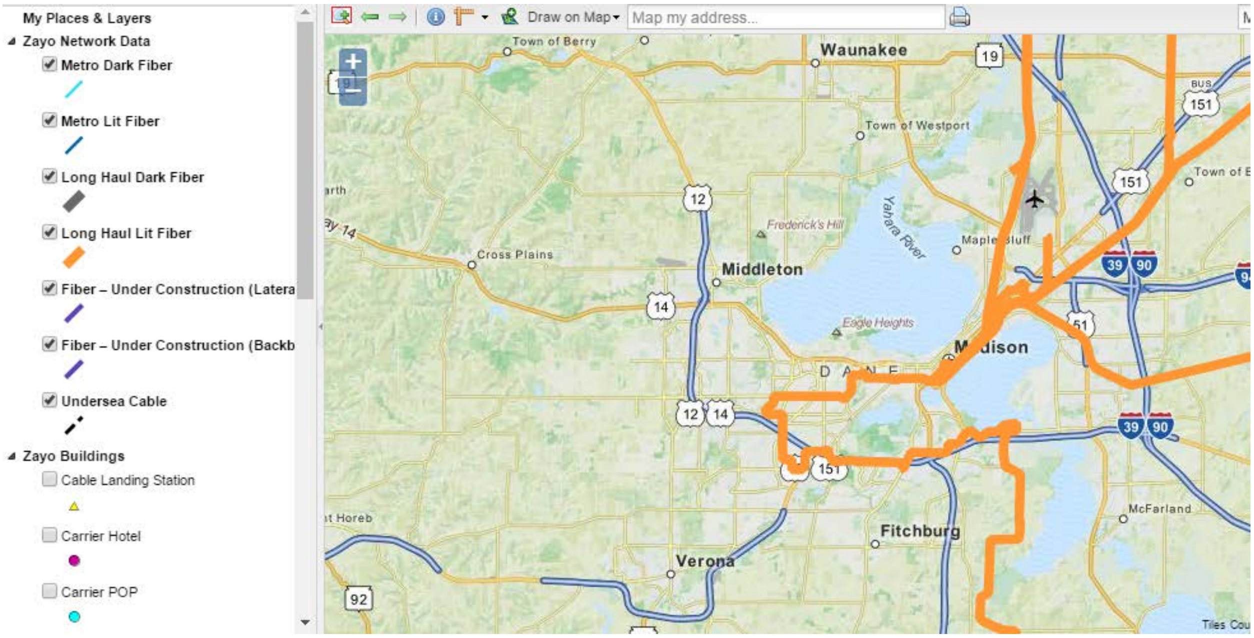
[44] Small business customers often subscribe to the same or comparable service as residential customers because the service meets the needs of the business at an affordable price point.

Figure 8: Level 3 Dark Fiber Routes[45]

Zayo provides dark fiber connectivity over its national network of metro and intercity fiber. The company claims to have proven expertise in deploying major new dark fiber networks and offers multiple financing options, including leases and indefeasible right of use (IRU) agreements. Pricing varies significantly depending on whether the building is on-net. If the location is off-net, construction and splicing costs would apply.[46]

[45] http://maps.level3.com/default/, accessed March 2016.
[46] http://zayofibersolutions.com/why-dark-fiber, accessed March 2016.

Figure 9: Zayo Fiber Map[47]



3.1.2 Lit Services

Almost all existing service providers offer enterprise-grade, Ethernet-based services. Bandwidths range from 1 Mbps to 100 Gbps. Ethernet service can be classified into three types: Ethernet Private Line (EPL or E-Line), Ethernet Virtual Private Line (EVPL), and Ethernet Local Area Network (ELAN). These may be known by different names among providers. EPL is a dedicated, point-to-point high bandwidth Layer 2 private line between two customer locations. The EVPL service is similar to EPL but is not dedicated between two locations. Instead, it provides the ability to multiplex multiple services from different customer locations onto one point on the provider's network (multiple virtual connections) to another point on the network. ELAN is a multipoint to multipoint connectivity service that enables customers to connect physically distributed locations across a Metropolitan Area Network (MAN) as if they are on the same Local Area Network (LAN).

The internet services over Ethernet are typically classified under two categories: Dedicated Internet Access (DIA) and MPLS Internet Protocol (IP) Virtual Private Networks (VPN), or "IP-VPN". Providers prefer to offer MPLS based IP-VPN services when the service locations are off-net, thus avoiding construction and installation costs. MPLS-based networks provide high performance for real-time applications such as voice and video, and are typically priced higher.

The carriers who provide these services in the Madison area are:

- AT&T

[47] http://www.zayo.com/network/interactive-map, accessed March 2016.

- CenturyLink
- Charter
- Level 3 Communications
- TDS Telecom
- US Signal
- Verizon
- Windstream Communications
- XO Communications
- Zayo Group

Prices depend on the bandwidth, location, and network configuration; whether the service is protected or unprotected; and whether the service has a switched or mesh structure.

AT&T has four different types of Ethernet products—GigaMAN, DecaMAN, Opt-E-MAN, and Metro Ethernet. GigaMAN provides a native-rate interconnection of 1 Gbps between customer end points. It is a dedicated point-to-point, fiber optic-based service between customer locations, which includes the supply of the GigE Network Terminating Equipment (NTE) at the customer premises. DecaMAN connects the end points at 10 Gbps and is transmitted in native Ethernet format similar to GigaMAN—only 10 times faster. Opt-E-MAN service provides a switched Ethernet service within a metropolitan area. It supports bandwidths ranging from 1 Mbps to 1,000 Mbps, and configurations such as point-to-point, point-to-multipoint, and multipoint-to-multipoint. Metro Ethernet service provides various transport capabilities ranging from 2 Mbps through 1 Gbps, while meeting IEEE 802.3 standards.[48] A 1 Gbps fiber-based internet service at an off-net location in Madison is priced at $4,135 per month.

CenturyLink provides point-to-point inter-city and intra-city configurations for full-duplex data transmission in the Madison vicinity, as depicted in Figure 10.The company typically offers speeds of 100 Mbps to 10 Gbps.[49]

48 http://www.business.att.com/service_overview.jsp?repoid=Product&repoitem=w_ethernet&serv=w_ethernet&serv_port=w_data&serv_fam=w_local_data&state=California&segment=whole accessed March 2016.

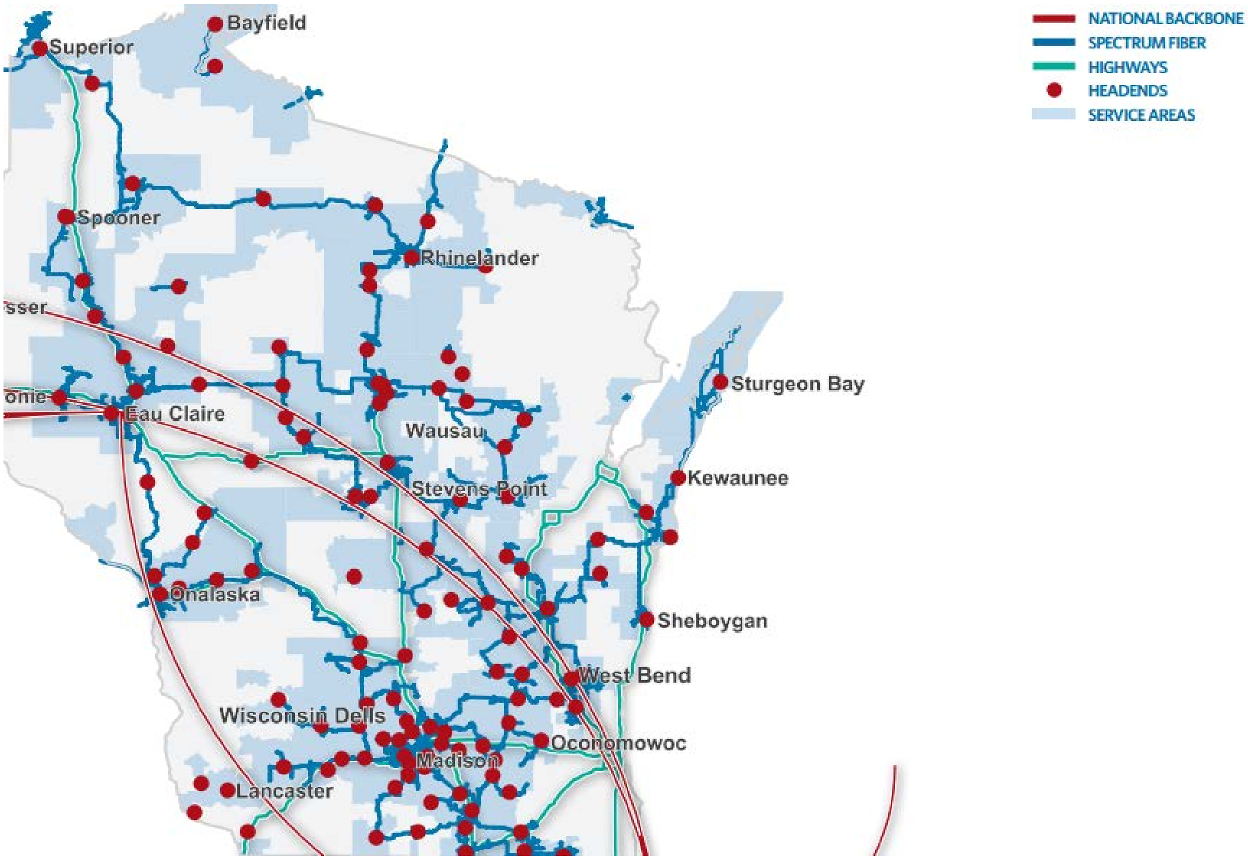
49 http://www.centurylink.com/business/asset/network-map/fiber-network-nm090928.pdf, accessed March 2016.

Figure 10: CenturyLink Network Map

Charter Communications offers Metro Ethernet services and direct Internet access (DIA) in Madison. Metro Ethernet services offer metro and long-haul connectivity and point-to-point, point-to-multipoint or multipoint-to-multipoint configurations. These include EPL, EVPL, and E-LAN services. A point-to-point EPL configuration offers a committed information rate (CIR) connection to connect both metro and long haul optical locations. It provides the customer full control of their network with the simplicity of a point-to-point connection. An EVPL service provides multiple point-to-point connections from the same customer Ethernet port, such as for connecting multiple remote offices to a central headquarters location. The E-LAN service connects all desired locations to create a secure, shared-data network. These services are offered with speeds from 10 Mbps to 10 Gbps with the ability to scale your bandwidth in 10 Mb or 100 Mb increments.[50] In Madison, on-net locations (already connected to their fiber network) can get 1 Gbps DIA service for $1,200 per month with a 36-month contract. Locations that are not already connected to their fiber can get a 1 Gbps DIA service for $7,000 per month with a 36-month contract. For an EPL service, a 1 Gbps connection costs $1,600 per month—but additional construction fees apply for locations not currently connected to its fiber. The Charter network in Madison is depicted in Figure 11.

[50] https://www.charterbusiness.com/mediacontent/pdfs/Charter_Business_Optical_Ethernet.pdf, accessed March 2016.

Figure 11: Charter Network[51]



Level 3 Communications' Metro Ethernet dedicated service is available in bandwidth options of 3 Mbps to 1 Gbps and its EVPL offers speeds ranging from 3 Mbps to 10 Gbps.[52] It is an end-to-end, Layer 2, switched Ethernet service delivered via an MPLS backbone. Internet services are available in a range of 14 speeds, up to 10 Gbps.[53]

TDS Telecom offers Metro Ethernet services in speeds scalable from 1.5 Mbps to 10Gbps in Madison.[54] Pricing is not publicly available for TDS Telecom's enterprise services.

US Signal offers Ethernet services from 100 Mbps to 1 Gbps. They also offer DIA services up to 1 Gbps speeds or higher.[55,56] Pricing for US Signal's enterprise services is not publicly available.

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[51] https://business.spectrum.com/mediacontent/pdfs/spectrum-business-wisconsin-KMA.pdf, accessed March 2016.

[52] http://www.level3.com/en/products-and-services/data-and-internet/vpn-virtual-private-network/evpl/, accessed March 2016.

[53] http://www.level3.com/~/media/files/factsheets/en_ethernet_fs_ethernetmatrix.pdf, accessed March 2016.

[54] http://www.tdsbusiness.com/products/data-networking/ethernet.aspx, accessed March 2016

[55] https://ussignal.com/network/carrier-services , accessed March 2016.

Verizon offers Ethernet services in certain locations in Madison under three different product categories:

- ELAN
- EPL
- EVPL

The ELAN service is a multipoint-to-multipoint bridging service at native LAN speeds. It is configured by connecting customer User-to-Network Interfaces (UNIs) to one multipoint-to-multipoint Ethernet Virtual Connection or Virtual LAN (VLAN), and provides two Class of Service options (CoS): standard and real time. The EPL is a managed, point-to-point transport service for Ethernet frames. It is provisioned as Ethernet over SONET (EoS) and speeds of 10 Mbps to 10 Gbps are available. EVPL is an all-fiber optic network service that connects subscriber locations at native LAN speeds; EVPL uses point-to-point Ethernet virtual connections (EVCs) to define site-to-site connections. It can be configured to support multiple EVCs to enable a hub-and-spoke configuration, and supports bandwidths from 1 Mbps to 10 Gbps.[57]

Windstream Communications has a nationwide presence serving major metropolitan areas, including the City. It offers DIA services in Madison with speeds up to 1 Gbps.[58],[59]

XO Communications offers carrier Ethernet and DIA services at multiple bandwidth options, ranging from 3 Mbps to 100 Gbps, over its Tier 1 IP network.[60]

Zayo delivers Ethernet in three service types, with bandwidth ranging from 100 Mbps to 10 Gbps, and options like Quality of Service (QoS) guarantees and route protection based on customer needs. The different types of services offered are: Ethernet-Line, which provides point-to-point and point-to-multipoint configurations with reserved bandwidth availability; ELAN, with multipoint configurations having a guaranteed service level; and Ethernet Private Dedicated Network (E-PDN) with a completely private, managed network operated by Zayo, with dedicated fiber and equipment.[61]

3.2 Residential and Small Business Services

Residential and small business customers in the Madison area have access to a range of services, though individual service options are dependent on location. Table 8 lists the service

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[56] https://ussignal.com/network/dedicated-internet-access accessed March 2016.
[57] http://www.verizonenterprise.com/products/networking/ethernet/, accessed March 2016.
[58] http://carrier.windstreambusiness.com/wordpress/wp-content/uploads/2014/10/Carrier-Ethernet-Ordering-Guide-10.8.14.pdf, accessed March 2016.
[59] http://www.windstreambusiness.com/shop/products/wi/Madison, accessed March 2016.
[60] http://www.xo.com/carrier/transport/ethernet/, accessed March 2016.
[61] http://www.zayo.com/ethernet, accessed March 2016.

providers and minimum price for each type of service that is available in at least some part of the City.

Table 8: Overview of Residential and Small Business Data Services in Madison

Service Type	Provider	Minimum Price (per month)
Cable	Charter	$39.99
DSL	AT&T	$35
	TDS Telecom	$80
Satellite	HughesNet	$49.99
3G/4G/Wireless Internet Service Provider	Verizon	$60
	T-Mobile	$20
	Sprint	$35
	AT&T	$50
	Netwurx	$47.45

3.2.1 Cable

Charter Communications offers Internet services via cable modem in standalone and bundled service packages in Madison. The Internet-only package offered by Charter is 60 Mbps download and 4 Mbps upload for $39.99 per month with a 12-month commitment. A promotion on a bundled service package with TV, Internet, and voice from Charter is being offered at $29.99 per month for each service for new customers.

Internet services for small businesses are offered in two tiers. A service offering for 100 Mbps download and 7 Mbps upload is available at $99 per month for the first 12 months. A 60 Mbps download and 4 Mbps upload is offered at $59.99 per month for the first 12 months. Discounted prices are available if bundled with another service like TV or voice.

3.2.2 Digital Subscriber Line (DSL)

AT&T offers DSL service for residential customers in Madison, starting at $35 per month for unbundled or standalone DSL service at 3 Mbps with a 12-month commitment. Additional options up to 45 Mbps are also available, as indicated in Table 9.

Table 9: AT&T Residential Internet—Internet Only

Internet Speed	Monthly Price (Regular)	Monthly Price (Promo Rate)
Up to 3 Mbps download	$47	$35
Up to 6 Mbps download	$52	$40
Up to 18 Mbps download	$62	$45
Up to 45 Mbps download	$82	$65

AT&T offers DSL-based small business services starting at $80 per month for 18 Mbps download and 1.5 Mbps upload speeds.

TDS Telecom is an Internet service provider that offers DSL speeds from 1 Mbps to up to 25 Mbps download (and 5 Mbps upload) for residential customers in Madison.[62]

TDS Telecom also offers fiber-based Internet services at certain locations in Wisconsin, including Madison suburb Verona.[63,64] It offers download speeds at 25 Mbps, 50 Mbps, 100 Mbps, 300 Mbps and 1 Gbps.

TDS Telecom offers business Internet speeds from 1.5 Mbps (512 Kbps upload) up to 100 Mbps (40 Mbps upload) in Madison.[65] Pricing ranges from $39 per month to $229 per month.

3.2.3 Satellite

Satellite Internet access is available in the area as well. **HughesNet** has four packages available for residential users: 1) Hughesnet Choice with speeds up to 5 Mbps download/1 Mbps upload, a monthly data cap of 5 GB, and 50 GB of "bonus" data (55 GB total) for $49.99 per month 2) HughesNet Prime Plus with speeds up to 10 Mbps download/1 Mbps upload, a 10 GB monthly data cap, and 50 GB of bonus data (60 GB total) for $59.99 per month; and 3) HughesNet ProPlus with speeds up to 10 Mbps/2 Mbps, a monthly data cap of 15 GB, and 50 GB bonus bytes (65 GB total) for $79.99 per month; and 4) HughesNet Max with speeds up to 15 Mbps/2 Mbps, a monthly data cap of 20 GB, and 50 GB of bonus data (70 GB total) for $129.99 per month.

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[62] http://tdstelecom.com/shop/internet-services/high-speed-internet-plans.html, accessed March 2016.
[63] http://info.tdstelecom.com/MediaRoom/Article.aspx?id=47ac4957-357f-410c-8fed-ea366f3e232c, accessed March 2016.
[64] https://www.tdsfiber.com/where/, accessed March 2016.
[65] http://www.tdsbusiness.com/Libraries/TDS_Resources/High-Speed-Internet-Rate-Sheet.sflb.ashx, accessed March 2016.

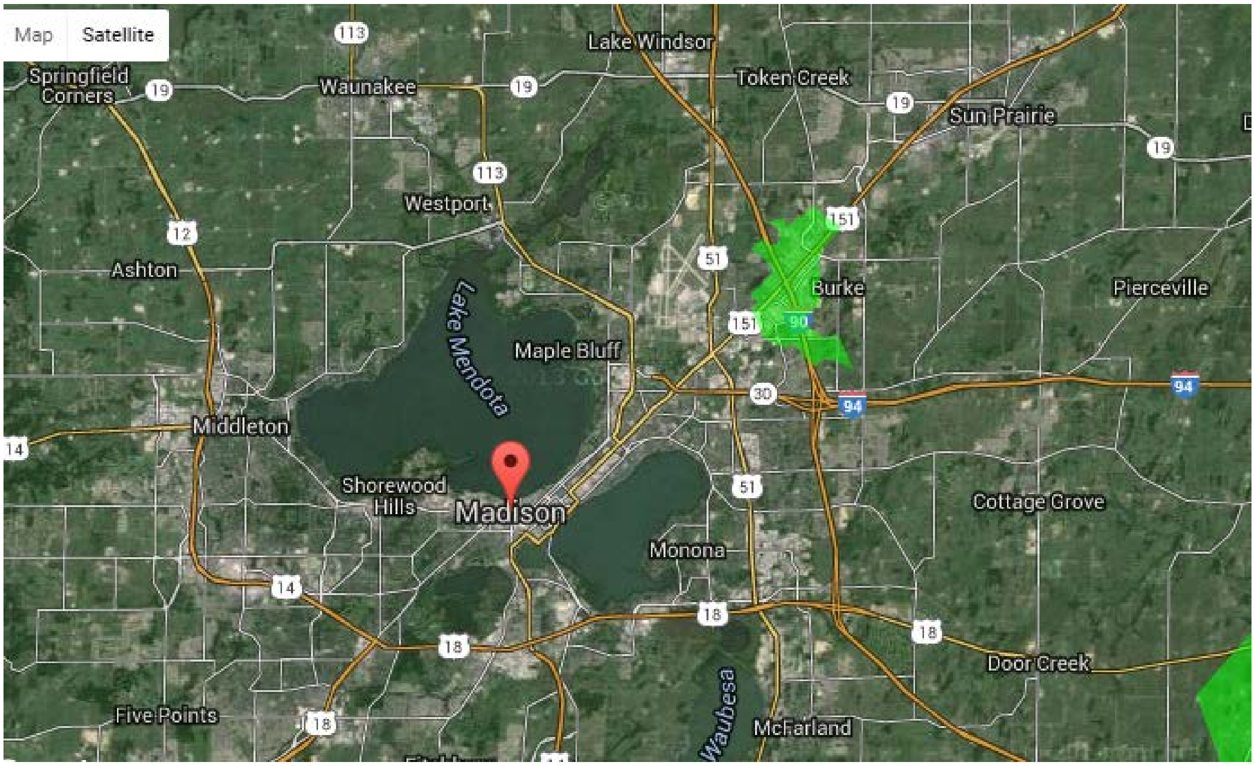
HughesNet has four business internet packages available, of which two packages are for Internet services to small businesses. The Business 50 package provides speeds of up to 5 Mbps download and 1 Mbps upload for $69.99 per month, with a 5 GB per month anytime allowance and 10 GB “bonus bytes” from 2:00 a.m. to 10:00 a.m., for a total monthly data allowance of 15 GB. This package requires a two-year agreement and only supports up to five users. The Business 100 package for $79.99 provides the 10 Mbps download and 1 Mbps upload speeds and offers a higher data allowance threshold of 20 GB per month anytime and 10 GB “bonus bytes” from 2 a.m. to 10 a.m., for a monthly data allowance of 30 GB. This package also requires a two-year agreement and is best for five to just over 10 users.

3.2.4 Wireless

AT&T provides 4G LTE wireless data service in the area, but only offers one package type with a 5 GB per month download allowance for $50 per month. There is an overage fee of $10 per 1 GB over the limit. There are also equipment charges, with or without a contract, and an activation fee.

Netwurx is a wireless Internet service provider (WISP) that provides services in certain parts of Madison for speeds up to 30 Mbps. The coverage map is depicted in Figure 12 (below).

Figure 12: Netwurx Wireless Coverage Map[66]



Netwurx's range of standard speeds and pricing available are indicated in Table 10.

Table 10: Netwurx Internet Services

Package	Internet Speed(Download/Upload)	Monthly Price
Basic	1 Mbps/512 kbps	$47.45
Basic+	1 Mbps to 6 Mbps/ 512 kbps to 2 Mbps	$47.45
Essential Home	5 Mbps/2.5 Mbps	$62.45
Enhanced Home	20 Mbps/10 Mbps	$84.95
Extreme Home	30 Mbps/15 Mbps	$129.95

Sprint also offers 4G LTE wireless data in Madison. The three data packages offered range from 100 MB per month data allowance for $15 per month, to 6 GB per month data allowance for

[66] http://www.netwurx.net/wireless-high-speed, accessed March 2016.

$50 per month, to 12 GB per month data allowance for $80 per month. Each MB over the limit is billed at a cost of $.05. A two-year contract is required, as well as an activation fee of $36 and equipment charges for three different types of devices. There is an early termination fee of $200.

Of the cellular wireless providers in the area, the least expensive wireless data option offered is from **T-Mobile**, for $20 per month with a limit of 1 GB per month. T-Mobile offers additional capabilities and increasing data limits at incremental costs in a total of six packages, up to $70 per month for up to 11 GB of data. Depending upon current promotions, the $35 activation fee is sometimes waived.

Verizon offers two 4G LTE data packages with multiple choices for data allowances and pricing, depending on the desired mobility and equipment chosen. The HomeFusion Broadband Package (LTE-Installed) is a data-only 4G LTE service with WiFi connectivity and wired Ethernet for up to four devices. Available download speeds are 5 Mbps to 12 Mbps, and upload speeds are 2 Mbps to 5 Mbps. Monthly prices range from $60 for a 10 GB data allowance, to $120 for a 30 GB data cap. Overages are charged at $10 per additional GB. A two-year contract is required, with a $350 early termination fee. Verizon offers a $10 monthly deduction for every month completed in the contract. The Ellipsis JetPack provides a mobile solution, with download speeds of 5 Mbps to 12 Mbps and upload speeds of 2 Mbps to 5 Mbps. Prices for the 12 options of data allowances range from $30 per month for a 4 GB data allowance, to $335 per month for 50 GB of data, in addition to a monthly line access charge of $20. The device is $0.99 with a two-year contract. There is a $35 activation fee.

4 Residential Market Research

Madison has a diverse and resilient economy, driven by an educated population, innovative workforce, embrace of technology, and its connections with the University of Wisconsin and state government. A foundation for Madison's successful business climate and quality of life is its use of technology, including reliable and robust access to the Internet.

As part of its efforts to evaluate and improve Internet access and quality for its residents, the City of Madison conducted a survey of residents in Spring 2016. Key findings include:

- Madison residents are highly connected, with 95 percent of respondents having some form of Internet connection. Specifically, 89 percent of residents have home Internet service and 77 percent have a cellular telephone with Internet.
- Older, low-income, and less-educated respondents are less likely than their counterparts to have some form of Internet access at their home.
- Approximately two-thirds of households use a cable modem Internet connection, while much smaller shares have DSL, satellite, fixed wireless, and other connections. The most frequent uses of home Internet are streaming movies, videos, or music, buying products online, and connecting to a work computer. Seven in 10 respondents occasionally use the Internet to access City of Madison information or services.
- Reliability of respondents' Internet connections ranks as the most important aspect of their Internet service, followed by connection speed and price paid. Residents are generally satisfied with the speed and reliability of their Internet service.
- Respondents indicated a willingness to switch to a very high-speed Internet connection, especially at monthly prices lower than $50 or for a one-time hookup fee at or below $250.
- More than one-half of respondents' employers allow telework, and more than one-fourth of responding households have a member who already teleworks.
- An equal share of respondents has antenna (over-the-air) television service, cable television, or television service through the Internet. Those under age 45 are less likely than older respondents to have cable television but are more likely to use the Internet. The most important television programming features are local programming and news programming.
- About six in 10 respondents said that the City should install a state-of-the-art communications network and either offer services or allow private companies to offer services to the public.

This section documents the survey process, discusses methodologies, presents results, and provides key findings that will help the City assess the current state and ongoing needs of its residents regarding high-speed communications services.

4.1 Survey Process

4.1.1 Overview

The City of Madison has a diverse and robust urban climate, and embraces new trends and technologies to improve its economy and quality of life. Supporting its innovative culture is use of the Internet and the myriad of applications and services that are enabled by robust Internet access and services.

As part of a broader effort to evaluate and improve high-speed communications services, the City of Madison conducted a mail survey of randomly selected residences in May 2016. The survey captured information about residents' current communications services, satisfaction with those services, desire for improved services, willingness to pay for faster Internet speeds, and opinions regarding the role of the City in enabling Internet access and service. A copy of the survey instrument is included in Appendix A.

The City acquired the services of Columbia Telecommunications Corporation (CTC) to help assess communications services within the City. CTC and its partner market research firm, Clearspring Research (together, the "Consultant"), coordinated and managed the survey project, including development of the draft questionnaire, sample selection, mailing and data entry coordination, survey data analysis, and reporting of results. CTC and Clearspring have substantial experience conducting similar surveys for municipalities nationwide.

4.1.2 Coordination and Responsibilities

A project of this magnitude requires close coordination between the City and the Consultant managing the project. This section briefly describes the project coordination and responsibilities.

In the project planning phase, the City and the Consultant discussed the primary survey objectives, the timing of the survey and data needs, and options for survey processes. The project scope, timeline, and responsibilities were developed based on those discussions.

The Consultant developed the draft survey instrument based on the project objectives and provided it to City staff for review and comment. The City provided revisions and approved the final questionnaire. The Consultant purchased a mailing list of randomly selected City households to receive the survey packet. The Consultant also coordinated all printing, mailing, and data entry efforts and provided regular updates to City staff. The Consultant performed all data coding and cleaning, statistical analyses, response summaries, and reporting of results.

The primary responsible party at the City was the Chief Information Officer. The Consultant's primary responsible parties were the Principal Analyst, the Principal Research Consultant, and the Research Director.

4.1.3 Survey Mailing and Response

A total of 3,750 survey packets were mailed first-class in May 2016 with a goal of receiving 600 valid responses. Recipients were provided with a postage-paid business reply envelope in which to return the completed questionnaire. A total of 930 useable surveys were received by the date of analysis,[67] providing a gross[68] response rate of 24.8 percent. The margin of error for aggregate results at the 95 percent confidence level for 930 responses is ±3.2 percent, within the initial sample design criteria. That is, for questions with valid responses from all survey respondents, one would be 95 percent confident (19 times in 20) that the survey responses lie within ±3.2 percent of the population as a whole (roughly 90,500 households in the City).

4.1.4 Data Analysis

The survey responses were entered into SPSS[69] software and the entries were coded and labeled. SPSS databases were formatted, cleaned, and verified prior to the data analysis. Address information was merged with the survey results using the unique survey identifiers printed on each survey. The survey data was evaluated using techniques in SPSS including frequency tables, cross-tabulations, and means functions. Statistically significant differences between subgroups of response categories are highlighted and discussed where relevant.

The survey responses were weighted based on the age of the respondent. Since older persons are more likely to respond to surveys than younger persons, the age-weighting corrects for the potential bias based on the age of the respondent. In this manner, the results more closely reflect the opinions of the Madison adult population as a whole.

Table 11 and Figure 13 summarize the weighting used for survey analysis.

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[67] At least 25 responses were received after analysis had begun, and are not included in these results.

[68] 90 surveys were undeliverable, mostly to vacant residences. The "net" response rate is 930/(3,750-90) = 25.4%.

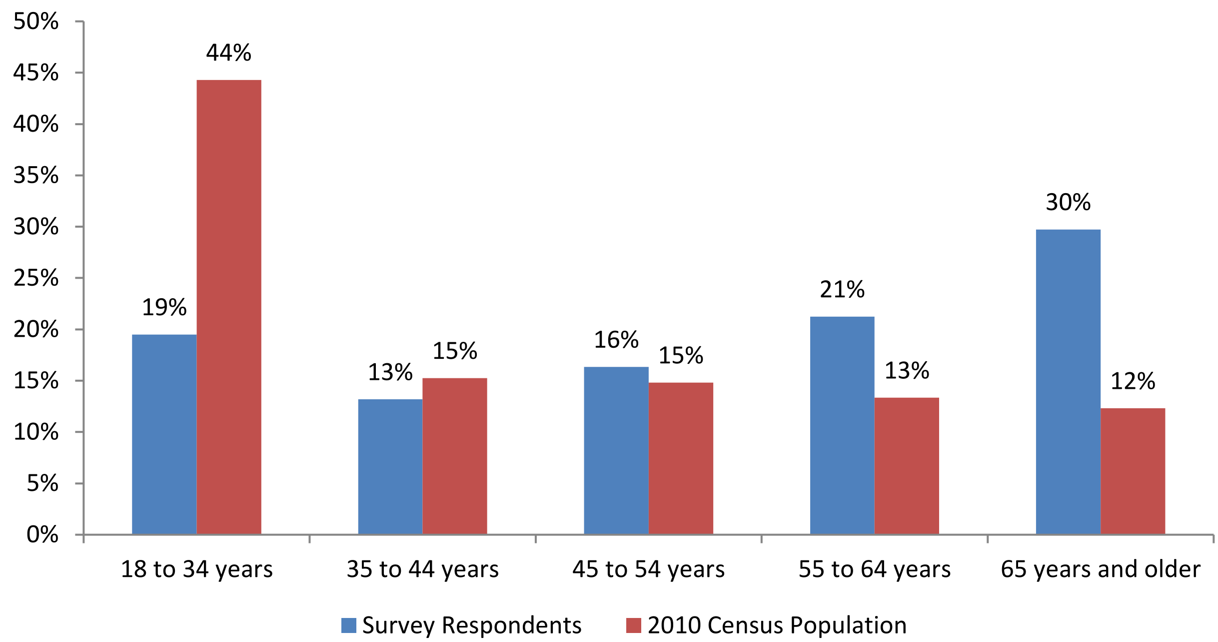
[69] Statistical Package for the Social Sciences (http://www-01.ibm.com/software/analytics/spss/)

Table 11: Age Weighting

Age Cohort	Census Population	Survey Responses**	Weight
18-34*	80,552	179	2.272
35-44	27,731	121	1.157
45-54	26,926	150	0.906
55-64	24,250	195	0.628
65+	22,383	273	0.414
Total	181,842	918	

*For Census data, the 20-34 age cohort was used since many younger adults will not live in separate households.
**Not all respondents provided their age.

Figure 13: Age of Respondents and Madison Adult Population



The following sections summarize the survey findings.

4.2 Survey Results

The results presented in this report are based on analysis of information provided by 930 sample respondents from an estimated 90,500 households in Madison. Results are representative of the set of City households with a confidence interval of ±3.2 percent at the aggregate level.

Unless otherwise indicated, the percentages reported are based on the "valid" responses from those who provided a definite answer and do not reflect individuals who said "don't know" or otherwise did not supply an answer because the question did not apply to them. Key statistically-significant results ($p \leq 0.05$) are noted where appropriate.

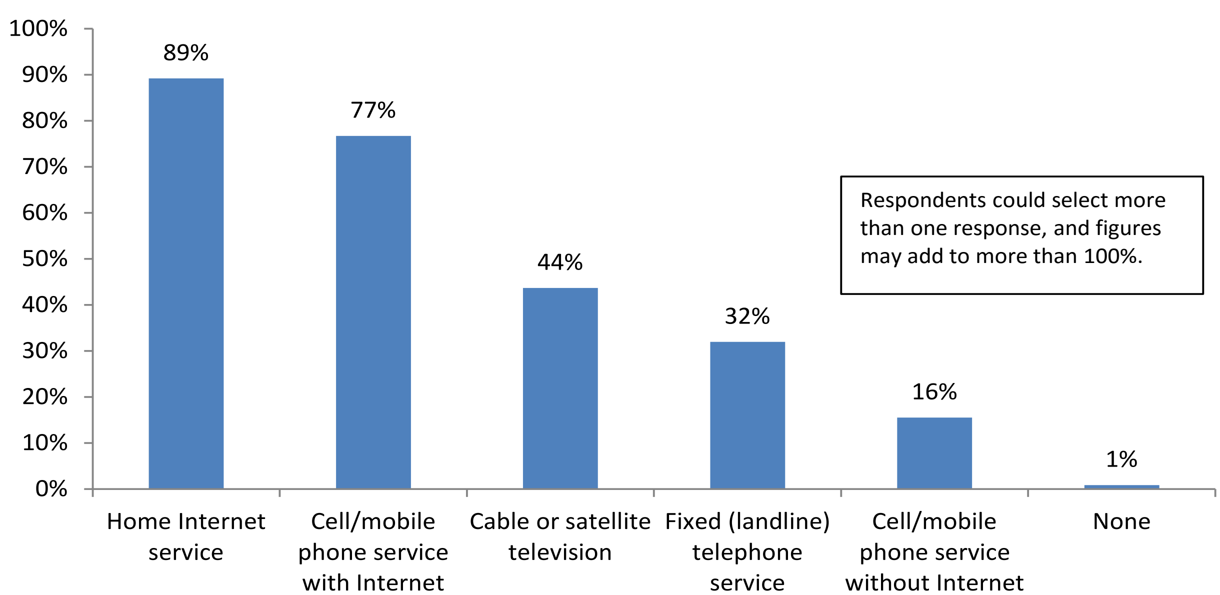
4.2.1 Home Internet Connection and Use

Respondents were asked about their home Internet connection types and providers, use of the Internet for various activities, and satisfaction and importance of features related to Internet service. This information provides valuable insight into residents' need for various Internet and related communications services.

4.2.1.1 Communications Services

Respondents provided information about the communication services currently purchased for their household. As illustrated in Figure 14, 89 percent of respondents purchase home Internet service, and 77 percent purchase cellular/mobile telephone service with Internet; 95 percent have some Internet access—either a home connection or via smartphone. Nearly one-third have fixed (landline) telephone service. Additionally, 44 percent of respondents have cable or satellite television (consistent with cable/satellite saturation reported later in the survey).

Figure 14: Communications Services Purchased



Use of communication services is correlated with the age of the respondent. In particular, those ages 65 and older are less likely to have Internet service in the home or to have cellular/mobile telephone service with Internet. They are more likely than younger respondents to have a fixed (landline) telephone service or cellular/mobile telephone service without Internet. Purchase of cable or satellite television services tends to increase with age, as shown in Figure 15.

Similarly, use of cellular/mobile telephone service with Internet and use of Internet service at home are higher for those with children ages 18 and younger at home, compared with those with no children in the household. Respondents with children at home are more likely than those without children at home to be ages 35 to 54 years of age, while those without children at home are more likely to be ages 18 to 34 years or 55 years or older (See Figure 16).

Figure 15: Services Purchased by Age of Respondent

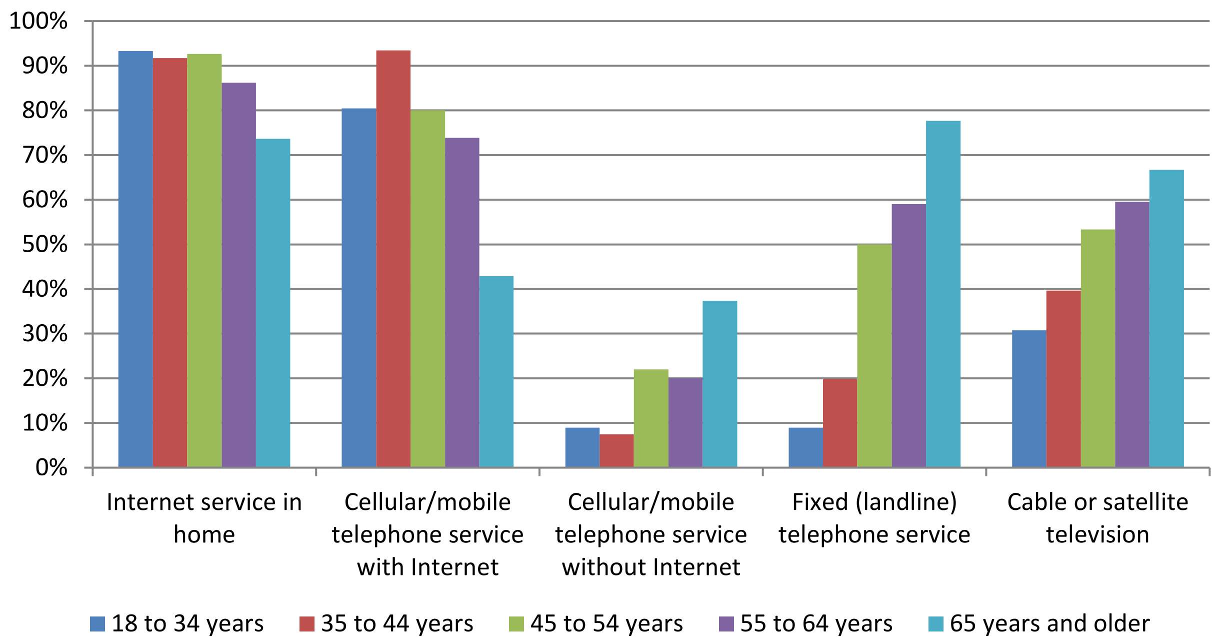
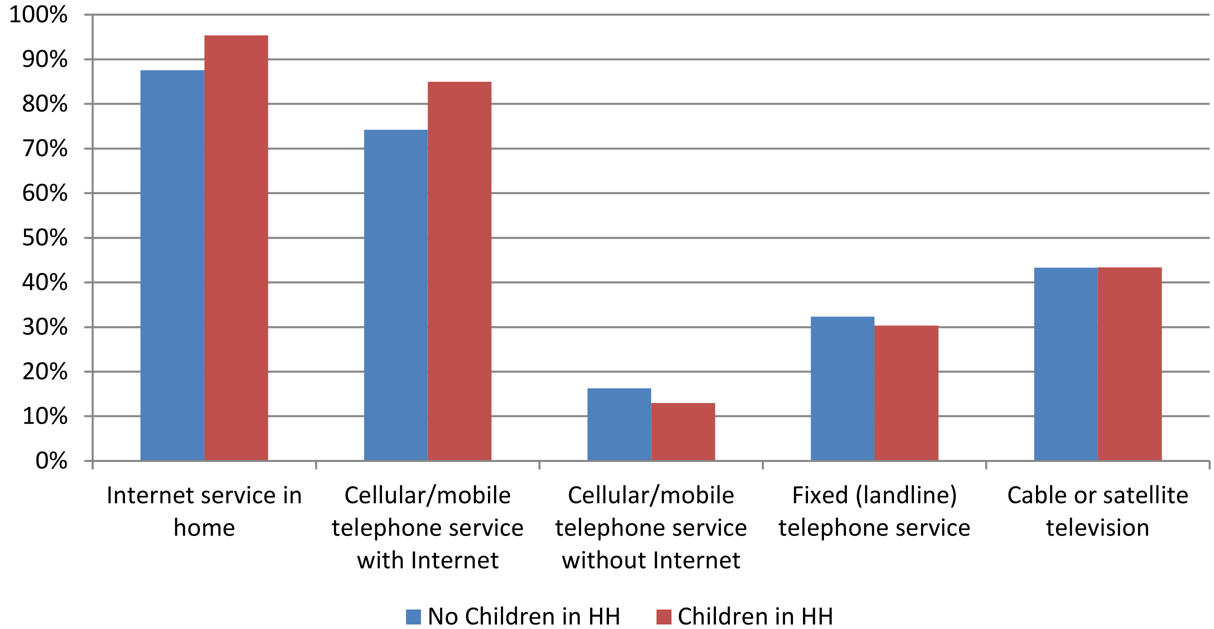
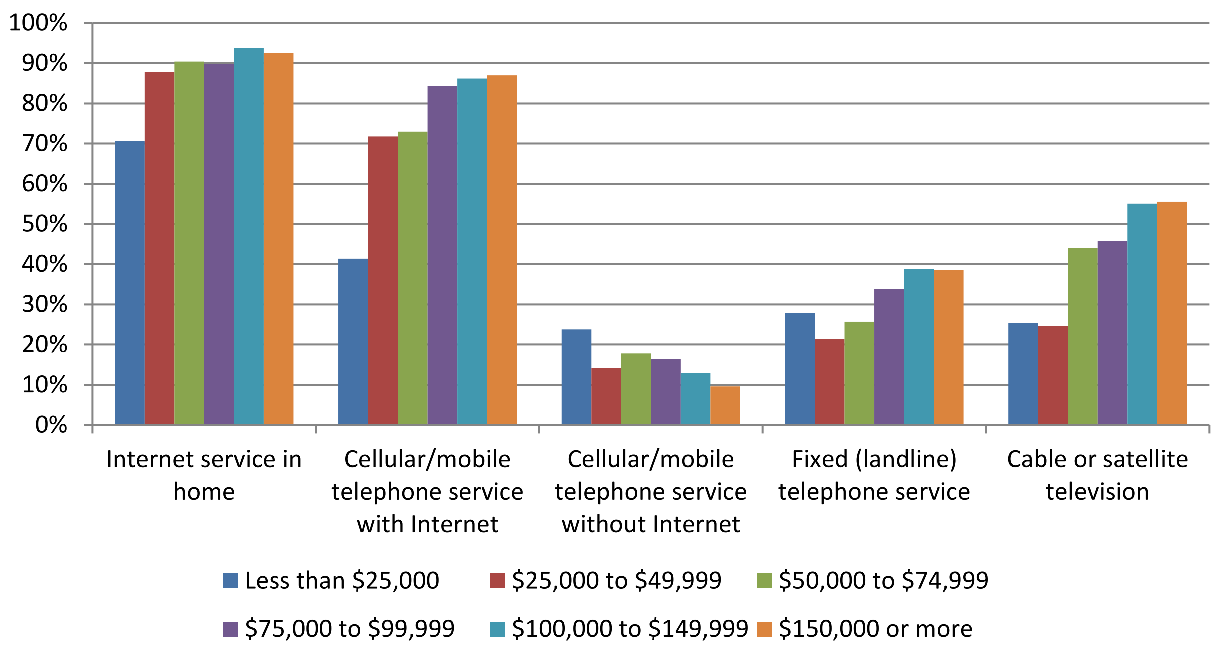


Figure 16: Services Purchased by Presence of Children in Household



The use of some communication services is also associated with household income. In particular, those earning under $25,000 per year are less likely to purchase Internet service in the home or to purchase cellular/mobile telephone service with Internet (see Figure 17).

Figure 17: Services Purchased by Household Income



As discussed previously, the majority of respondents have some Internet access, including 71 percent who have both home Internet service and a cellular/mobile telephone service with Internet (smartphone). Just 18 percent of respondents have a home connection only (no smartphone), and just 5 percent have a smartphone only (no home Internet).

When controlling for age of respondent, Internet usage is lower for households earning less than $25,000 per year for and respondents with a high school education or less. This holds true within all age groups, except for the 18 to 34 cohort for which Internet saturation is universally high.

Table 12: Internet Access by Key Demographics

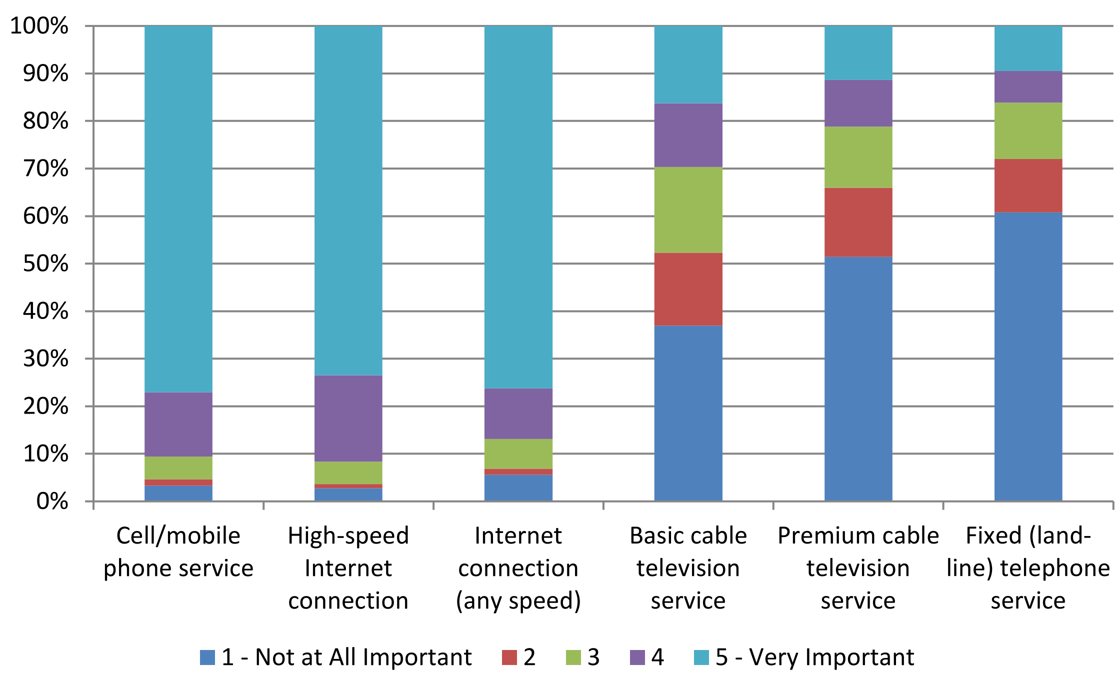
		Home Internet Connection Only	Smartphone Only	Both Home/ Smartphone	Total Internet Access	No Internet Access	*Count*
Gender	Female	20%	5%	70%	94%	**6%**	*427*
	Male	16%	6%	73%	95%	**5%**	*488*
Age Group	18 to 34 years	17%	4%	77%	97%	**3%**	*407*
	35 to 44 years	6%	7%	86%	99%	**1%**	*140*
	45 to 54 years	17%	4%	76%	97%	**3%**	*136*
	55 to 64 years	19%	7%	67%	93%	**7%**	*122*
	65 years and older	37%	7%	36%	80%	**20%**	*113*
Race/ Ethnicity	Other race/ethnicity	20%	6%	66%	93%	**7%**	*90*
	White/Caucasian only	18%	5%	72%	95%	**5%**	*814*
Education Level	HS education or less	25%	9%	47%	81%	**19%**	*80*
	Two-year college or technical degree	20%	6%	67%	94%	**6%**	*116*
	Four-year college degree	17%	4%	76%	97%	**3%**	*407*
	Graduate degree	16%	6%	74%	96%	**4%**	*314*
Household Income	Less than $25,000	35%	6%	36%	76%	**24%**	*61*
	$25,000 to $49,999	23%	7%	65%	94%	**6%**	*188*
	$50,000 to $74,999	22%	5%	68%	95%	**5%**	*174*
	$75,000 to $99,999	12%	7%	77%	97%	**3%**	*165*
	$100,000 to $149,999	10%	3%	83%	97%	**3%**	*190*
	$150,000 or more	11%	5%	82%	98%	**2%**	*111*
Number of Children in Household	No Children in HH	19%	6%	68%	93%	**7%**	*697*
	Children in HH	14%	3%	82%	99%	**1%**	*221*
Total Household Size (Adults + Children)	1	22%	6%	59%	87%	**13%**	*230*
	2	18%	5%	73%	97%	**3%**	*395*
	3	21%	8%	67%	96%	**4%**	*135*
	4 or more	8%	2%	89%	99%	**1%**	*157*
Own or Rent Residence	Own	15%	4%	76%	95%	**5%**	*596*
	Rent	23%	7%	63%	93%	**7%**	*320*
Year at Current Address	Less than 1 year	16%	5%	72%	94%	**6%**	*99*
	1 to 2 years	16%	2%	77%	95%	**5%**	*197*
	3 to 4 years	17%	8%	73%	99%	**1%**	*158*
	Five or more years	19%	6%	68%	93%	**7%**	*467*

4.2.1.2 Importance of Communication Services

Respondents were asked about the importance of various communications services to their household. Internet and cell/mobile phone services were by far the most important, with roughly three-fourths saying cell/mobile phone service, High-speed Internet service, or Internet connection of any speed are "very important," as shown in Figure 18.

Just a small segment of respondents placed moderate or high importance on basic cable television service, premium cable television service, or fixed (landline) telephone service. Although 30 percent of respondents indicated that basic cable television service is of some importance, 37 percent said it is "not at all important." Furthermore, one-half said premium cable television service is "not at all important," and six in 10 said fixed (landline) telephone service is "not at all important." As noted previously, only 32 percent of Madison homes have landline telephone service.

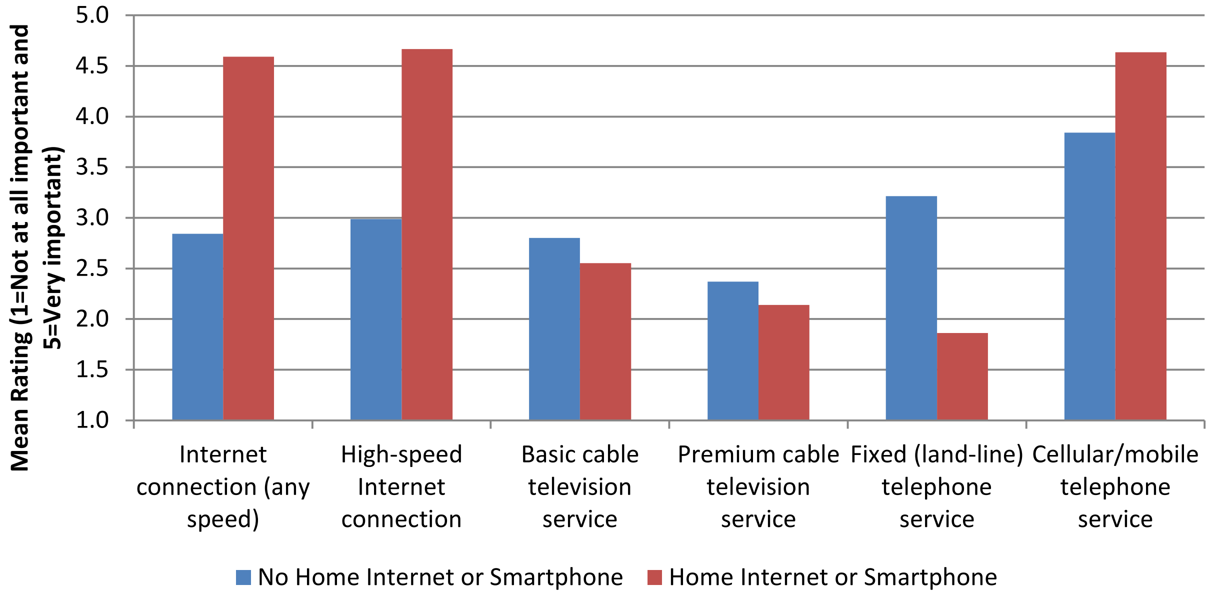
Figure 18: Importance of Communications Service Aspects



As noted previously, only a small share of respondents does not have any Internet connection in their home. Therefore, conclusions regarding this segment of respondents are generally not considered statistically significant, but rather viewed as indicative for those not having home Internet but answering questions regarding the importance of Internet and other metrics.

For households without home Internet service, the importance placed on cell/mobile telephone service, High-speed Internet service, or Internet connection of any speed is much lower than for those with some form of Internet access. Just a small segment of respondents with no Internet access said these features are "very important" (see Figure 19).

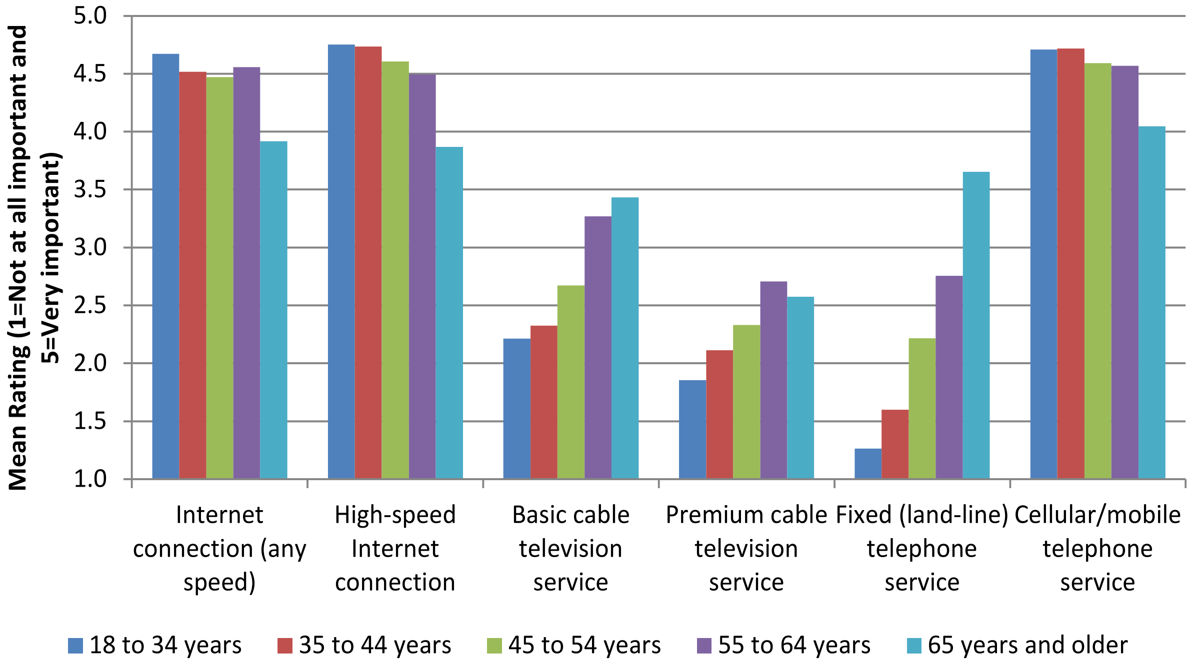
Figure 19: Importance of Communications Services by Home Internet Service



Although more than one-third (35 percent) of those without Internet said these services are "very important," this represents less than 2 percent of the total survey sample. This implies that there is not a sizeable gap between desire for Internet services and access to these services. As noted previously, those ages 65+, less-educated, and lower-income respondents are less likely to have home Internet or a smartphone. Only for the 18 to 34 age group did respondents without Internet place high importance on Internet-related services (suggesting there may be issues with access to Internet for this sub-group), but this is based on a small number of respondents and may not be statistically reliable.

Figure 20 illustrates the importance of communications services by the age of the respondent. The importance of an Internet connection and cellular telephone service is lower for those ages 65 and older. Conversely, the importance of cable television and landline telephone services tends to increase with the age of the respondent.

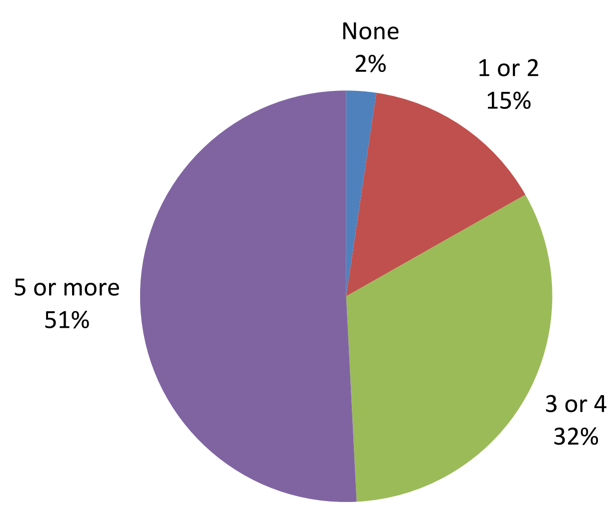
Figure 20: Importance of Communications Services by Age of Respondent



4.2.1.3 Personal Computing Devices

Respondents were asked to indicate the number of personal computing device they have in the home. As might be expected, all respondents with Internet access (either home connection or smartphone) have at least one personal computing device. Six in 10 respondents without Internet access also have a personal computing device.

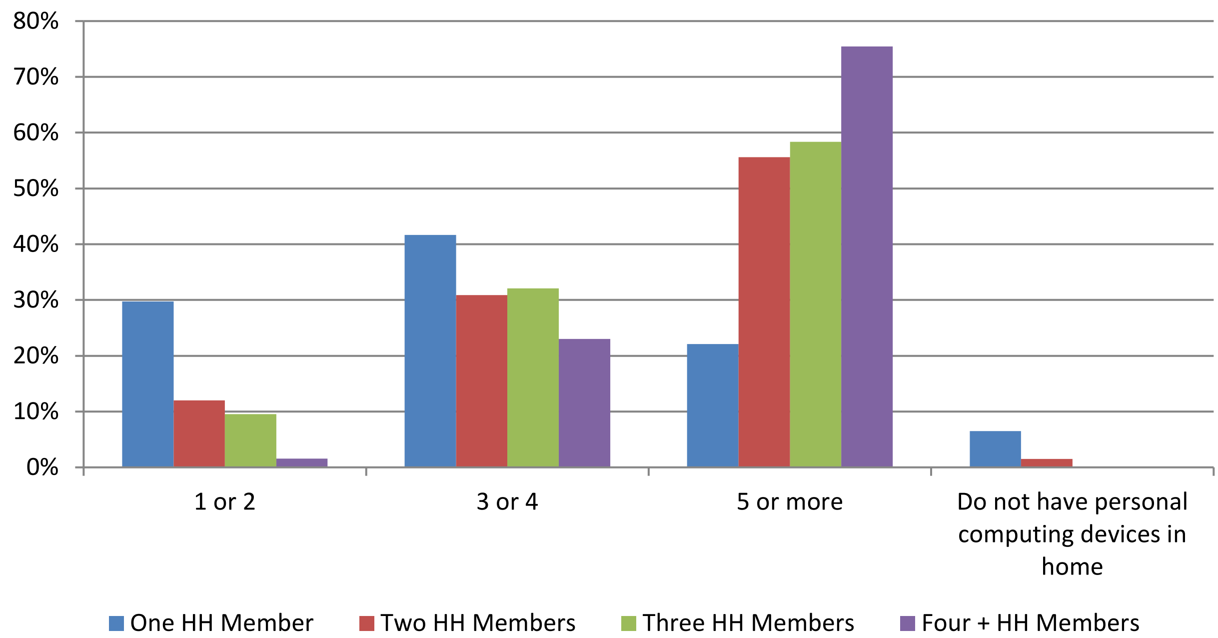
Figure 21: Number of Personal Computing Devices



One-half of respondents have five or more personal computing devices. Another 32 percent have three or four devices, and 15 percent have one or two devices (see Figure 21).

The number of personal computing devices in the home correlates with household size. Three-fourths of households with four or more residents have at least five personal computing devices (see Figure 22).

Figure 22: Number of Personal Computing Devices in Home by Household Size



Similar to respondents ages 65 and older, those with household earning under $25,000 per year, and those with a high school education or less are less likely to have home Internet or personal computing devices, although saturations are still relatively high. (See Figures 23 to 25.)

Figure 23: Have Computing Device(s) and Internet in Home by Age of Respondent

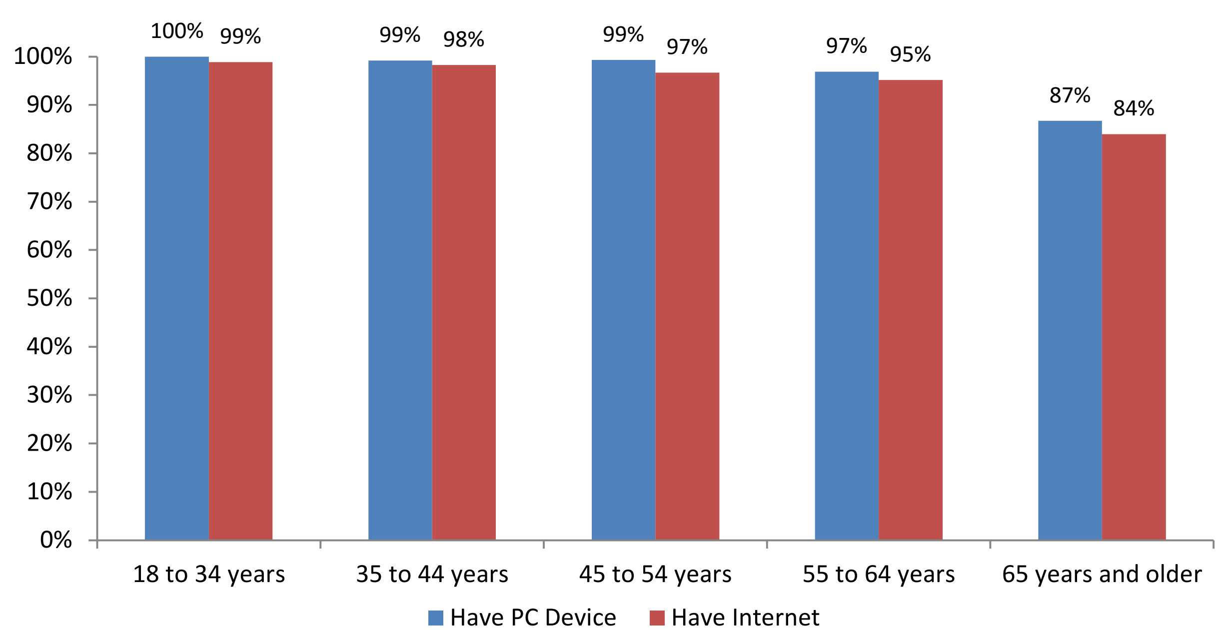


Figure 24: Have Computing Device(s) and Internet in Home by Level of Education

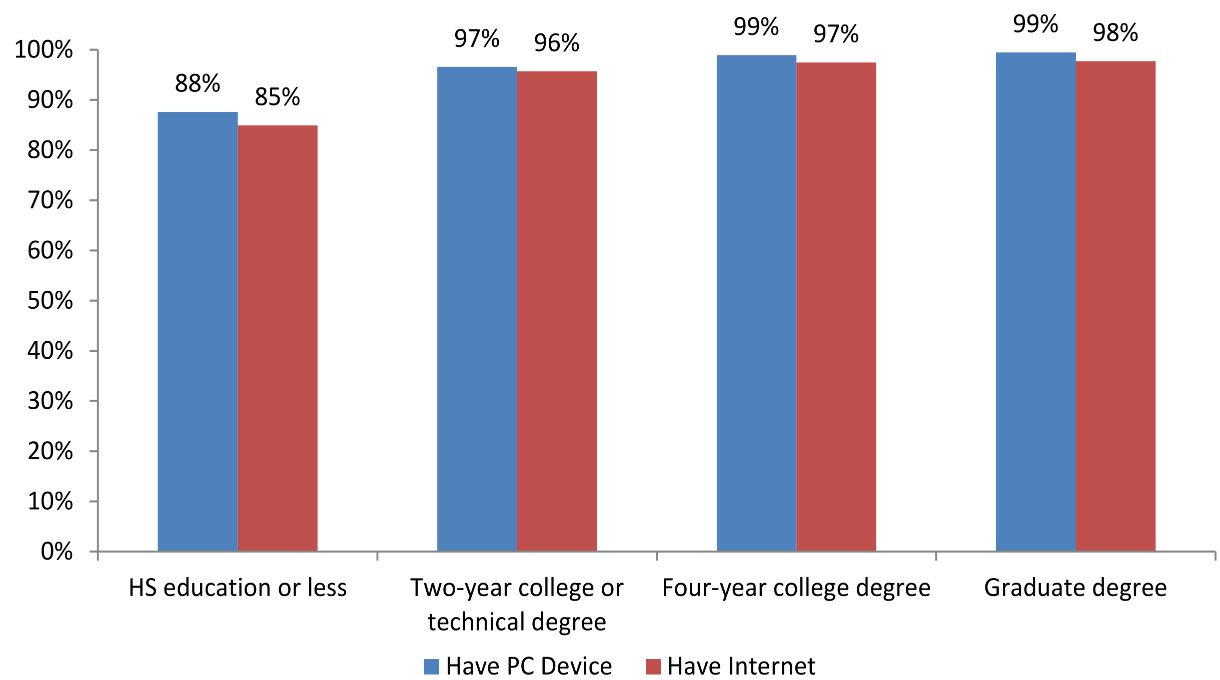
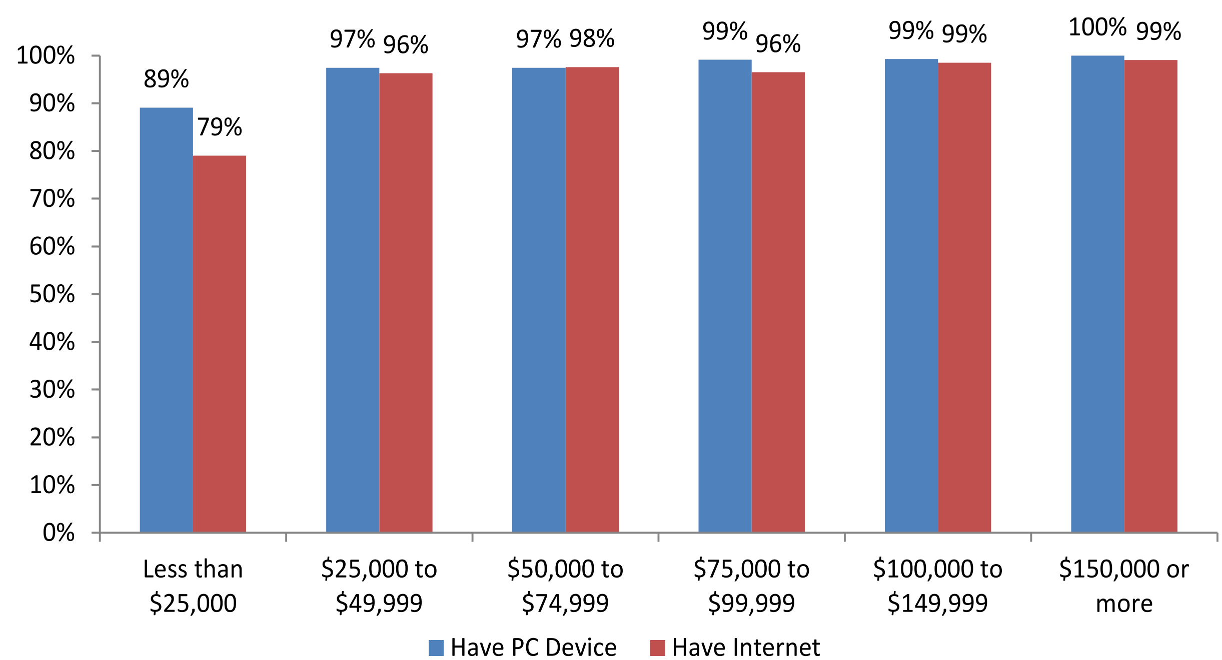


Figure 25: Have Computing Device(s) and Internet in Home by Household Income

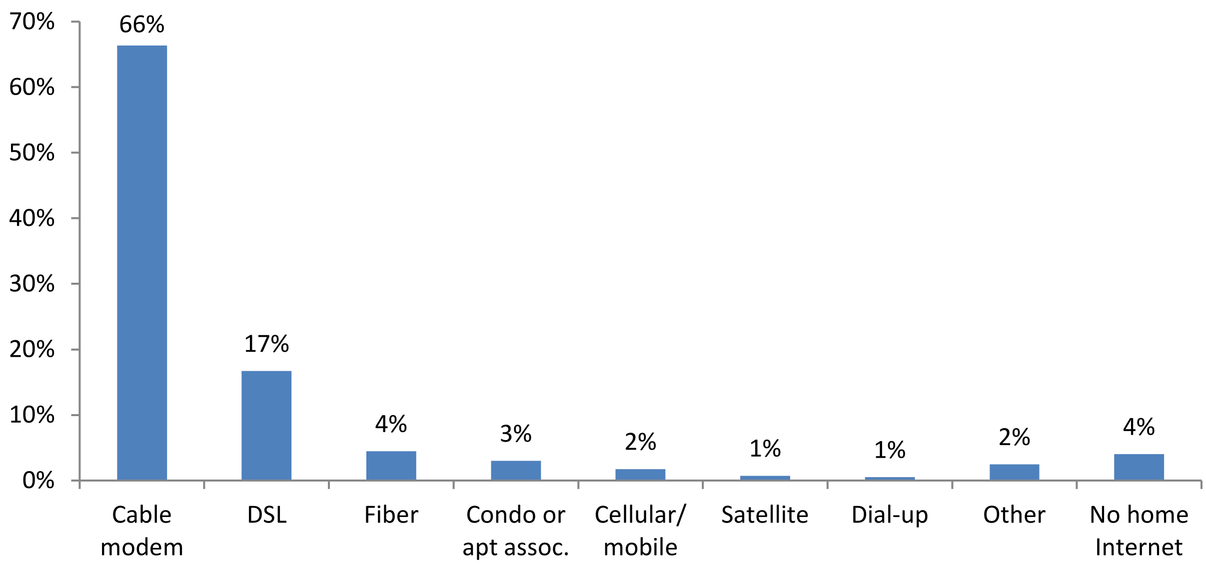


4.2.1.4 Internet Services Purchased

Respondents were asked about their purchase of Internet services for their home, as well as the cost and speed of services purchased.

As shown in Figure 26, the majority of homes (96 percent) reported having home Internet service, consistent with 95 percent reporting Internet access via a home connection or via a smartphone in Question 1. Two-thirds of respondents have a cable modem connection as their primary connection, and 17 percent have a Digital Subscriber Line (DSL). Only 2 percent indicated that they use a cellular/mobile device as their primary Internet connection.

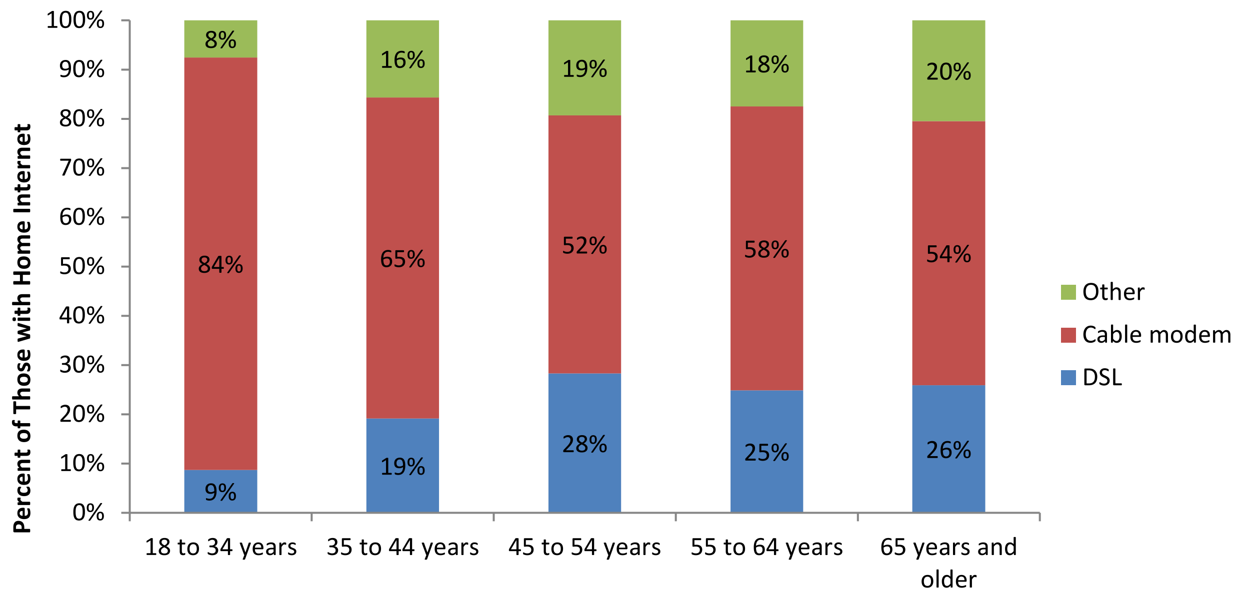
Figure 26: Primary Home Internet Service



Eighteen of 34 responding households without Internet access (and who provided a response) said that the expensive cost is the main reason for not purchasing home Internet service.

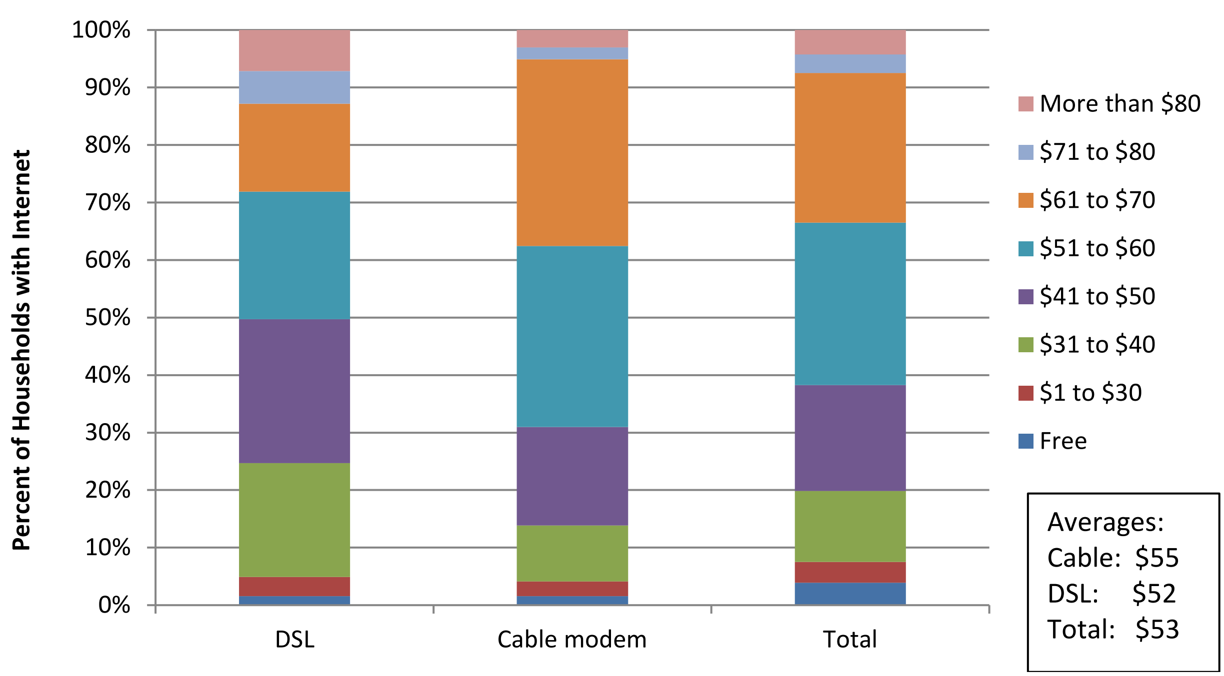
Purchase of home Internet connection or a smartphone was discussed in detail in the previous section. But, among those with home Internet, the connection type also varies significantly by age of respondent. Specifically, those ages 18 to 34 are more likely than older respondents to have a cable modem connection, and they are less likely to have DSL or another type of Internet connection, as shown in Figure 27.

Figure 27: Primary Home Internet Service by Age of Respondent



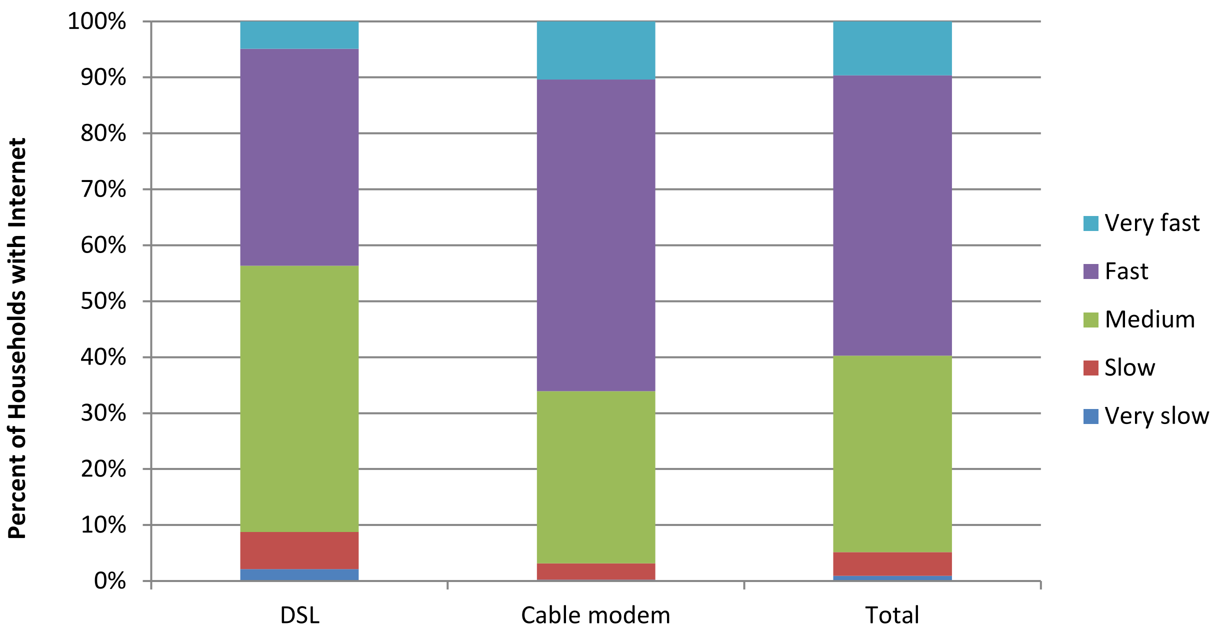
Madison households pay approximately $53 per month for Internet service, on average. The average monthly price is slightly higher for cable than for DSL, as illustrated in Figure 16. More than two-thirds (69 percent) of those with a cable modem pay more than $50 per month, compared with 50 percent of those with DSL. More than one-half of all respondents with Internet pay between $51 and $70 per month.

Figure 28: Estimated Average Monthly Price for Internet Service



Most Internet subscribers described their Internet speed as "medium" (35 percent) or "fast" (50 percent), while only 5 percent said it was "slow" or "very slow." Cable Internet subscribers tended to rate their connection speed as somewhat faster than DSL, as illustrated in Figure 29.

Figure 29: Internet Speed (Respondent Opinion)



4.2.1.5 Internet Service Aspects

Respondents were asked to rate their levels of importance and satisfaction with various Internet service aspects. Respondents rated connection reliability as the most important aspect, followed by the connection speed and price, as shown in Table 13.

Table 13: Importance of Internet Service Aspects

Service Aspect	Mean	Top-Two Box Percentages (Somewhat Important / Very Important)
Speed of Connection	4.5	30% / 62%
Reliability of Connection	4.8	9% / 89%
Price of Services	4.4	29% / 58%
Overall Customer Service	4.2	35% / 37%
Ability to Bundle with TV service	2.4	9% / 10%

Legend: Somewhat Important, Very Important; axis 0% 20% 40% 60% 80% 100%

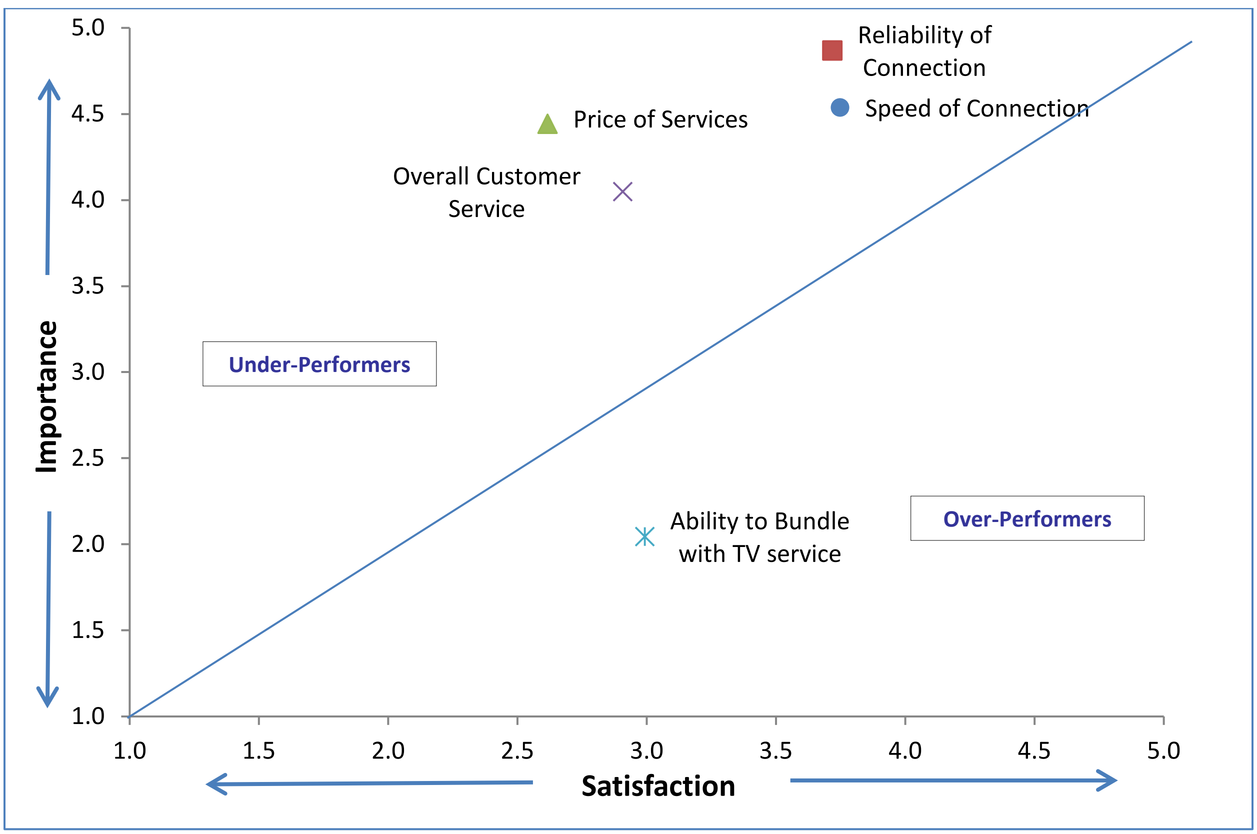
Respondents also rated the speed and reliability of their connection as the aspects with which they are most satisfied, as shown in Table 14. The lowest satisfaction aspect was for the price of service, which is typical in satisfaction surveys.

Table 14: Satisfaction with Service Aspects

Service Aspect	Mean	Top-Two Box Percentages	
Speed of Connection	3.7	45%	21%
Reliability of Connection	3.7	41%	23%
Price of Services	2.6	13%	6%
Overall Customer Service	2.9	23%	6%
Ability to Bundle with TV service	3.0	16%	12%
Somewhat Satisfied / Very Satisfied		0% 20% 40% 60% 80% 100%	

A comparison of the importance placed upon Internet service aspects and satisfaction levels provides insight into aspects that are meeting consumers' needs and aspects where satisfaction falls short of importance levels. The importance scores and performance scores were plotted to help visually determine areas in which Internet service providers are doing well and areas that might need improvement. The "upper quadrant" of this "quadrant analysis" indicates that the price, reliability, and overall customer service are the largest "underperforming" aspects (that is, they are farthest from the equilibrium line), as illustrated in Figure 30.

Figure 30: Internet Service Aspect "Quadrant" Analysis



The difference between importance and satisfaction of home Internet aspects is also presented in the "gap" analysis table below. Again, the largest gaps between importance and performance are for price, reliability, and overall customer. Note that reliability has one of the highest satisfaction rankings, but the importance of reliability is extremely high. The only aspect with higher satisfaction than importance is the ability to bundle Internet with TV service.

Table 15: Internet Service Aspect "Gap" Analysis

	Mean Satisfaction	Mean Importance	GAP < = >	Customer Expectations
Ability to Bundle with TV service	3.0	2.0	0.9	Exceeded
Speed of Connection	3.7	4.5	-0.8	Not Met
Overall Customer Service	2.9	4.0	-1.1	Not Met
Reliability of Connection	3.7	4.9	-1.2	Not Met
Price of Services	2.6	4.4	-1.8	Not Met

4.2.1.6 Willingness to Pay for Faster Internet

Respondents were asked if they would be willing to switch to very fast Internet service (1 Gbps) for various price levels. The mean willingness to switch across this array of questions is illustrated in Figure 31, while detailed responses are illustrated in Figure 32.

Figure 31: Mean Willingness to Switch to 1 Gbps Internet at Price Levels

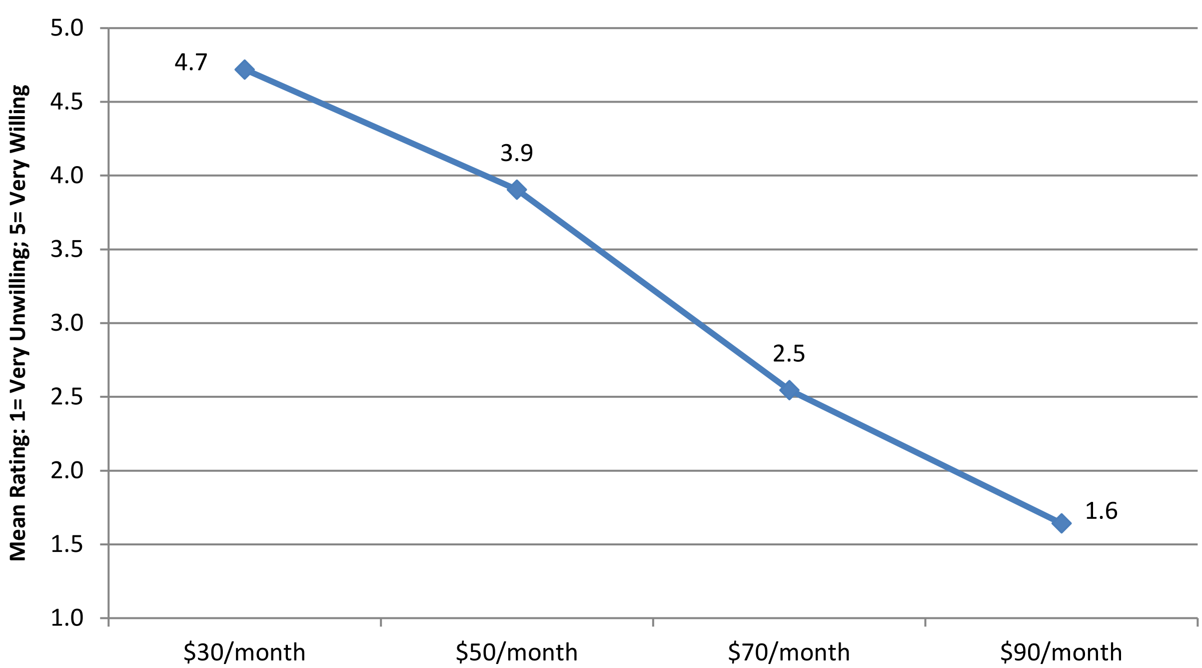
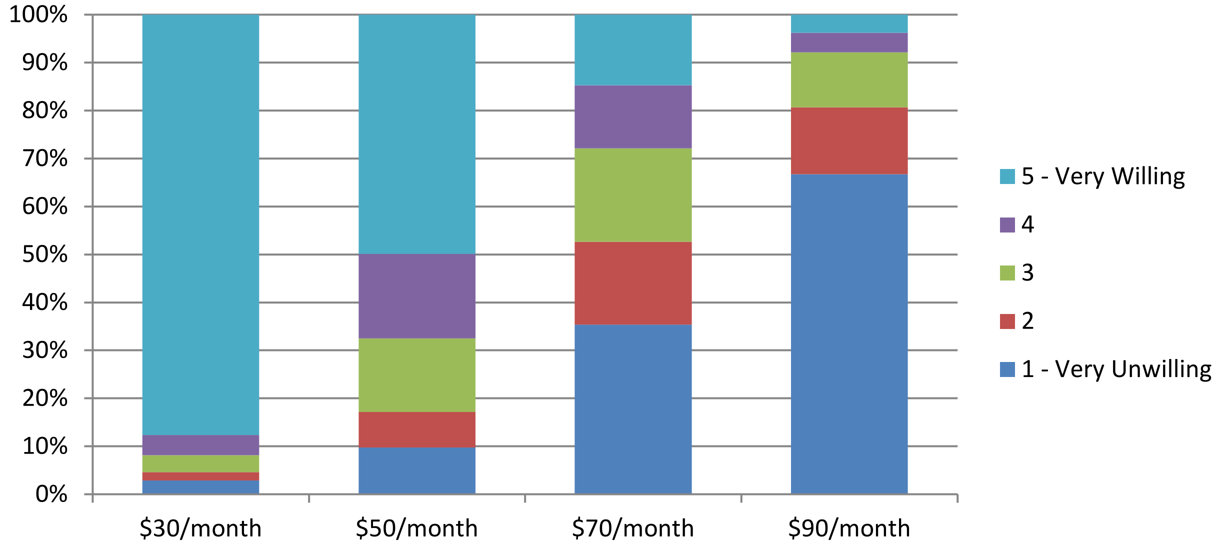
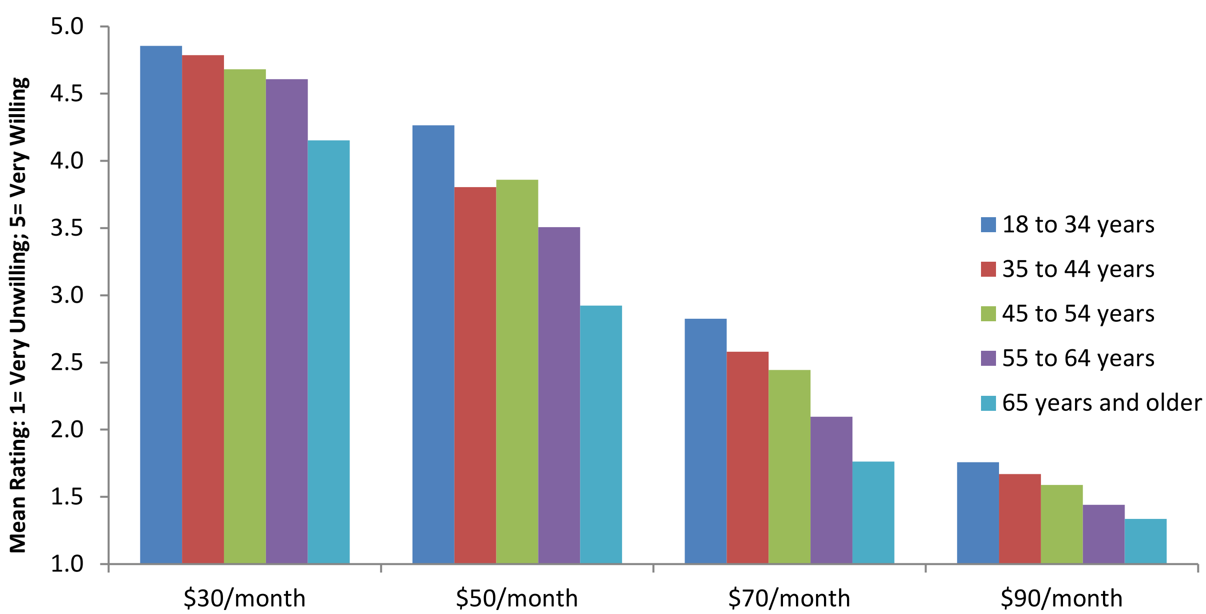


Figure 32: Willingness to Switch to 1 Gbps Internet at Various Price Levels



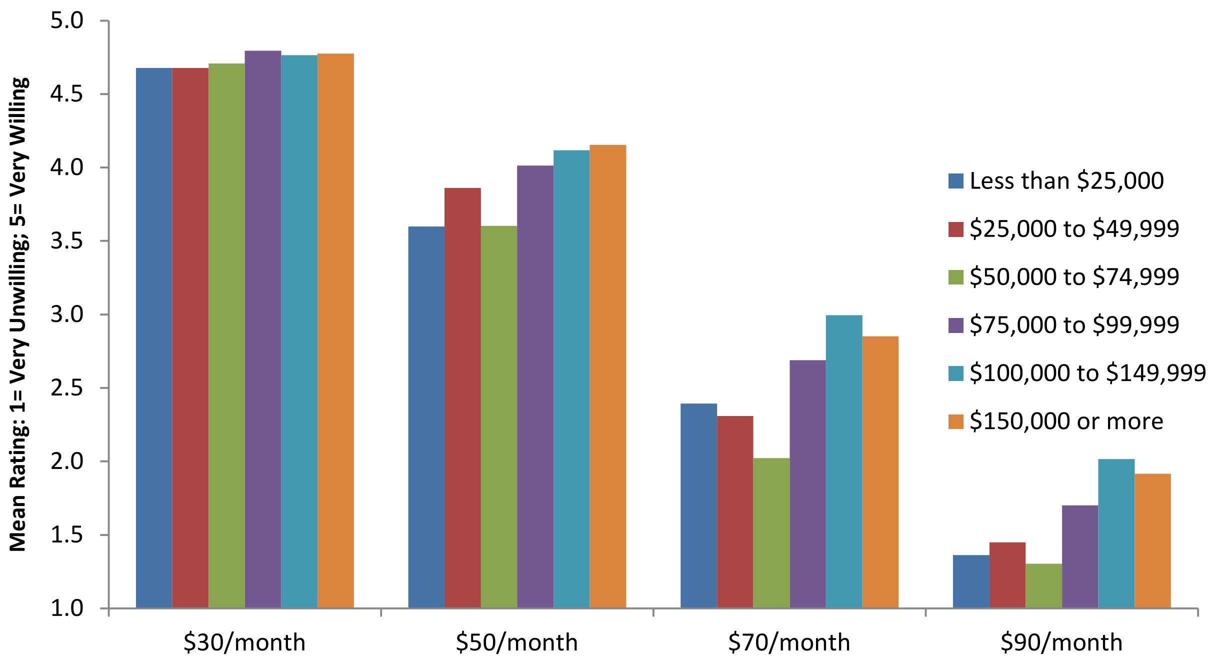
As is evident in Figure 31 and in Figure 32, respondents' willingness to switch to very fast Internet service (defined at 1 Gbps service in the survey) is very high at $30 per month, but drops considerably as the price increases. At a price of approximately $70 per month, the mean rating falls below 3.0 (neither willing nor unwilling). From another perspective, 92 percent are somewhat or very willing to switch to 1 Gbps Internet for $30 per month, dropping to 68 percent at $50 per month, 28 percent at $70 per month, and 8 percent at $90 per month.

Figure 33: Willingness to Switch to 1 Gbps Internet by Age of Respondent



The willingness to switch to very fast Internet service tends to decrease as age increases, and it increases as household income increases (particularly at the higher price points).

Figure 34: Willingness to Switch to 1 Gbps Internet by Price and Household Income



4.2.1.7 Internet Uses and Importance

Respondents were asked about their use of the Internet for various activities, as illustrated in Figure 35. The most common use of the Internet (among those listed) is watching movies, videos, or TV. Nearly three-fourths (72 percent) frequently use the Internet for this purpose. Approximately one-half frequently use the Internet for shopping online, listening to music, or connecting to a work computer. Use of the Internet for running a home business or playing online games is less frequent. Seven in 10 occasionally use the Internet to access City of Madison information or services; just 9 percent access the site frequently.

The use of the Internet for some activities varies by age, as illustrated in Figure 35. Younger respondents are much more likely to use the Internet for many applications, especially listening to music and watching videos or movies. With the exception of accessing the City of Madison website, Internet subscribers ages 65+ are less likely to ever use the Internet for the various activities evaluated.

Figure 35: Home Internet Activities

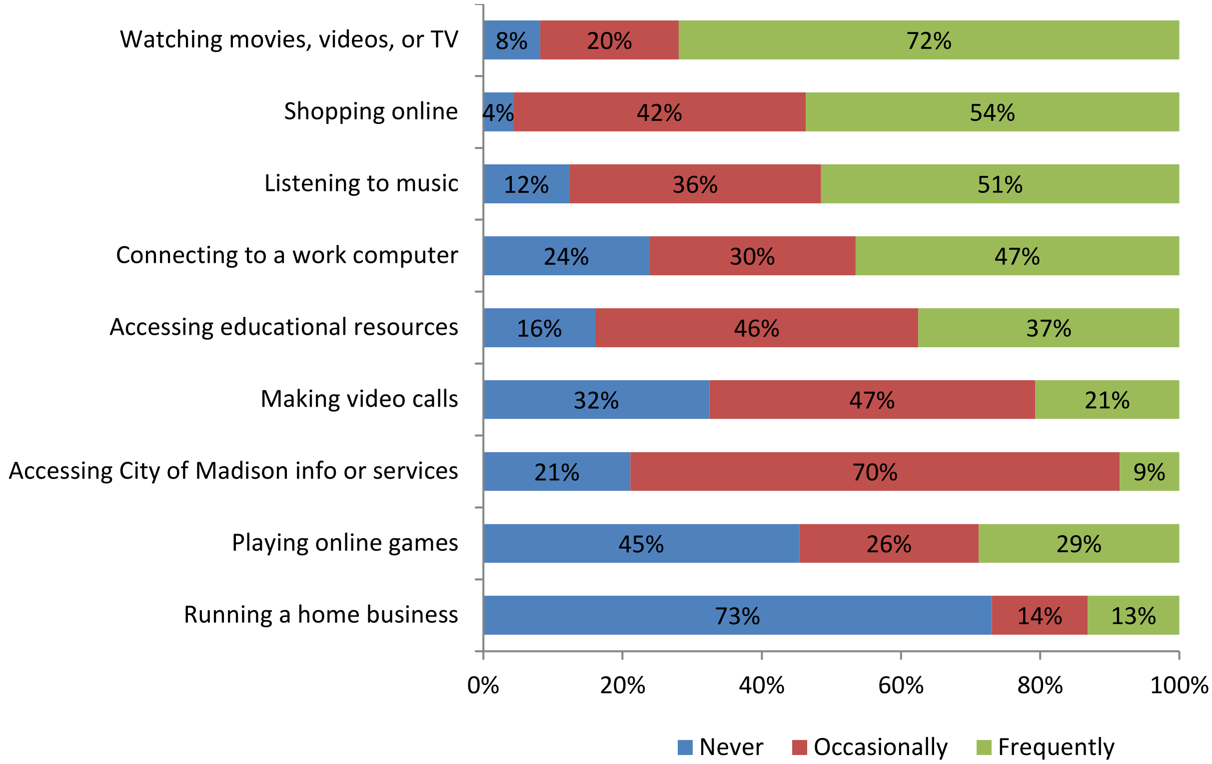
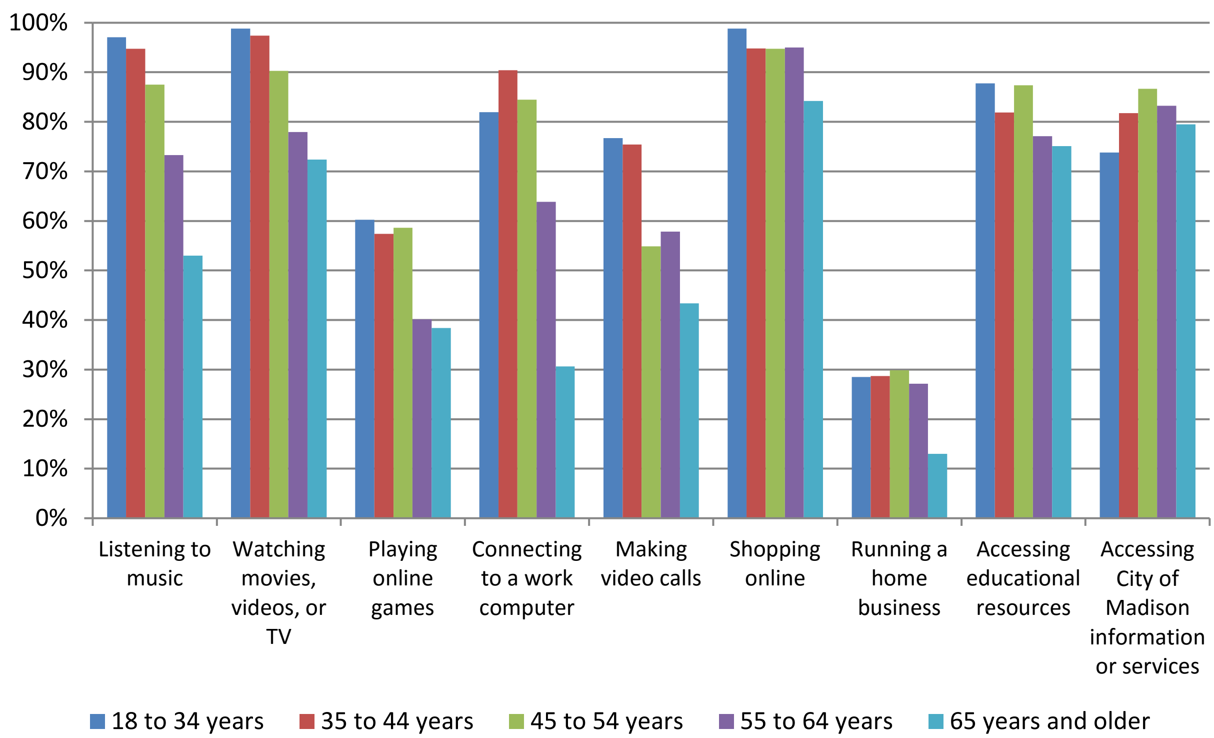


Figure 36: Home Internet Activity by Age of Respondent (Percent Ever Using)



Respondents were asked to rate the importance of aspects when selecting a home Internet provider. The most important aspect is the service provider not placing "caps" on total data use. Six in 10 respondents with Internet said this aspect is "very important." One-half said that buying Internet service with very high connection speeds is "very important." The least important aspect of home Internet service is paying for service based on usage. Just one-fourth of respondents gave this aspect a rating of "4" or "5" (see Figure 37).

Figure 37: Importance of Aspects When Selecting a Home Internet Provider

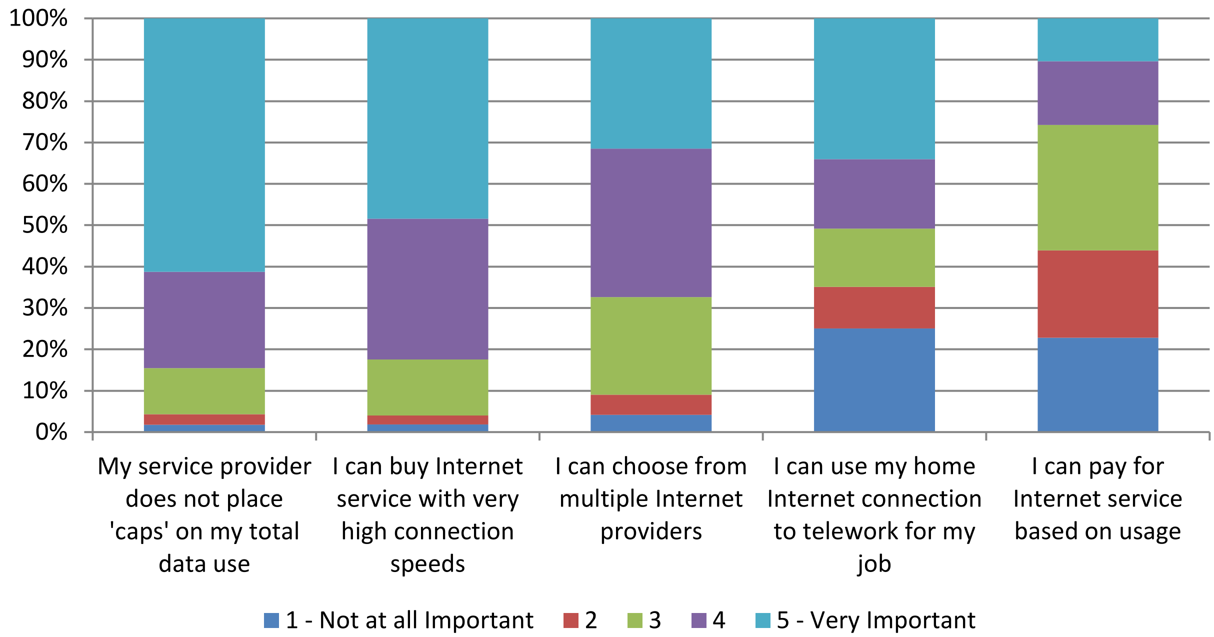
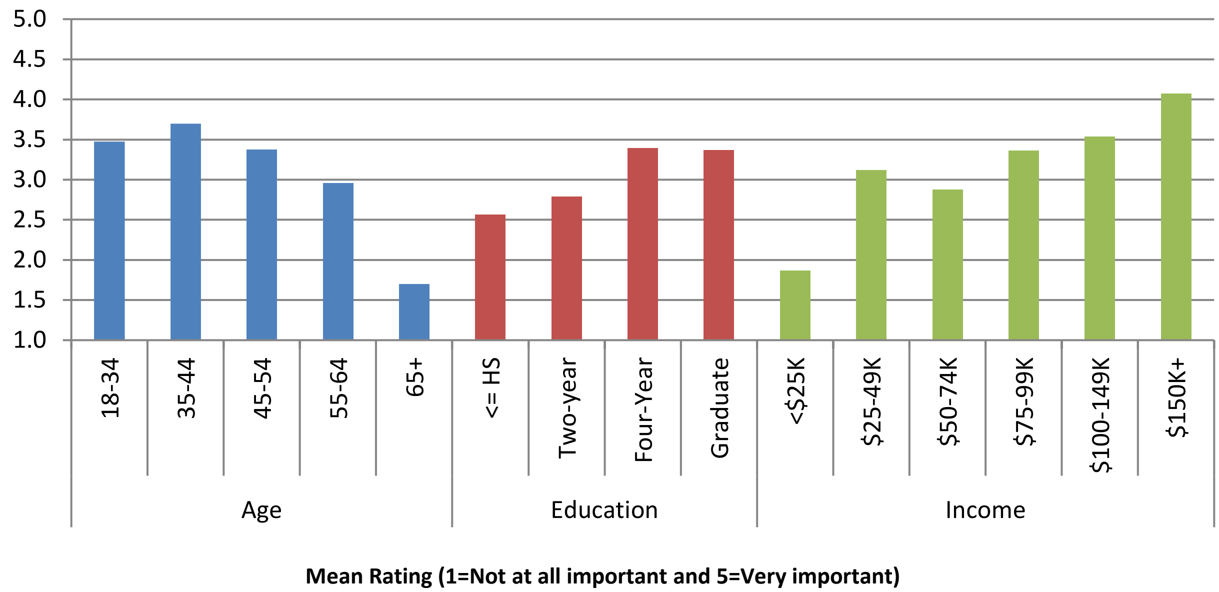


Figure 38: Importance of Home Internet Service to Telework by Demographics



The importance of using a home Internet connection to telework varies by key demographic groups. As might be expected, those ages 65 and older (who are more likely to be retired) gave a lower mean rating to this aspect. The average importance rating also increases as household income increases, and those with at least a four-year college degree placed more importance on this aspect than did those with less education, as illustrated in Figure 38.

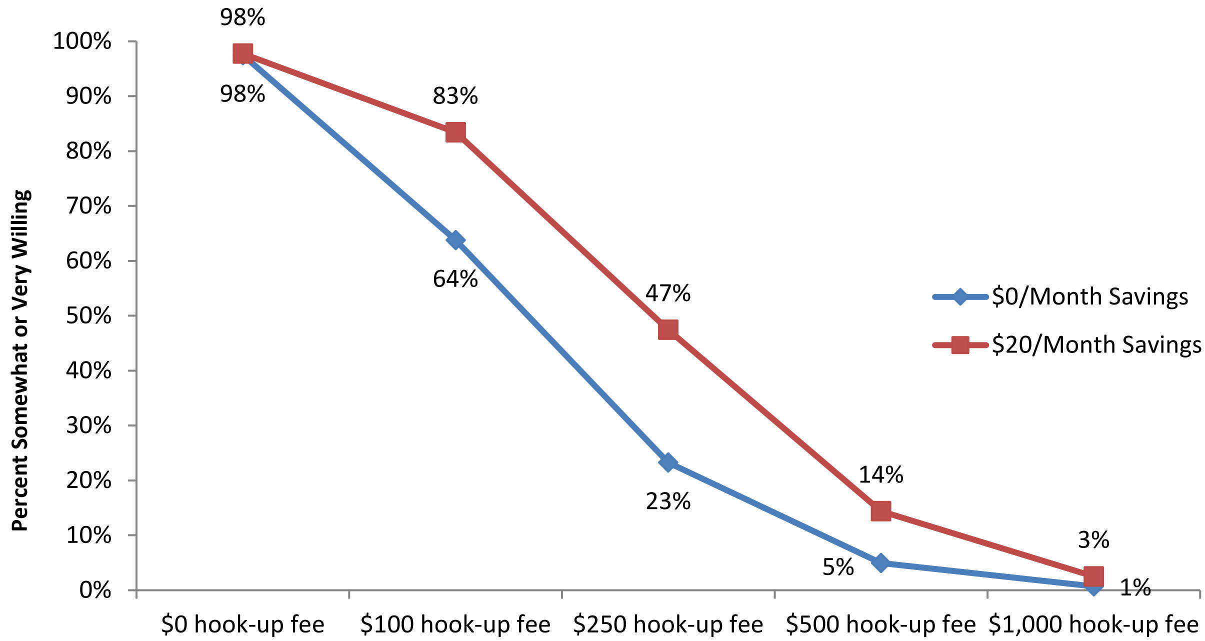
4.2.1.8 Willingness to Pay Hook-Up Fee for Fiber-Optic Network

Respondents were asked if they would be willing to pay an upfront hook-up fee to connect to a fiber-optic communications network with very fast Internet (1 Gbps) for: no savings per month and for $20 savings per month on their communications bill. Almost all respondents would be very willing to switch to the network (for $0 savings and for $20 savings) for no hook-up fee. Additionally, they would be more willing to pay the fee for some savings on their monthly communications bill. Respondents are somewhat willing to pay a $100 hook-up fee, particularly for $20 per month savings, but willingness to pay a hook-up fee falls sharply at higher price points, as shown in Figure 39.

Figure 39: Average Willingness to Pay Upfront Hook-Up Fee for Fiber Optic Network

Almost all respondents (98 percent) are somewhat or very willing to pay no fee to connect to the network. The majority would pay a $100 hook-up fee for no savings (64 percent) or a $20 savings per month (83 percent). Although nearly one-half would be at least somewhat willing to pay a $250 hook-up fee for a $20 per month savings, this falls to 23 percent if there were no monthly savings on their bill, as illustrated in Figure 40.

Figure 40: Willingness to Pay Upfront Hook-Up Fee for Fiber Optic Network



The willingness to pay an upfront hook-up fee tends to increase as household income increases, for either no monthly savings or for a $20 per month savings (see Figure 41 and Figure 42).

Figure 41: Willingness to Pay Upfront Hook-Up Fee by Household Income

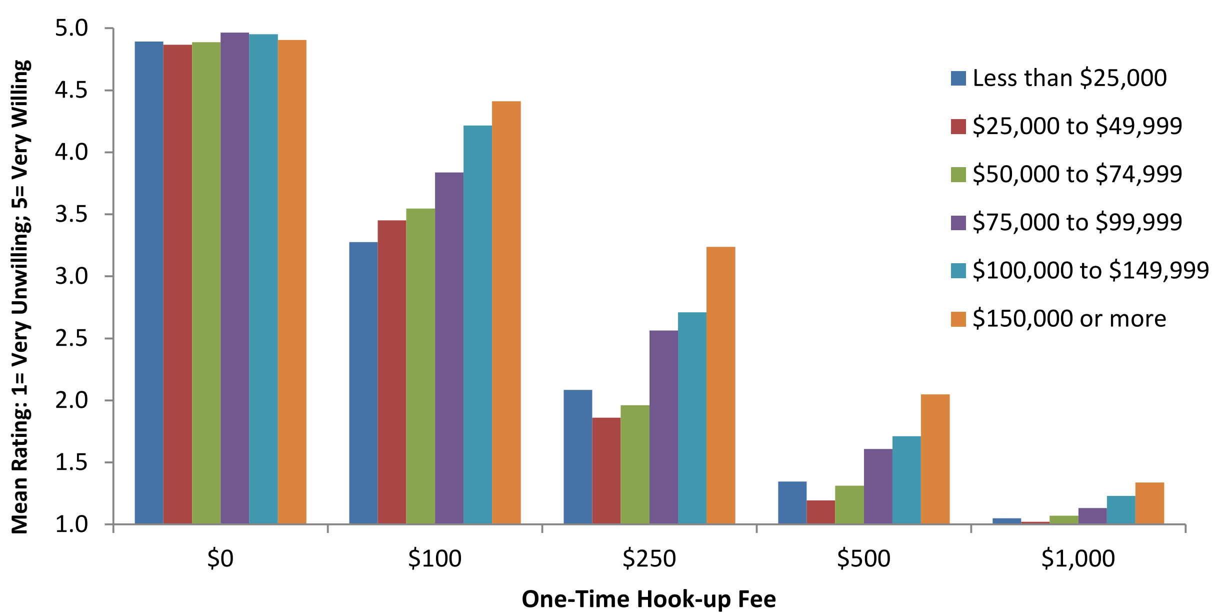
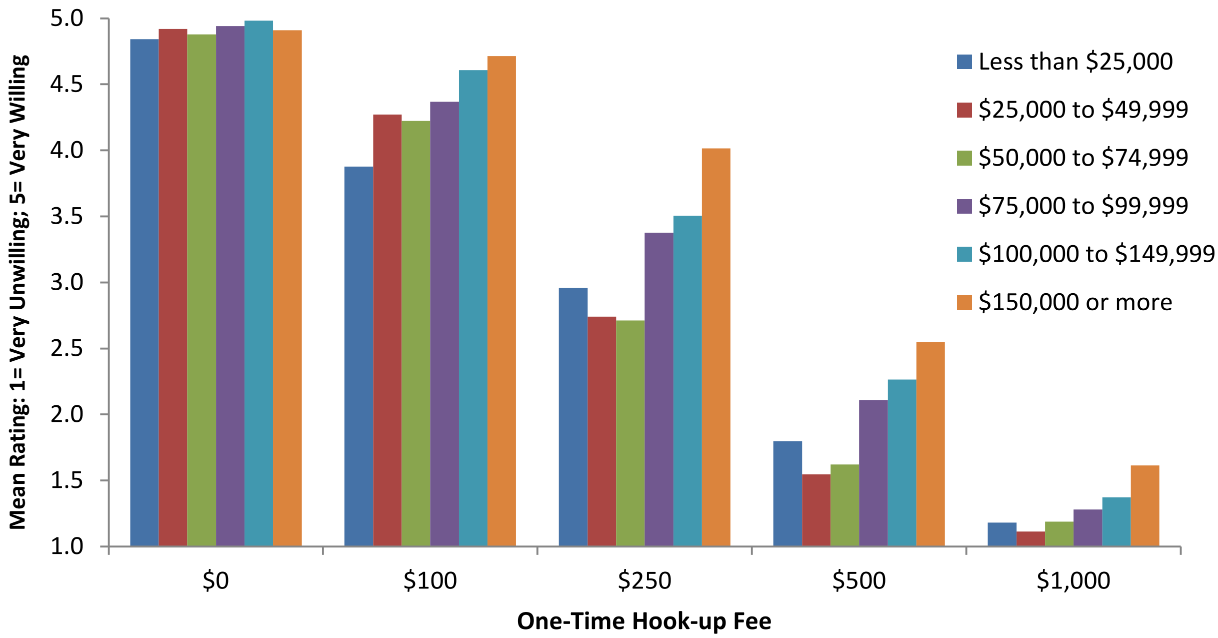


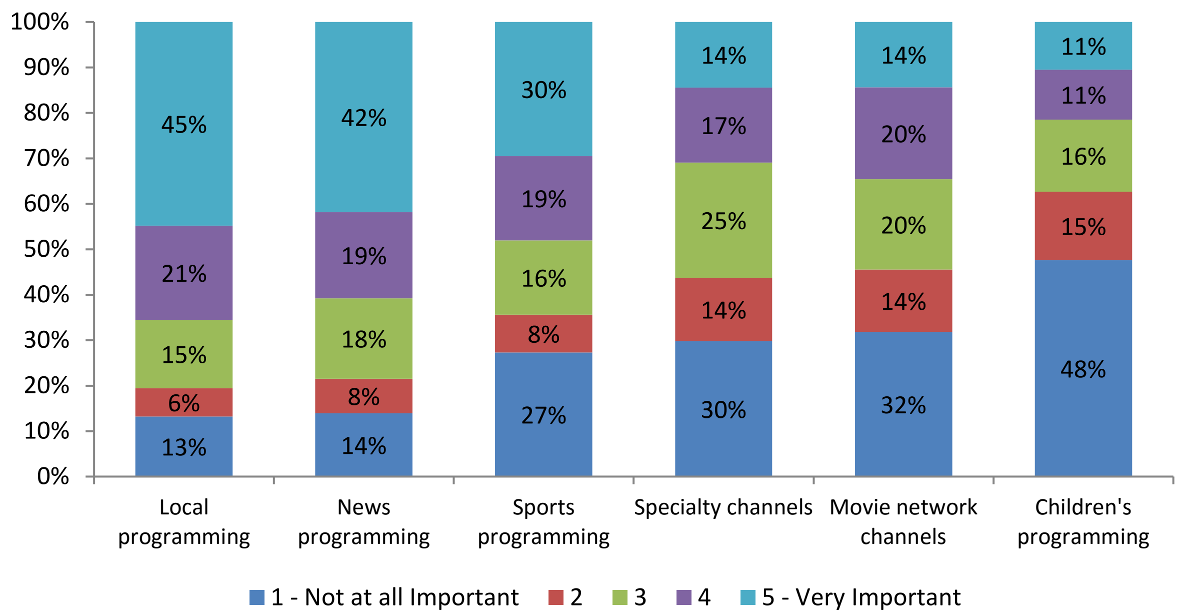
Figure 42: Willingness to Pay Upfront Hook-Up Fee for $20/Month Savings by Income



4.2.2 Television and Telephone Service

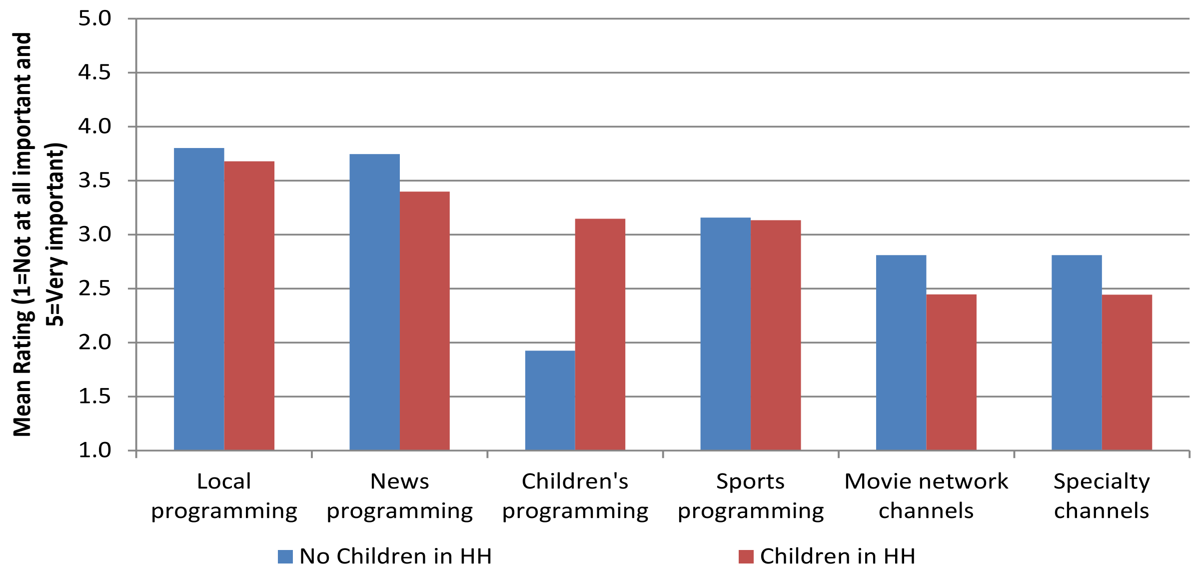
Respondents were asked to evaluate the importance of television programming features, as well as what television and telephone services they receive at home. The most important television programming aspects are local programming and news programming, while the least important is children's programming, as illustrated in Figure 43.

Figure 43: Importance of Television Programming Features



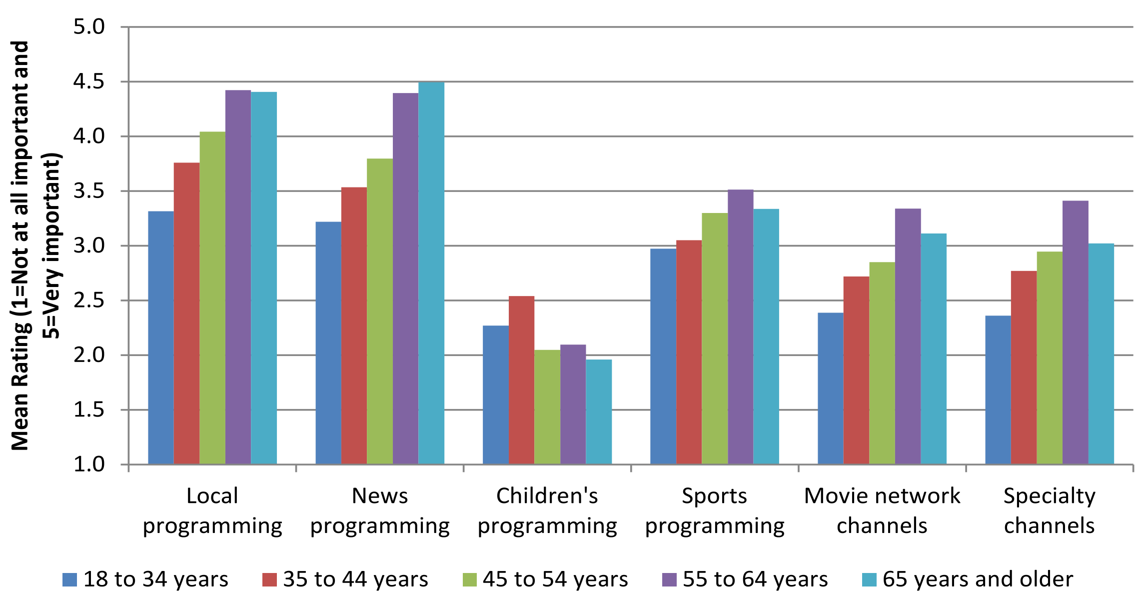
Specifically, about six in 10 gave a rating of "somewhat" or "very important" to local programming and news programming. Nearly one-half (48 percent) of respondents said that children's programming is "not at all important." Although those with children at home gave a higher importance rating to this aspect than did those without children in the household, it is still of only moderate importance overall, as shown in Figure 44.

Figure 44: Importance of Television Programming Aspects by Children in Household



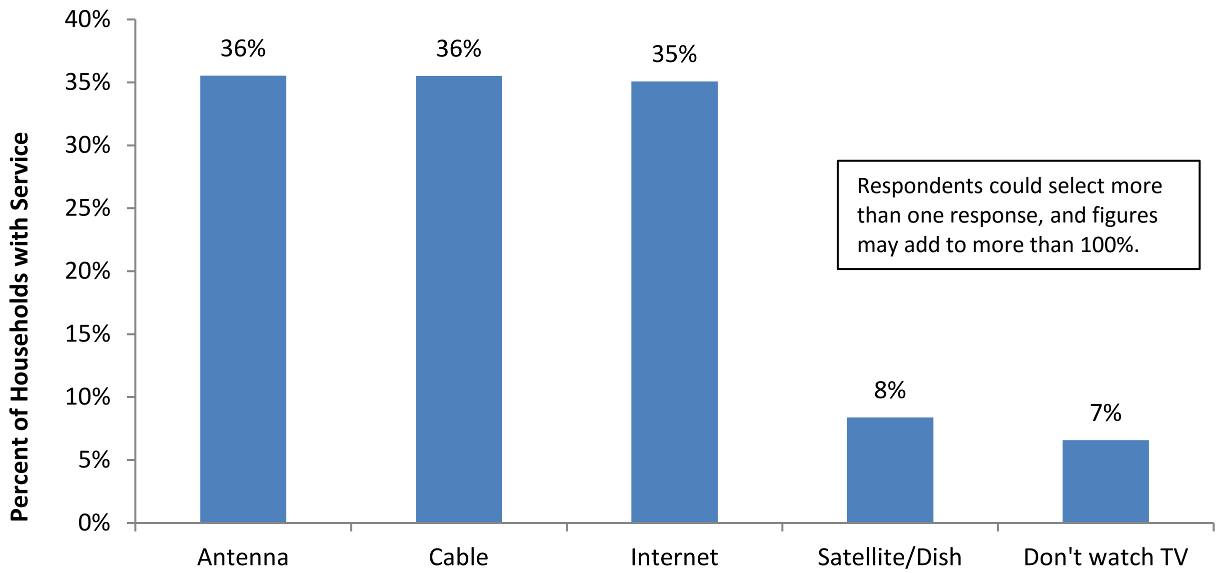
Additionally, the importance placed on local programming and news programming is higher for those ages 65 and older, compared with younger respondents (see Figure 45).

Figure 45: Importance of Television Programming Aspects by Age of Respondent



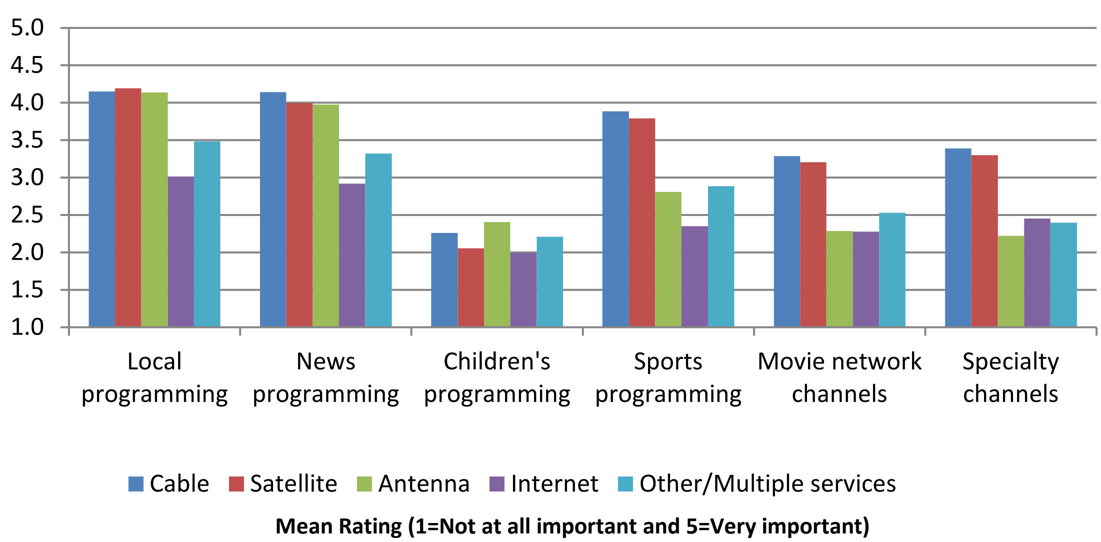
Equal shares of respondents have antenna (over-the-air) television service, cable television, or television service through the Internet. Just 8 percent have satellite/dish, and 7 percent do not watch television (see Figure 46).

Figure 46: Types of Television Service in Home



More than one-fourth of respondents have cable television service only, 20 percent have antenna only, 15 percent use the Internet only, and 7 percent have satellite TV service only. Another 28 percent use more than one type of television service, mainly antenna and Internet. Those who use the Internet as their primary television service placed less importance on key programming features, such as local programming and news programming (see Figure 47).

Figure 47: Importance of Television Programming Features by Types of Television Service



Subscription to television services varies significantly by key demographics. Specifically, those under age 45 are less likely than older respondents to have cable television but are more likely to use the Internet. Similarly, renters (of whom 72 percent are ages 18 to 34) are less likely than homeowners to have cable or satellite television, and they are more likely to use the Internet or not watch TV (see Figure 48 and Figure 49).

Figure 48: Types of Television Service in Home by Age of Respondent

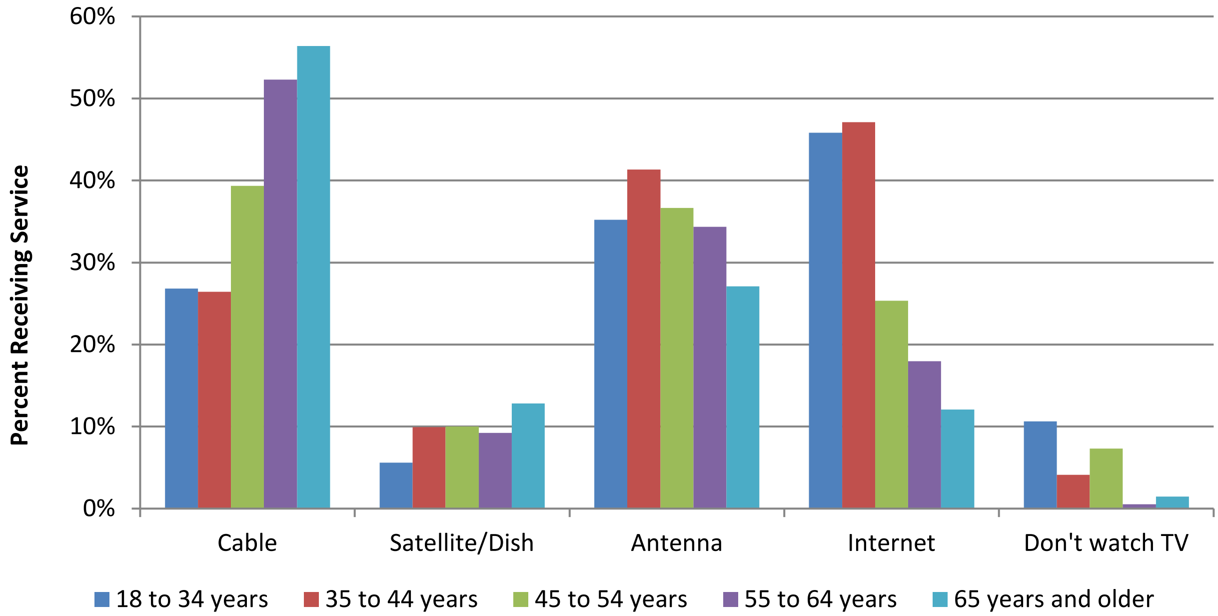
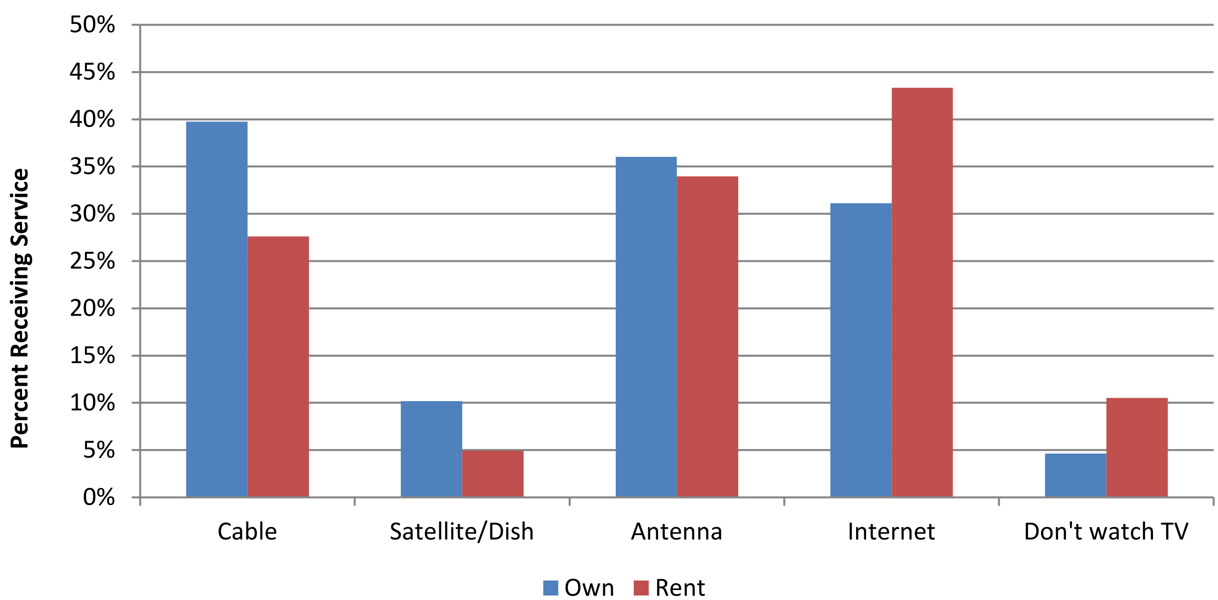
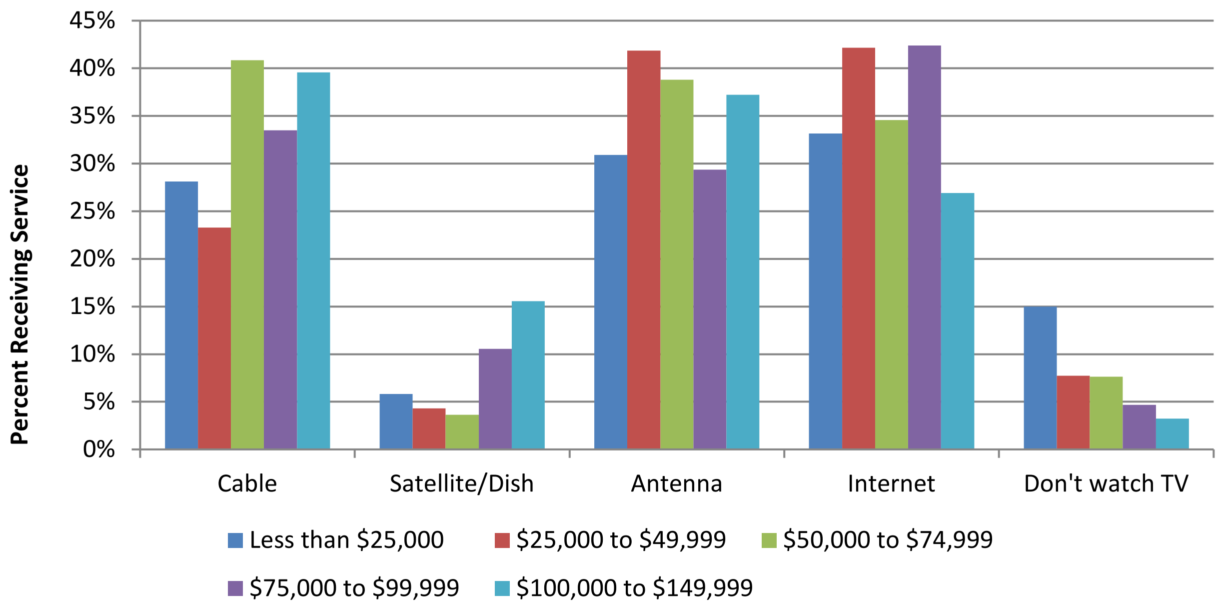


Figure 49: Types of Television Service in Home by Home Ownership



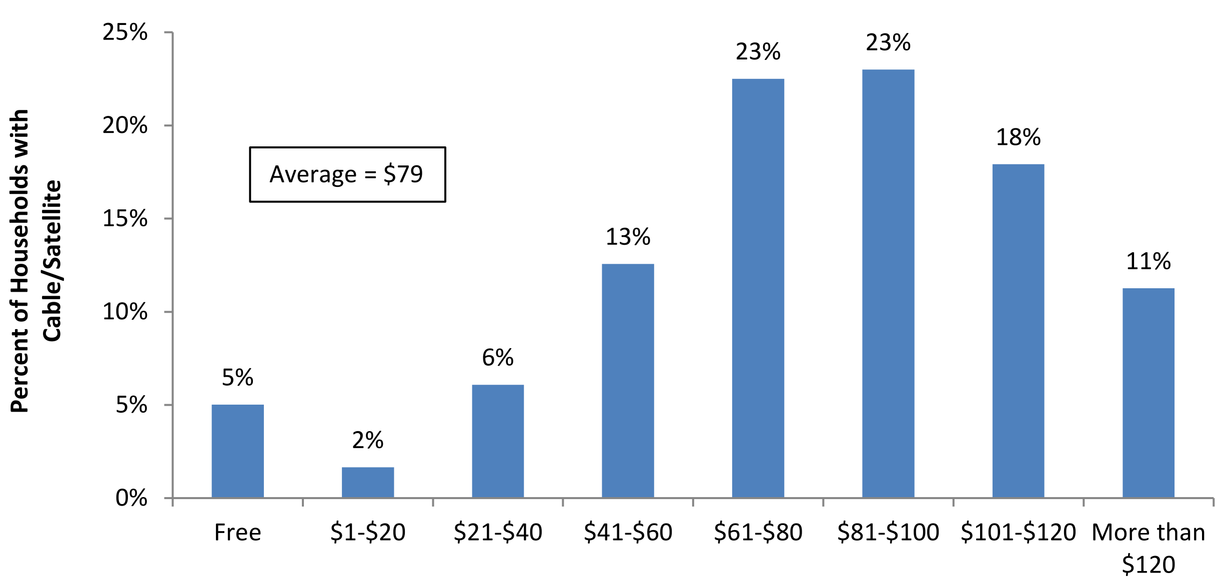
Additionally, respondents earning less than $50,000 were less likely to reporting having cable television (see Figure 50).

Figure 50: Types of Television Service in Home by Household Income



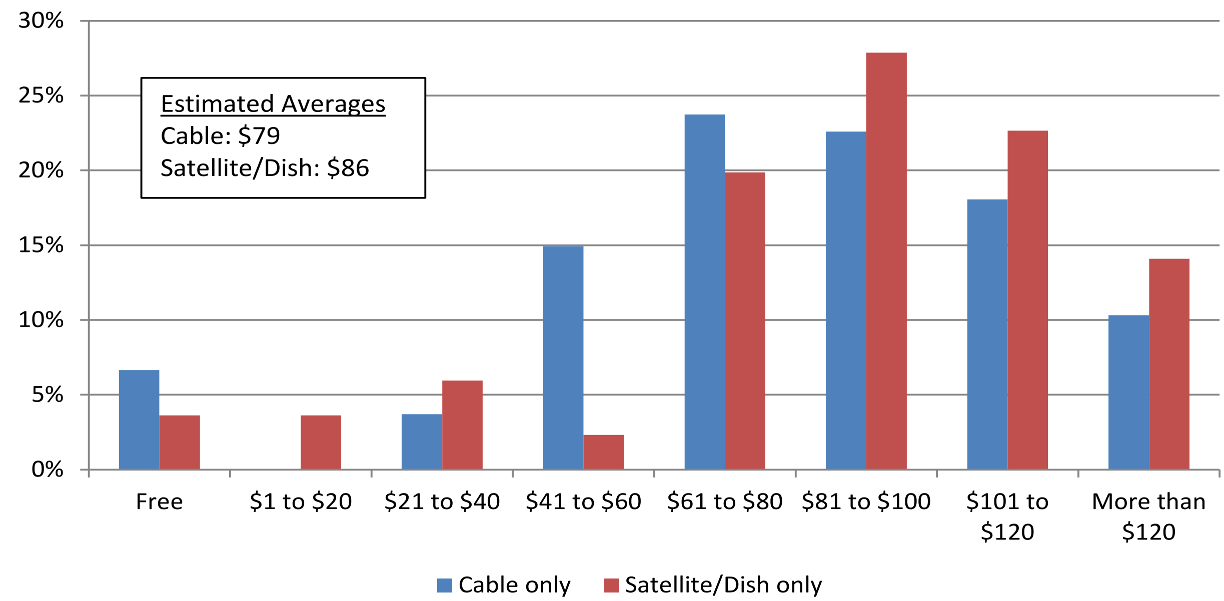
The estimated average monthly price for cable or satellite television service is $79, with 29 percent paying over $100 per month, as illustrated in Figure 51. Nearly one-half of those receiving cable or satellite pays between $61 and $100 per month.

Figure 51: Monthly Price of Cable or Satellite TV Service



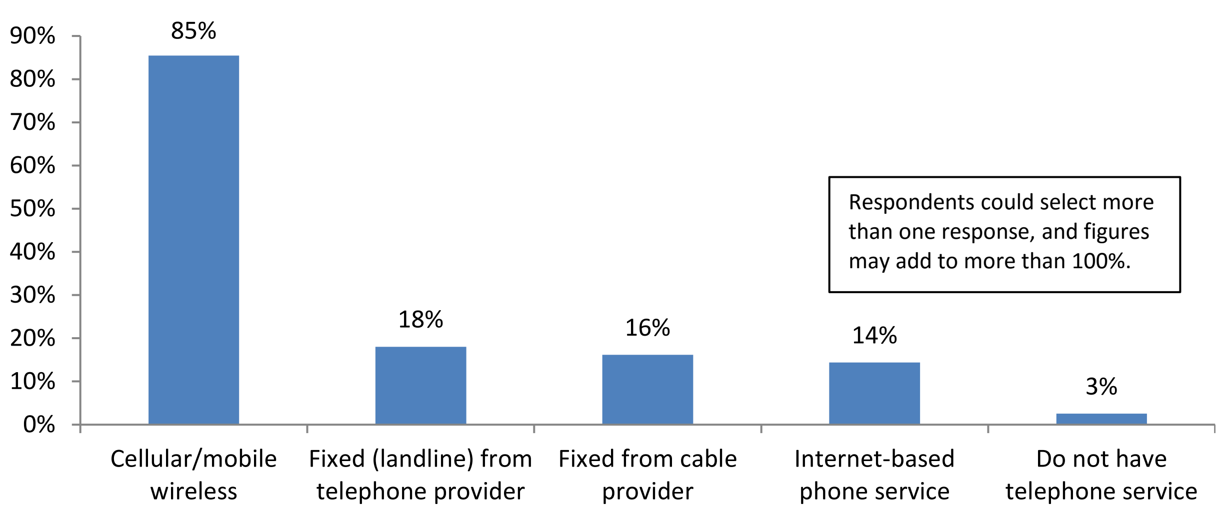
The cost per month for cable is slightly higher than the cost of satellite TV, as illustrated in Figure 52. The estimated monthly cost of cable is $79, and the estimated monthly cost of satellite television is $86.

Figure 52: Monthly Price of TV Service by Service Type



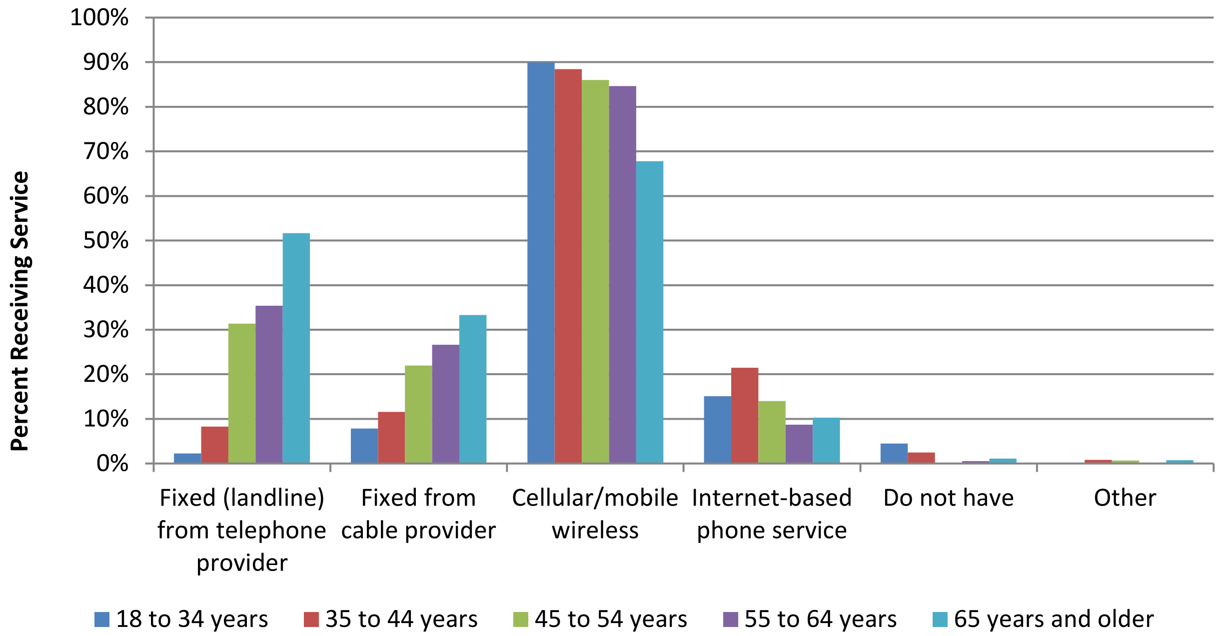
Respondents were asked about their telephone services, both at their home and cellular/ mobile. As illustrated in Figure 53, 85 percent of respondents have a wireless telephone. About one-third have a landline, including 18 percent from a traditional provider and 16 percent from their cable provider. In addition, 14 percent use some form of an Internet-based phone service.

Figure 53: Home Telephone Service(s)



As illustrated in Figure 54, respondents ages 65+ are more likely than younger respondents to have landline telephone service, either from a traditional provider or their cable provider, and they are less likely to have cellular/mobile wireless telephone service.

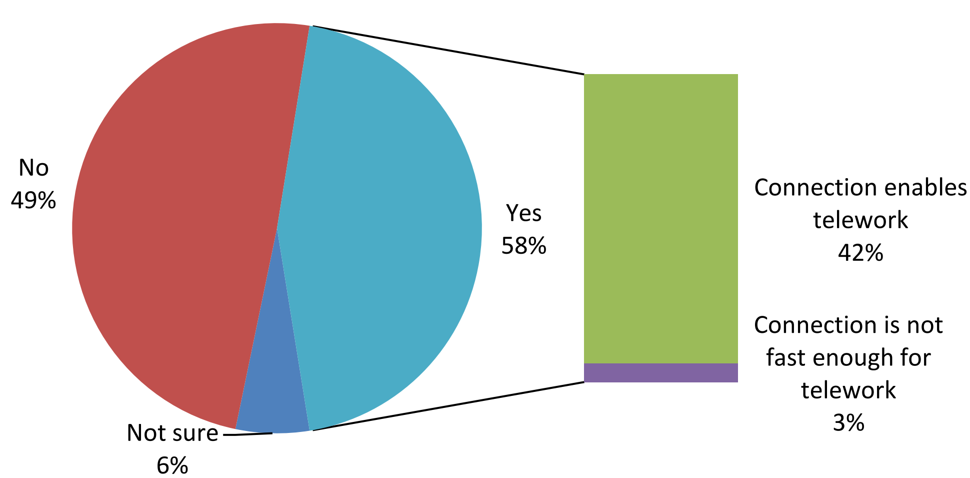
Figure 54: Home Telephone Service(s) by Age of Respondent



4.2.3 Telework and Home Businesses

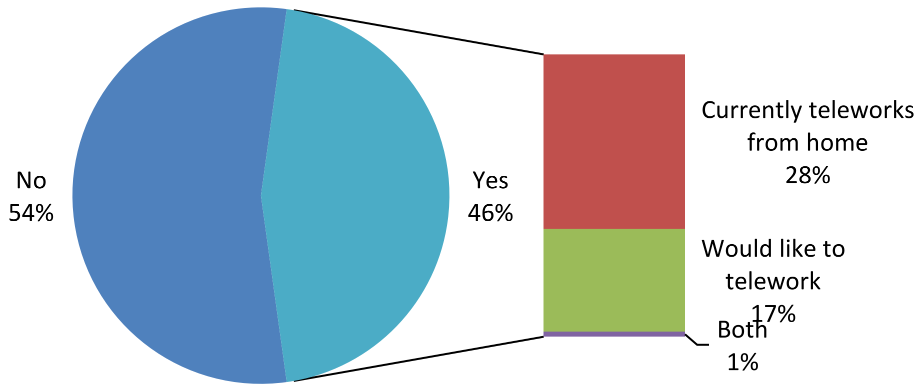
Over one-half of respondents indicated that a member of their family is allowed by their employer to telework. While 58 percent are allowed to telework, only 3 percent indicated that their Internet connection was not fast enough to allow telework (see Figure 55).

Figure 55: Employer Allows Telework



As shown in Figure 56, approximately 28 percent of respondents indicated that someone in their family already teleworks from home and another 17 percent would like to telework. (One percent stated both).

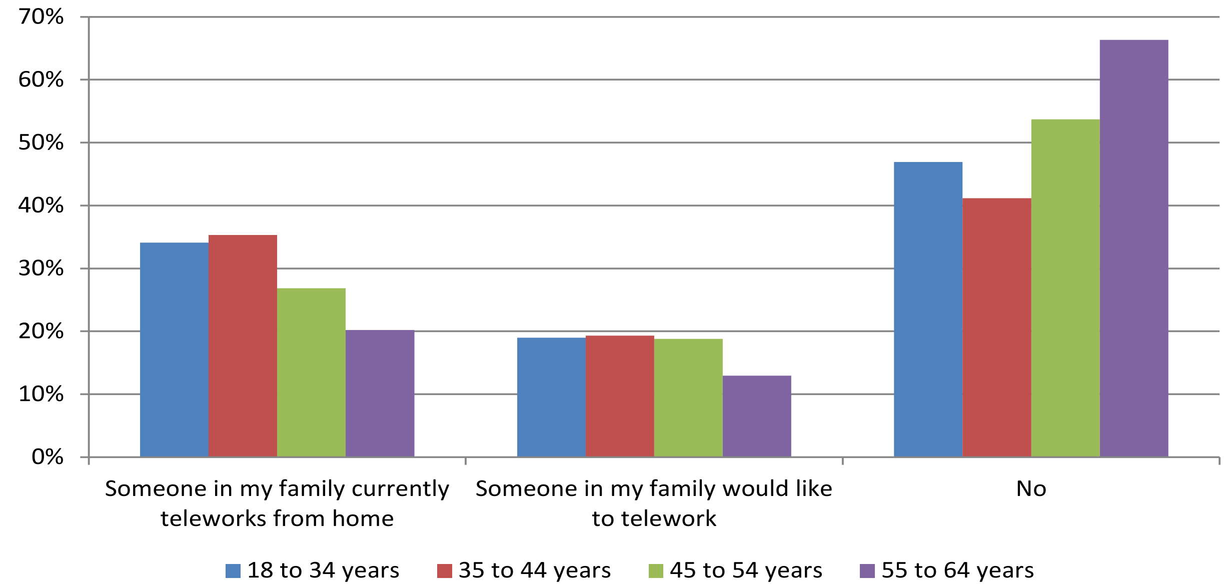
Figure 56: Household Member Teleworks



The majority (64 percent) of household members who are allowed to telework and who have a fast enough home Internet connection do indeed telework from home. This indicates that a substantial additional share may telework if feasible, allowed by their employer, and if their connection were fast enough to enable telework.

Respondents ages 65 and older are less likely than younger respondents to have a household member who teleworks, as may be expected since it is assumed that a larger share of respondents in this age cohort may be retired (see Figure 57).

Figure 57: Current Teleworking and Interest by Age of Respondent



In addition, those with a higher education and those with a higher estimated household income are more likely to have a household member who teleworks, as shown in Figure 58 and Figure 59, respectively.

Figure 58: Current Teleworking and Interest by Level of Education

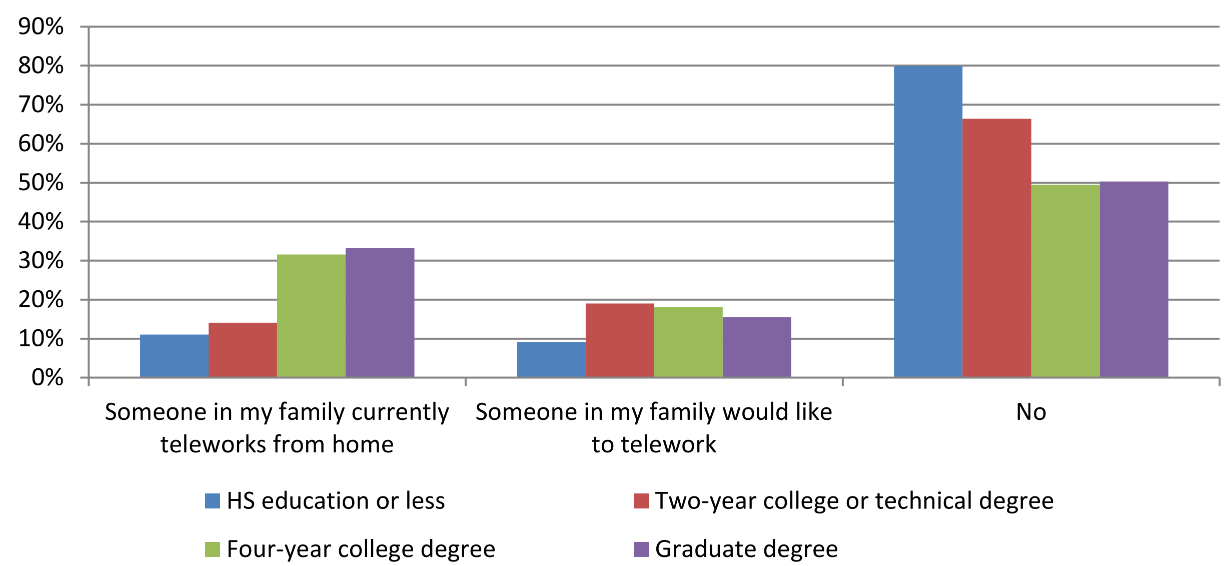
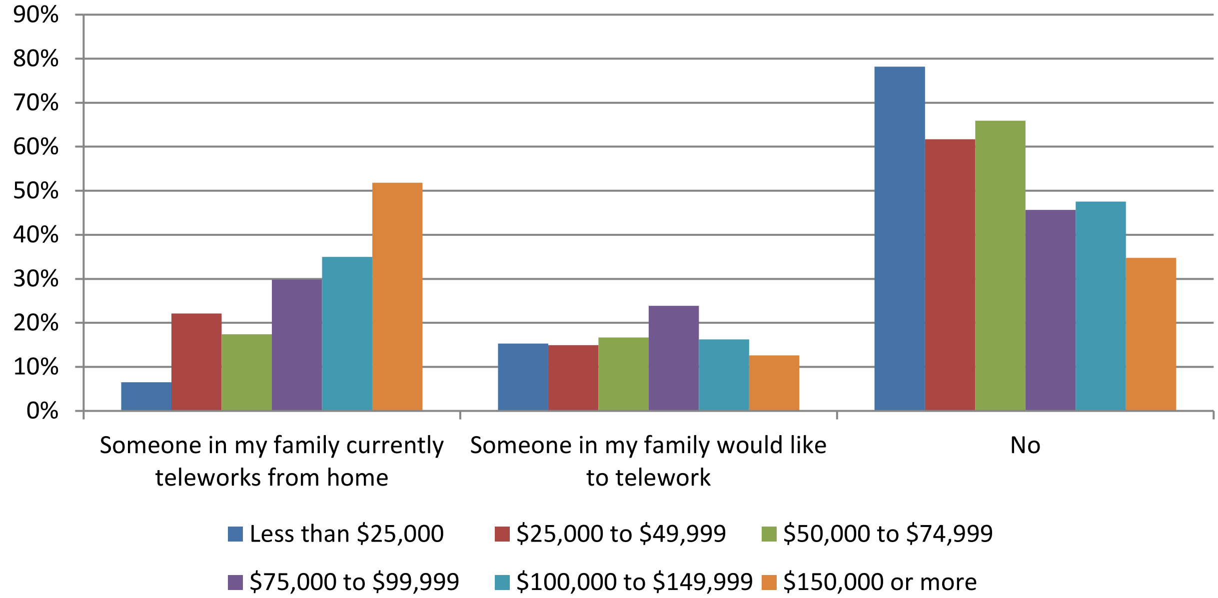


Figure 59: Current Teleworking and Interest by Household Income



More than one-fifth (22 percent) of respondents either has a home-based business or is planning to start one within the next three years, as illustrated in Figure 60. Of those who operate or are planning to start a home-based business, 79 percent indicated that a high-speed Internet connection is (or would be) very important to this business, as indicated in Figure 61.

Figure 60: Own or Plan to Start a Home-Based Business

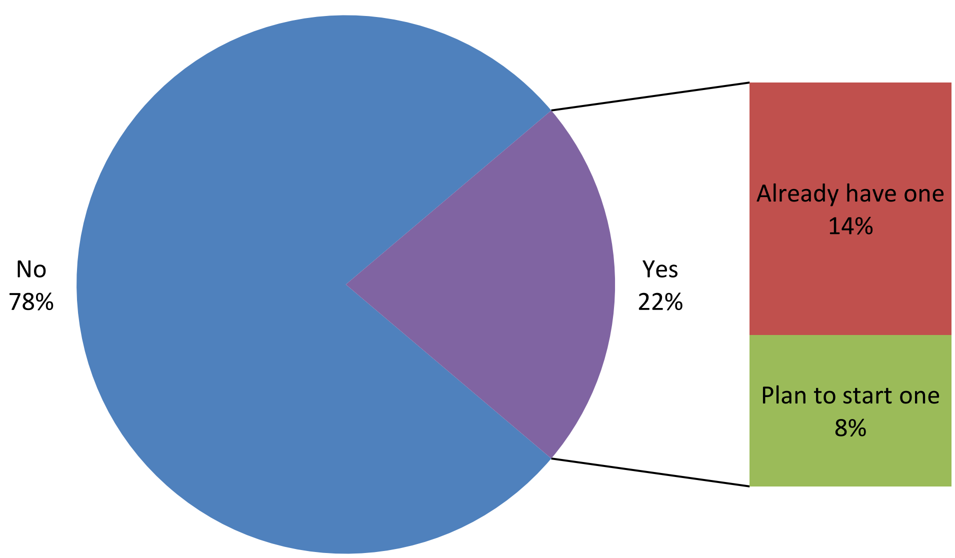
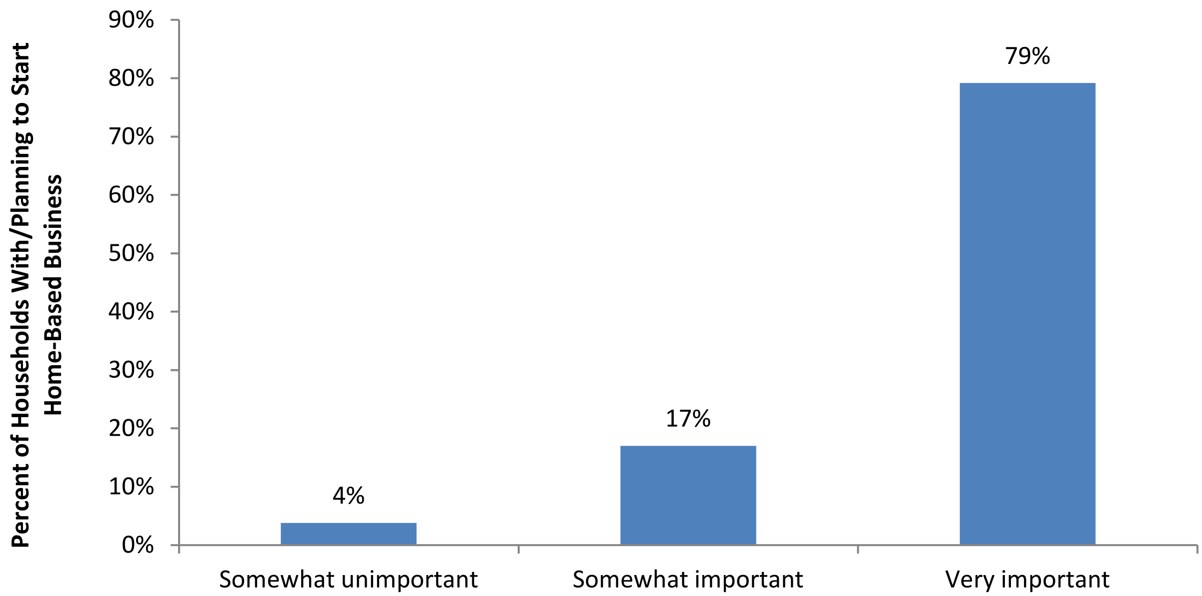


Figure 61: Importance of High-Speed Internet to Home Business



4.2.4 Respondent Opinions

Respondents were asked their opinions about the City's role in providing or promoting broadband communications services within the City. The most favorable opinions were that the City should help ensure that all residents, students, and teachers have access to competitively-priced broadband services. Figure 62 illustrates the mean ratings, while Figure 63 provides detailed responses to each portion of the question.

There is not a strong level of agreement that the City should build a publicly-financed network (to either offer services to the public or to allow private sector companies to offer services on the network); however, respondents were more likely to agree than disagree with these statements.

Figure 62: Opinions About the City's Role(s) (Mean Ratings)

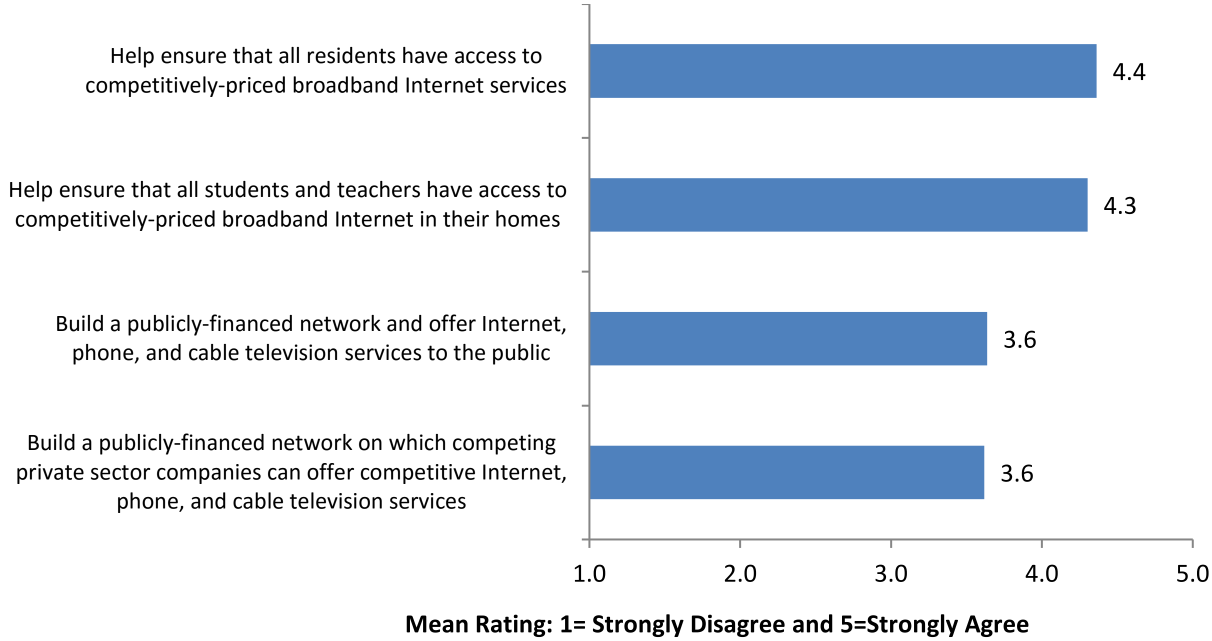
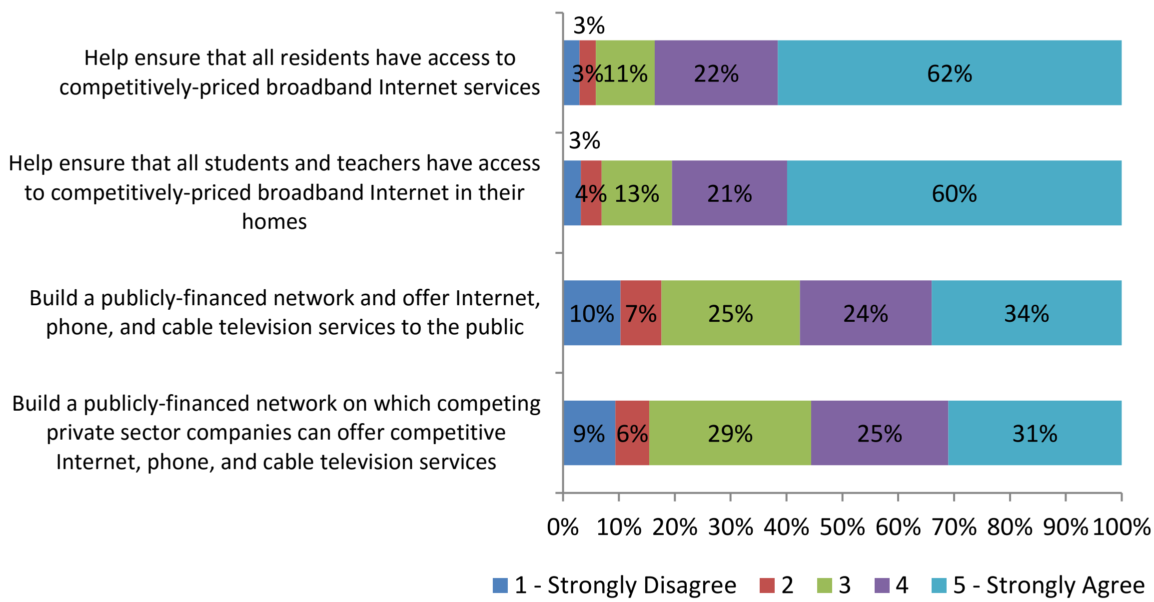
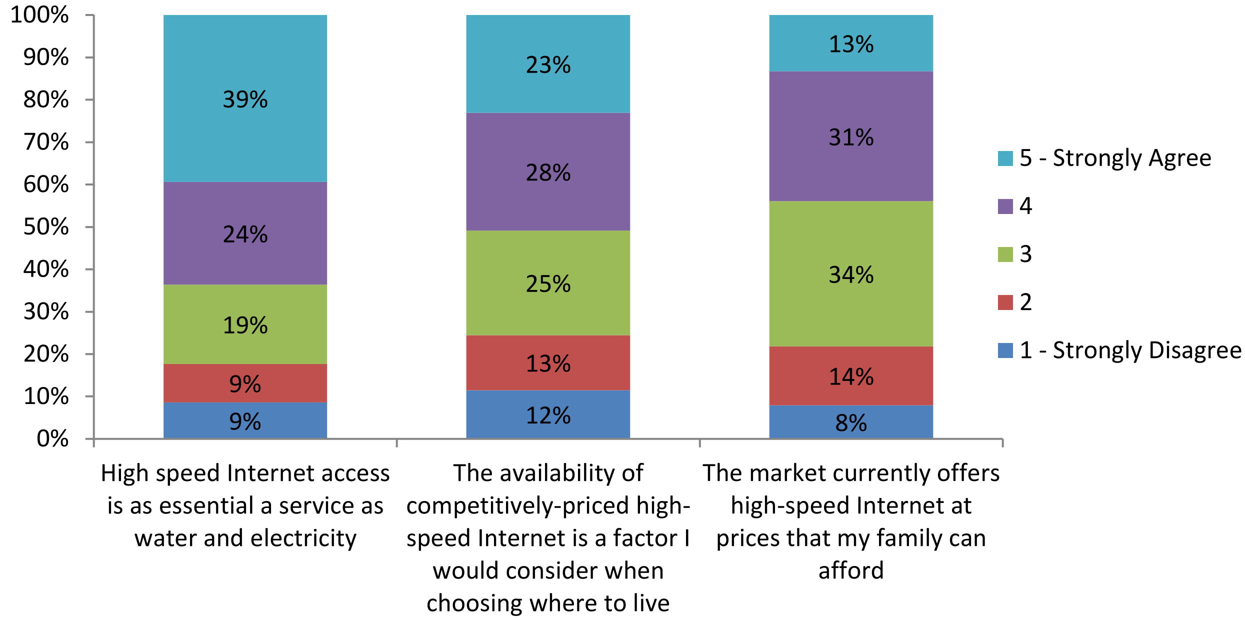


Figure 63: Opinions About the City's Role(s)



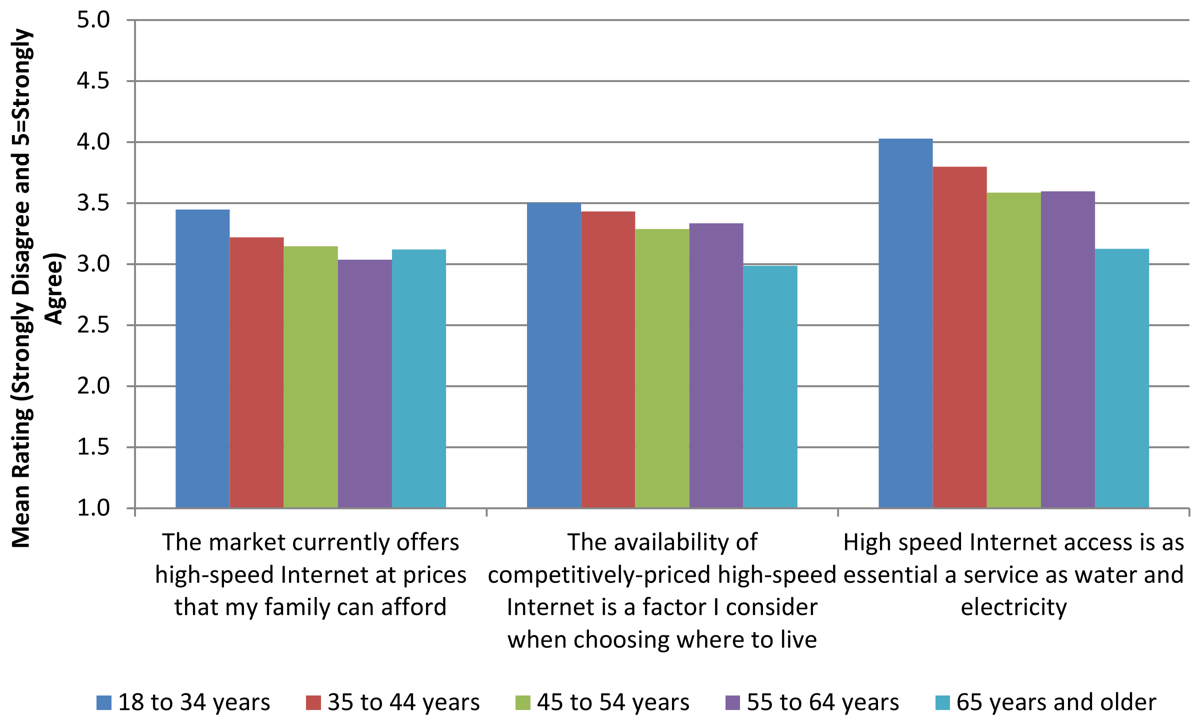
Respondents were also asked their opinion of the current broadband market. Four in 10 strongly agreed that high-speed Internet is an essential service. Much smaller shares thought that the market currently provides high-speed Internet at prices they can afford or that the availability of high-speed Internet is a factor they consider when choosing where to live, as illustrated in Figure 64.

Figure 64: Opinions About Broadband Internet



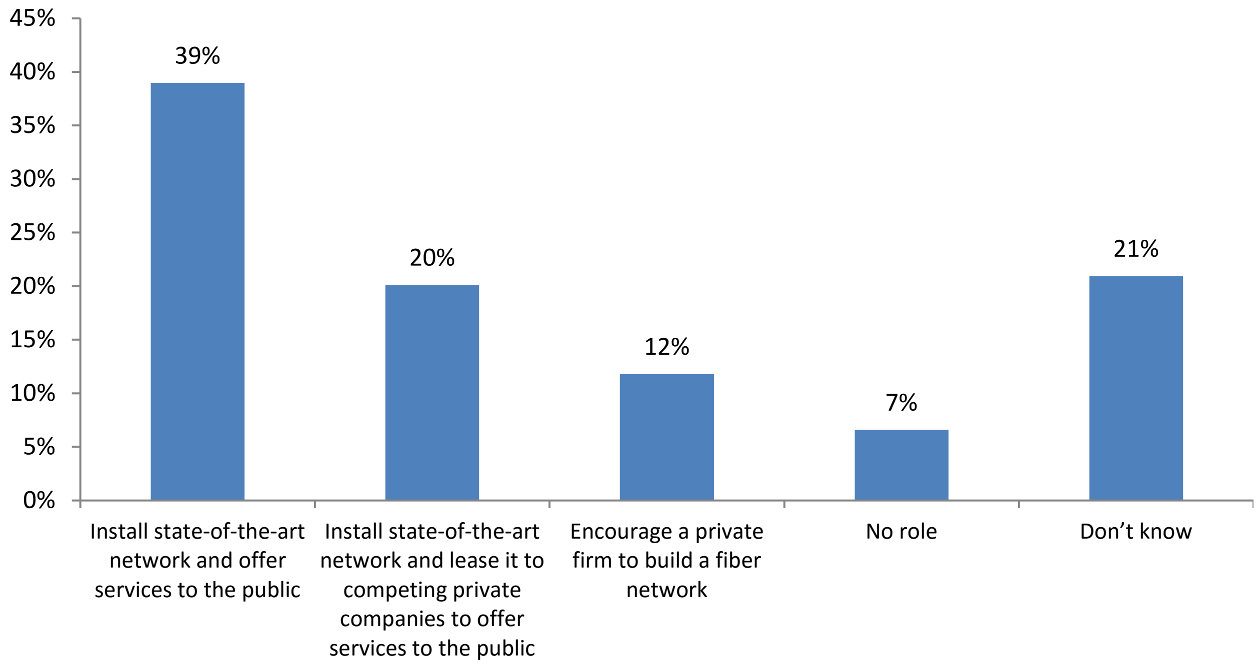
The opinions of the broadband market varied somewhat by the age of the respondent. As Figure 65 illustrates, younger respondents were more likely to agree that high-speed Internet is an essential service.

Figure 65: Opinions About Broadband Internet by Age of Respondent



Respondents were asked what the ***main*** role of the City should be with regards to Internet infrastructure and services. About six in 10 respondents indicated that the City should install a state-of-the-art communications network. About four in 10 respondents thought the City should install a network and offer services to the public. An additional 20 percent said that the City should build the communications network and lease it to competing companies to offer services to the public. Twelve percent thought the City should encourage a private firm to build a communications network. Only 7 percent thought the City should play no role, and 21 percent were unsure, as illustrated in Figure 66.

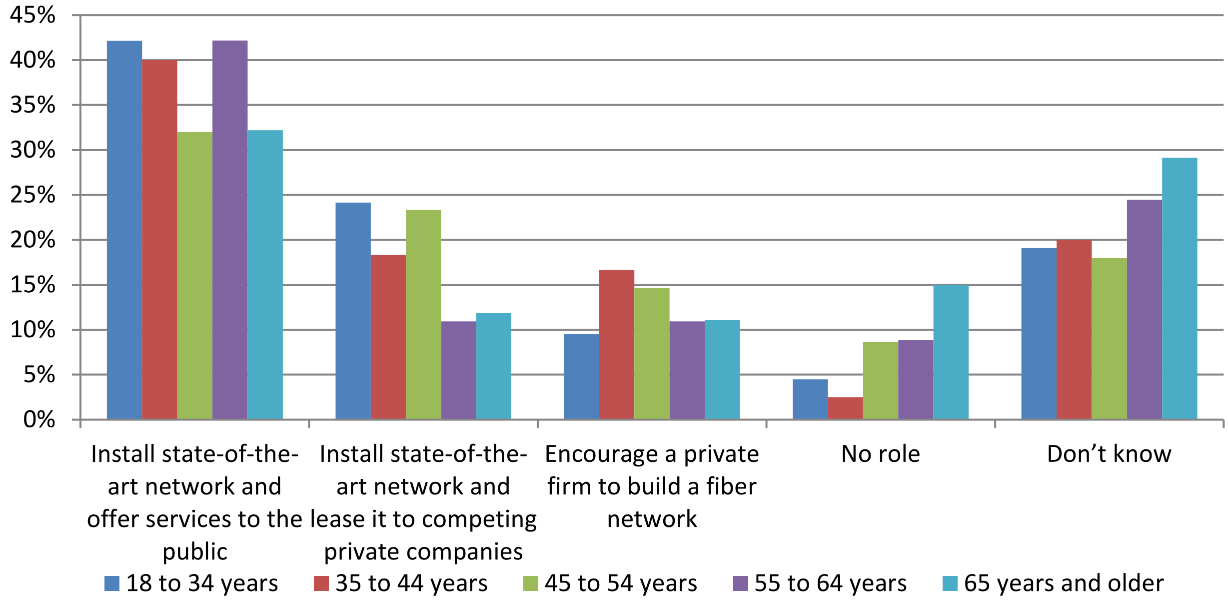
Figure 66: Main Role of the City with Respect to Broadband Access



Support for installation of a state-of-the-art network tends to decline somewhat as age increases. Two-thirds of those ages 18 to 34 would support the installation (either to offer services to the public or to lease to competing private companies), compared with 44 percent of those ages 65 and older (see Figure 67).

These responses indicate a relatively clear signal about residents' desire to have a state-of-the-art communications network and for the City to play some role in its installation. It should be noted that this question did not specifically ask about how that network should be financed or funded. Questions regarding consumers' willingness to pay monthly fees or hook-up costs for access to that network were presented previously.

Figure 67: Main Role of the City with Respect to Broadband Access by Age of Respondent



4.2.5 Respondent Information

Basic demographic information was gathered from survey respondents and is summarized in this section. Several comparisons of respondent information and other survey questions were provided previously in this report.

As indicated previously regarding age-weighting, disproportionate shares of survey respondents were in the older age cohorts relative to the City's adult population as a whole. Approximately 30 percent of survey respondents are ages 65 an older, compared with only 12 percent of the population. Conversely, only 19 percent of survey respondents are under age 35, compared with 44 percent of Madison's population. The survey results have been adjusted to account for these differences, as discussed earlier in this report.

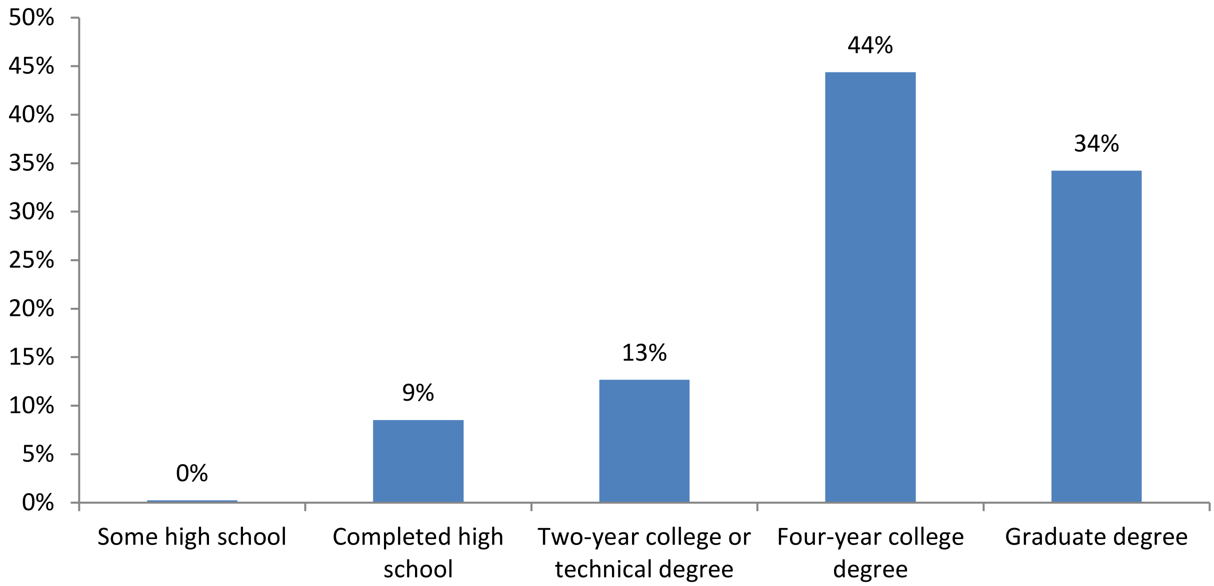
Respondents ages 35 to 54 are more likely than older and younger respondents to have children in the household. They are more likely to earn over $50,000 per year, compared with older and younger respondents. Those ages 65 and older are somewhat more likely to have just one resident in their household. Those ages 18 to 34 are more likely than older respondents to be renters, and they have lived in their home for fewer years on average. (See Table 16: Demographic Profile by Age of Respondent.)

Table 16: Demographic Profile by Age of Respondent

		18-34	35-44	45-54	55-64	65+	Total
Gender	Female	45%	45%	46%	51%	51%	47%
	Male	55%	55%	54%	49%	49%	53%
	Weighted Count	*402*	*140*	*136*	*122*	*113*	*914*
Race/Ethnicity	Other race/ethnicity	12%	12%	9%	7%	6%	10%
	White/Caucasian only	88%	88%	91%	93%	94%	90%
	Weighted Count	*398*	*138*	*134*	*121*	*112*	*904*
Highest level of education	Some high school	0%	0%	1%	0%	1%	0%
	Completed high school	5%	8%	11%	11%	15%	9%
	Two-year college or technical degree	9%	13%	9%	18%	21%	13%
	Four-year college degree	54%	42%	38%	42%	24%	44%
	Graduate degree	32%	37%	41%	28%	39%	34%
	Weighted Count	*407*	*139*	*135*	*122*	*112*	*917*
Approximate 2015 household income	Less than $25,000	7%	4%	3%	7%	14%	7%
	$25,000 to $49,999	28%	17%	12%	11%	24%	21%
	$50,000 to $74,999	20%	13%	20%	25%	19%	20%
	$75,000 to $99,999	16%	25%	17%	19%	19%	19%
	$100,000 to $149,999	17%	28%	27%	24%	17%	21%
	$150,000 to $199,999	7%	6%	10%	7%	4%	7%
	$200,000 or more	4%	7%	11%	6%	3%	6%
	Weighted Count	*404*	*137*	*133*	*111*	*98*	*889*
Total Household Size (Adults + Children)	1	24%	23%	22%	25%	37%	25%
	2	45%	26%	33%	55%	58%	43%
	3	17%	15%	16%	13%	5%	15%
	4 or more	14%	36%	29%	7%	0%	17%
	Weighted Count	*407*	*138*	*136*	*122*	*110*	*917*
Number of children in household	No Children in HH	79%	54%	60%	89%	98%	76%
	Children in HH	21%	46%	40%	11%	2%	24%
	Weighted Count	*407*	*138*	*136*	*122*	*110*	*917*
Own/rent residence	Own	44%	75%	83%	86%	85%	65%
	Rent	56%	25%	17%	14%	15%	35%
	Weighted Count	*407*	*139*	*136*	*119*	*110*	*916*
Number of years lived at current address	Less than 1 year	19%	7%	5%	3%	3%	11%
	1 to 2 years	39%	15%	3%	7%	4%	21%
	3 to 4 years	23%	27%	9%	8%	5%	17%
	Five or more years	19%	52%	83%	83%	88%	51%
	Weighted Count	*407*	*139*	*136*	*122*	*110*	*921*

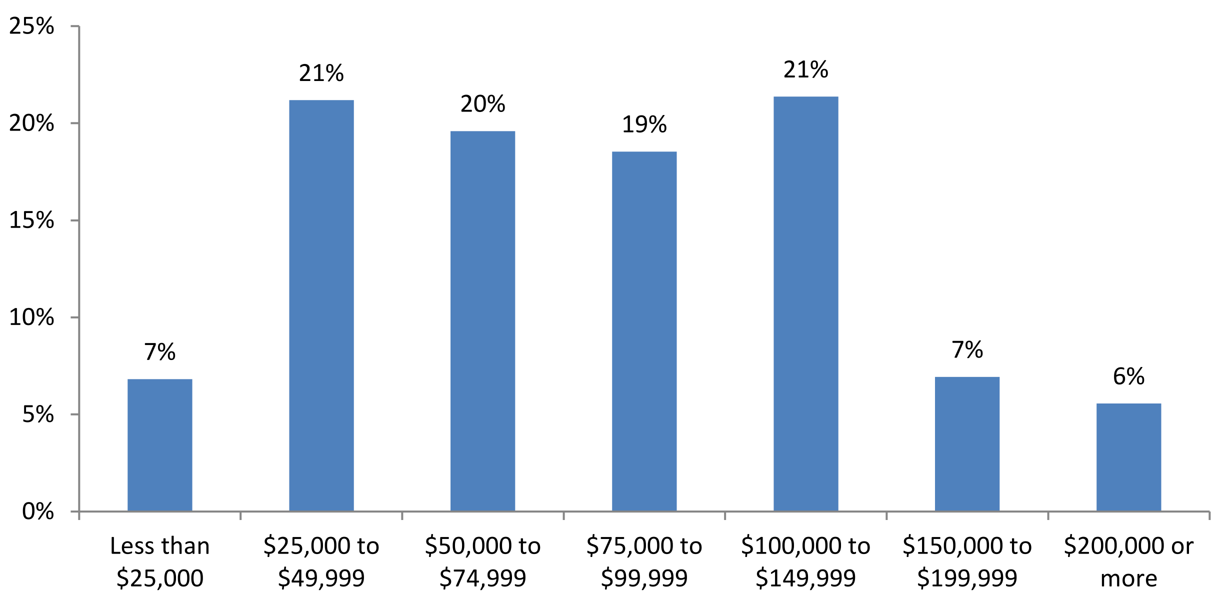
The respondents' highest level of education attained is summarized in Figure 68. More than three-fourths of respondents have a four-year college degree or a graduate degree.

Figure 68: Education of Respondent



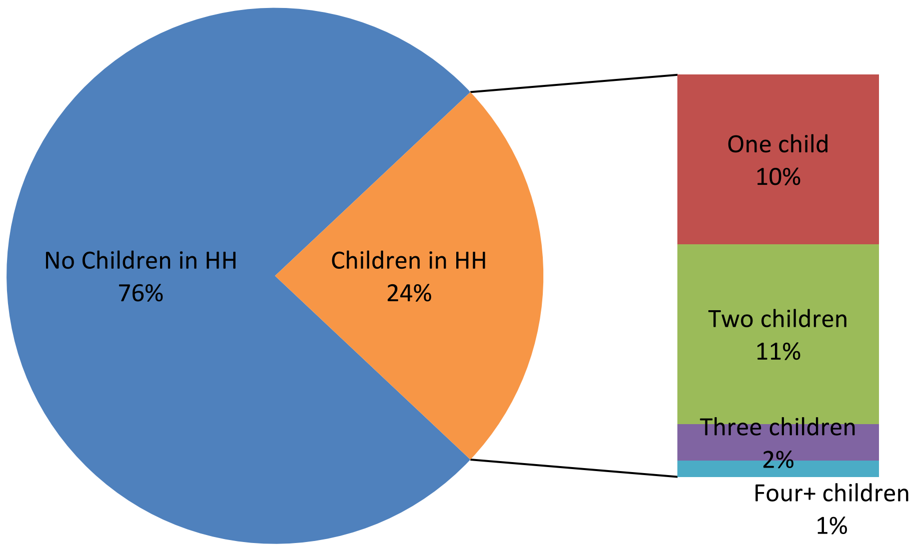
Just 7 percent of respondents are in the lowest income bracket with 2015 household income of less than $25,000. Another 21 percent of respondents earned $25,000 but less than $50,000. About 45 percent of respondents had household incomes of $100,000 or more, as illustrated in Figure 69.

Figure 69: 2015 Household Income



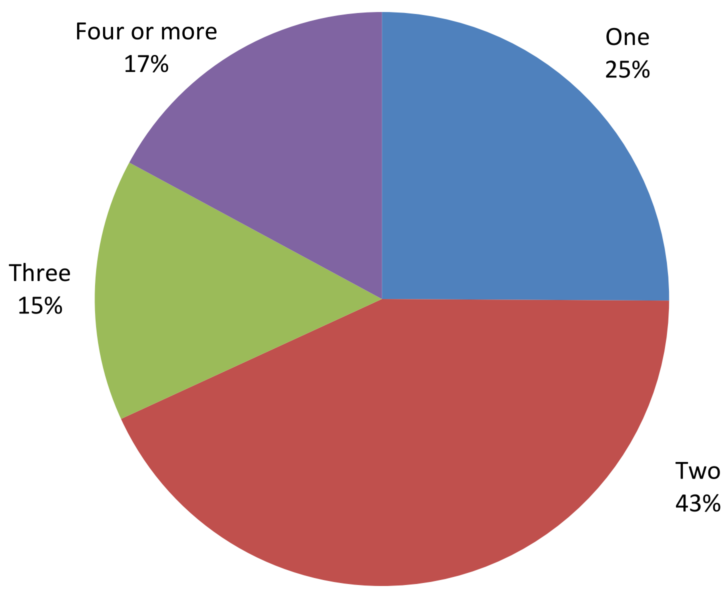
Respondents were asked to indicate the number of adults and children in their household. About one-fourth of respondents have at least one child under age 18 living at home, as shown in Figure 70.

Figure 70: Number of Children in the Household



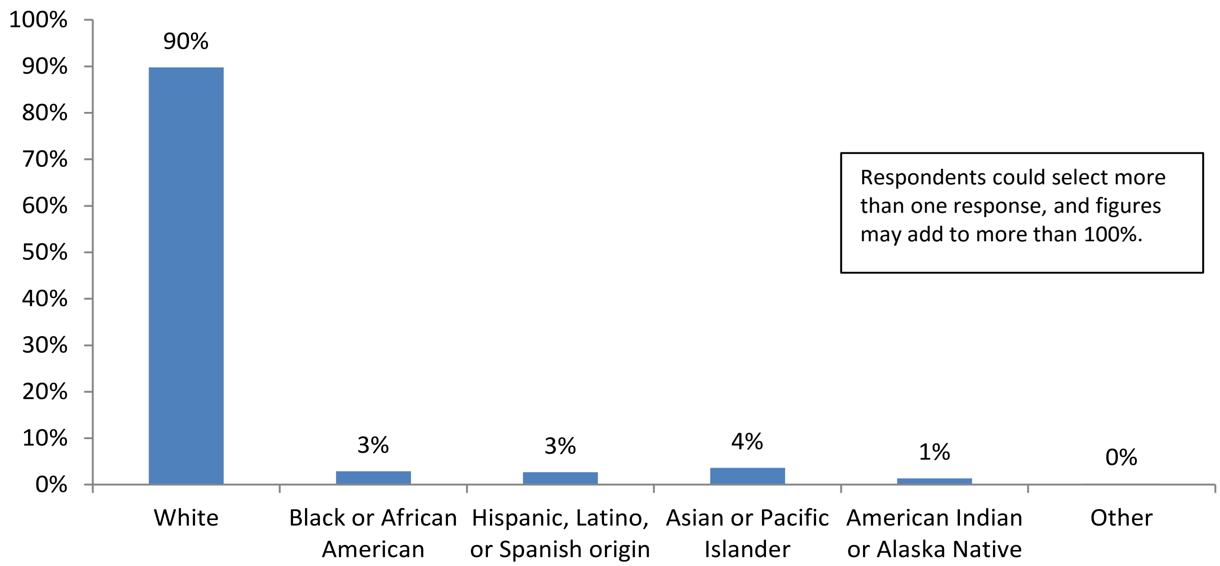
One-fourth of respondents have just one person living in the household, and 43 percent have two household members (including both adults and children). One-third have three or more household members (see Figure 71).

Figure 71: Total Household Size



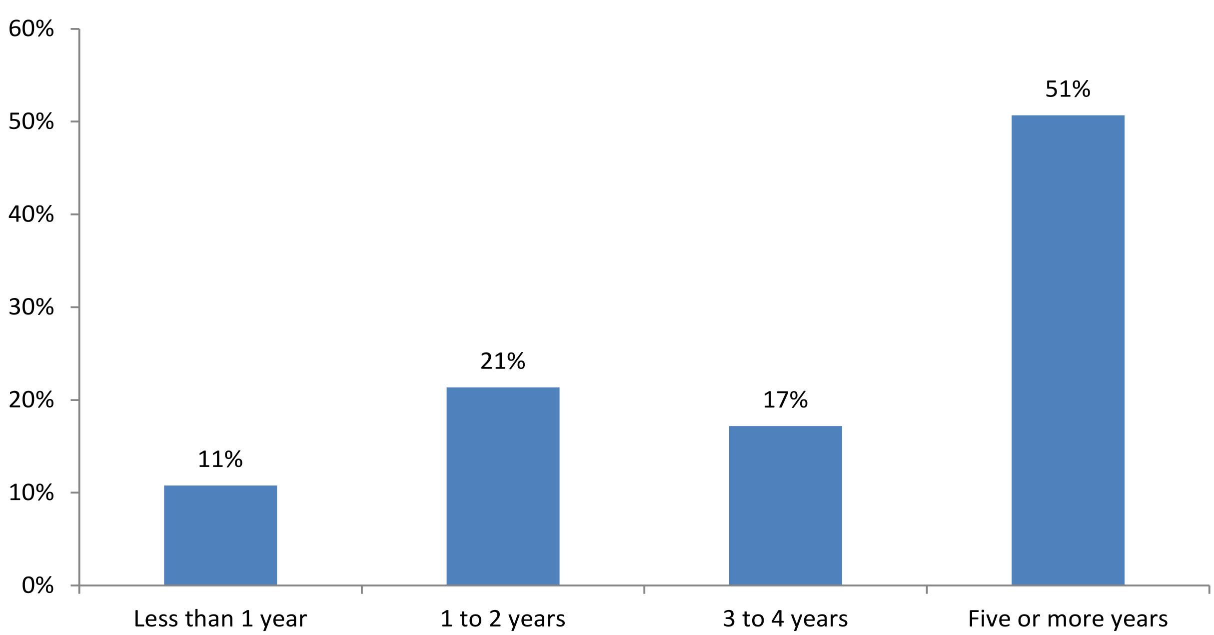
Additionally, the survey sample is split 47 percent women, and 53 percent. Nine in 10 are White only, and one in 10 represent other races/ethnicities, as shown in Figure 72.

Figure 72: Race/Ethnicity of Respondent



Nearly two-thirds of respondents (65 percent) are homeowners. More than half of respondents have lived at their residence for five or more years, as shown in Figure 73.

Figure 73: Length of Residence at Current Address



5 Framework for Options to Meet City's Goals: Public–Private Partnership Models

5.1 Overview of Partnership Frameworks

Public–private partnerships are generally unique to the communities that develop them and entail specific parameters that directly benefit both the community and the chosen private partner. As the City evaluates broadband public–private partnerships, it should consider both the opportunities and potential pitfalls, and pay particular attention to three interwoven issues:

1. Risk
2. Benefit
3. Control

These factors are key considerations for both the City and its potential partner(s). A successful partnership must balance each partner's needs, and there will inevitably be some tradeoff within this framework for each model.

5.1.1 Risk

It is not possible to entirely avoid risk if the City opts be involved at any level in broadband deployment. But calculated risk often yields benefits that would otherwise have been unattainable. One of the most enticing components of a public–private partnership is that it can considerably reduce the City's risk while helping achieve a community's broadband goals.

Public financing (directly with bond issuance or indirect with payment guarantees) to support the partnership will likely be one of the City's greatest risks, though we believe this is a worthwhile investment to enable the City to retain some ownership and control of the assets in a dark FTTP partnership model. Although it will entail some financial and political risk because it will likely require public financing—either through municipal bonds or leveraging tax funds—the long-term dividends will likely be advantageous. This is especially true if the City is able to execute a meaningful partnership with a private entity that will share in the risk.

The City may enter into an agreement that requires it to directly seek bonding for capital investment, or it may find a partner that is willing to use its own capital. It is important to note that even if the City does not directly seek bonds, and the City must commit to a guaranteed payment the City's credit rating and bonding ability may still be impacted if a private partner obtains the financing.

Operations tend to be unpredictable and costly and often represent a great risk for municipal fiber networks. Cities that try to enter the retail market directly are often targeted by hostile incumbent providers that make it very challenging for the City to compete. Part of the attraction to the public–private partnership model is that private entities tend to be equipped to understand the retail business and to help the City mitigate its risk in this area. Given this, the dark FTTP partnership model is most likely to offset the City's risk.

5.1.2 Benefit

As the City considers this endeavor, it should continually weigh the benefits it might expect to receive as part of a public–private partnership against its potential risk. One positive component of emerging partnerships nationwide is that there is potential for a great degree of flexibility. That is, the City is in a position to consider its priorities and pursue those benefits on the frontend of a partnership arrangement.

Conversely, although public–private partnership models are relatively new and evolving all the time, there are several recent examples that the City can look to as guidance on how it might want to proceed. It is too soon to fully map what long-term benefits of partnership might look like, but there are some lessons that can be picked up from some communities that have sought various degrees of partnership.

Although benefits cannot be reliably calculated at this stage, the City can potentially look to other communities to get a sense of the goals other partnerships prioritized for the public entity's benefit. This may help the City determine how to balance its risks, and which areas to focus on in its pursuit of a partner. Madison is a desirable market with much to offer a private partner, especially if the City is willing to directly invest in the dark fiber network.

5.1.3 Control

Because this is the start of the City's broadband initiative, it can choose in the negotiation process its desired level of involvement in infrastructure deployment, network maintenance, and operations. That is, the City can essentially determine from the outset what level of involvement it would like to have at every stage and in every arena of the public–private partnership process.

There are numerous ways that the City can retain some control within the public–private partnership, and perhaps the most important is through retaining ownership of the physical assets. Again, this must be balanced with risk, as it is likely that the City will be required to fund at least part of the capital investment in assets if it hopes to retain control.

The more ownership the City has, the greater degree of control it can maintain. This enables the City to make decisions about placement of the assets, rate of deployment, and the network's overall footprint. Further, it ensures that if the partnership does not succeed, the City still has a physical asset that it can use to deliver services directly or to negotiate a new partnership.

5.2 Public–Private Partnership Models

In this section, we outline the emerging public–private partnership models in the industry today. Although we believe that Model 3—the shared investment and risk model which entails a dark FTTP partnership—will be most beneficial for the City, it is valuable to understand other models that may be available to the City.

5.2.1 Model 1: Private Investment, Public Facilitation

In this approach to public–private partnership, the public sector's cost is significantly reduced. The model focuses not on a public sector investment, but on modest measures the public sector can take to enable or encourage greater private sector investment. The most prominent example of this model is Google Fiber's deployments, including its networks in Austin, Kansas City, Nashville, and elsewhere. Ting Internet[70] is taking a similar approach in smaller markets, including Holly Springs, North Carolina.

This model is seen as the ideal for many communities that wish to minimize public cost. At least in Google Fiber's deployments, the private sector partner's requirements have largely focused on making local government processes more efficient. In return for these relatively low-cost public sector commitments, the communities that are partnering with Google Fiber or Ting Internet benefit from the company's deployment of FTTP infrastructure (and, in many cases, competitive upgrades by the incumbent cable and telephone companies).

This model relies on the private companies to make the investment, while partner communities take certain steps to enable them to build in an expeditious, efficient, low-cost manner. Though Google Fiber is the most prominent example, there is also significant interest among smaller companies—which have fewer resources than Google but can deliver next-generation broadband to businesses and institutions on a targeted basis.

While this model reduces the public sector's cost and risk compared to other models, there is a potential public relations risk. Public expectations can get very high with the announcement of new fiber deployment. If a local government is strongly identified as a partner, it may be held accountable by the community if something goes wrong with the private sector partner's business plan or deployment.

5.2.1.1 Strategies for Encouraging Private Investment

There are a number of strategies the City can take to encourage new private investment and reduce some of the costs and time for private sector entities to deploy advanced broadband services. These can, for example, take the form of specific economic development incentives such as tax benefits to encourage providers to build new infrastructure. MetroNet, a small Midwest ISP, developed a partnership with the City of Crawfordsville, Indiana, to purchase the

[70] Ting, https://ting.com/.

municipal utility's fiber network.[71] The city is assisting MetroNet with financing the purchase and expanding the footprint of the fiber network.

Communities typically offer this type of benefits to new entrants in a market that are willing to invest in next-generation infrastructure, but they can offer those benefits to incumbents if the incumbents will also invest in the same kind of infrastructure.

Another key strategy is for the community to develop and strengthen the local infrastructure assets that enable the deployment of broadband.[72] These include public assets such as fiber, conduit, and real estate. For example, new network deployments can benefit enormously from access to existing government fiber strands, underground communications conduit in which fiber is placed, or real estate where equipment or exterior huts can be located.

Communities can further facilitate the underground construction of conduit and fiber by implementing a "dig-once" policy for all road and related transportation projects, and facilitating in-building access through construction specifications for new buildings.[73]

Building and expanding community infrastructure over time is a low-cost, low-risk strategy that will have real impact and expand options down the road. For example, the City of Mesa, Arizona, began a dig-once initiative in the early 2000s; the city intended to install its own rings of conduit during private sector construction projects, then sell access back to the private sector. Any time the city opened up a street, such as to install water or sewer utilities, it put in conduit.[74] In some instances, the city also added fiber to empty conduit for city purposes or to potentially lease to private providers. In total, the city installed as much as 200 miles of conduit. Mesa targeted four economic development areas in particular, with redundant conduit, fiber, and electric infrastructure. Among those areas was the land around the Phoenix-Mesa Gateway Airport, where Apple announced in early 2015 that it would build a $2 billion data center.

A third important strategy is to improve access to information—an asset that communities might not have considered.[75] Sharing information demonstrates a willingness to engage with the private sector to spur investment. Communities should seek to make data available wherever possible both for public and private uses.

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[71] "MetroNet plans to expand current fiber optic system," *The Paper of Montgomery County Online,* Mar. 18, 2014, http://goo.gl/5eHuJt.

[72] "Gigabit Communities: Technical Strategies for Facilitating Public or Private Broadband Construction in Your Community," CTC Technology & Energy, Jan. 2014, p. 6–12, http://www.ctcnet.us/gigabit/.

[73] For more discussion of "dig once" policies and related collaborative strategies, see "Gigabit Communities."

[74] "Transcript: Community Broadband Bits Episode 139," Institute for Local Self-Reliance, Feb. 26. 2015, http://goo.gl/pFzN6k.

[75] "Gigabit Communities," p. 13–16.

Geographic information systems (GIS) or similar databases that hold information such as street centerlines, home and business locations, demographics, and details on existing utilities, public infrastructure, ROW, and available easements can be extremely helpful for a locality's own broadband planning, potential public–private partnerships, or a network service provider that is evaluating the deployment of new infrastructure in a community.

Access to this information may attract and speed new construction by private partners, while enabling the community to meet its goals for new, better broadband networks—and potentially to realize revenues for use of the assets.

Finally, the City can take steps to enable broadband construction by making government processes around permitting, ROW access, and inspections more efficient and smooth.[76] In some communities, for example, permitting processes have been moved online, alleviating the need for wasteful and time-consuming paper-based processes. These actions can signal to private partners that there is an investment opportunity in the jurisdiction and that the City will not be a bottleneck or create additional costs.

These steps should take into consideration the needs of the community, balance public interest and public safety, and account for local resources and capacity. For example, the City can choose to be fully transparent about its permitting and ROW processes—including timelines—to enable the communications industry to expeditiously plan and deploy networks.

5.2.1.2 Potential Benefits and Pitfalls

The above strategies can make a difference in the economics of buildout for a private partner. However, they will not dramatically change the underlying economics of broadband network construction and operation. In a best-case scenario, the public sector can reduce the cost of outside plant construction for a broadband network by up to an estimated 8 percent.[77]

Thus these measures can be substantial, but not transformative. Indeed, many incumbent providers overstate the extent to which local government and regulation are hurdles for developing next-generation broadband infrastructure.

Communities should be wary, then, of private sector entities seeking benefits without offering concrete investment proposals. From a business standpoint, for example, incumbents do not need additional support from the City to keep maintaining (or even upgrading) their existing broadband networks and services.

[76] *Id.*, p. 14.
[77] "Gigabit Communities."

5.2.1.3 Case Study: Holly Springs, NC

Over the course of many years, the Town of Holly Springs designed, engineered, and constructed a backbone fiber network to connect municipal buildings. To their great credit, Holly Springs' visionary elected officials chose to build a fiber network with dramatically higher capabilities than the need apparent at the time—knowing that a robust fiber backbone might attract interest from private ISPs that recognize the potential to leverage that backbone to more efficiently build their own FTTP infrastructure.

But a robust backbone network was not enough. The town's government also developed policies and strategies to attract private broadband investment. As a result, Ting Internet announced in mid-2015 that it will bring "crazy fast fiber internet" to the homes and businesses of Holly Springs. Ting plans to expand on Holly Spring's existing fiber pathways and offer symmetrical gigabit Internet access to homes and businesses.

A key factor in Ting's decision to invest in Holly Springs was the fact that the town not only was willing to lease excess fiber in its backbone, but that it also brought best practices to bear in its willingness to work with Ting and facilitate Ting's efforts. Among other things, the town offered efficient government processes, access to information and facilities, and facilitation and support—all of which boosted Ting's confidence about this community as an investment opportunity.

5.2.2 Model 2: Private Execution, Public Funding

This model, which involves a substantial amount of public investment, is a variation on the traditional municipal ownership model for broadband infrastructure—but with private rather than public sector execution. In this model, a selected private partner takes responsibility for some combination of design, construction, financing, operations, and maintenance,[78] funded by the public partner over some period of time.

While this public–private partnership structure is new to broadband, it is used in Europe and increasingly in the U.S. for traditional infrastructure projects such as highways, toll roads, and bridges. The model seeks to leverage the strengths of the private sector to deliver turnkey services and solutions over an extended time of 20 to 40 years.

Unlike transportation or utility infrastructure, however, broadband does represent a somewhat competitive marketplace. Thus, applying the model to broadband in the U.S. creates political and financial risk for the public sector because public funding is used to fund an infrastructure that some residents may not want or choose to use. Indeed, if the broadband network is unsuccessful at generating revenue to cover all public sector costs, the public sector often

[78] "Financial Structuring of Public–Private Partnerships (P3s)," U.S. Department of Transportation, 2013, http://goo.gl/gCJIZK.

remains on the hook for those payments. At its core, this model thus involves the public sector essentially becoming the guarantor in the event that the partnership does not secure sufficient revenue to cover all costs, including the profit margins required by the private partners.

And for communities that think this is a way to get financing without bonding, that is only partially true. The public sector partner does not have to bond, but the partnership financing will most likely be considered by auditors, state authorities, and the bond markets as counting against the public sector entity's borrowing capacity.

Despite these risks, the model offers benefits to the public sector by removing significant logistical barriers from large-scale public broadband projects and offering a comprehensive solution (including extensive turnkey private execution and private capital) for the entire community.

One of the most fascinating aspects of the huge escalation in interest in this space over the past few years (catalyzed significantly by Google Fiber) is the emergence of a group of companies that are working with traditional public–private partnership models to develop strategies for enabling local governments to get FTTP networks built.

While the field is very fast developing and constantly changing, at least three companies have emerged so far with fully articulated business models and business propositions for localities: Macquarie Capital, SiFi Networks, and Symmetrical Networks.

All three companies are proposing interesting and innovative approaches—each with the same core concept (though with considerably different detail): The public sector's willingness to contract in the long term is what will enable and secure construction of the network. To date we are not aware of any commitments that these entities have reached with a public entity to deploy a FTTP network.

These variations on the private execution, public funding model are as of yet untested; we urge caution for that reason. But we note that this model is a promising means by which to develop a network that can serve the entirety of the community, not just the parts selected by a private investor.

5.2.2.1 Macquarie Capital

Macquarie Capital and its partner companies, which have pioneered this model in the broadband market in the U.S.,[79] will provide financing, construction, operations, and service delivery over the network. To fund all this activity and investment, the locality will pay Macquarie on an ongoing basis by placing a monthly fee on all local property owners' utility

[79] "Macquarie Capital," Macquarie Group, http://goo.gl/uvUEjv.

bills. Macquarie intends that multiple ISPs will compete over the network, giving consumers a choice of providers and the benefits of price competition (and creating a revenue stream for ISPs, who will pay Macquarie). Macquarie projects that network revenues will grow substantially over time; as service revenues generated by the ISPs increase, Macquarie commits to sharing some of its revenues with the locality.

Macquarie is an experienced and sophisticated entity, and offers a comprehensive solution. We note, however, that its open access business model is not tested and that the utility fee is likely to prove a heavy lift politically in most American communities.

5.2.2.2 SiFi Networks

In the SiFi Networks approach to this model, a local FTTP network is built and operated by SiFi and its partners at public sector expense. SiFi will provide financing and, with its partners, turnkey construction and operations—all of which will be compensated by lease payments from the public sector partner. SiFi will then bring to the community one or more ISP partners, with which the locality will contract to provide open access services over the network.

In SiFi's vision, the ISPs will make minimum payment guarantees to the locality in return for the opportunity to provide services over the network; those amounts will be negotiated and based on the public sector partner's actual costs. If multiple competing ISPs or even a single ISP is willing to make such commitments on a long-term basis, and if those ISPs are viable entities—with commitments backed by real resources—then the model will reduce the public sector partner's risk in terms of the ongoing payments to SiFi and its partners.

The viability of the model thus hinges on the willingness of ISPs to make such commitments, and the ISPs' confidence that they can realize sufficient revenues and margins to justify the commitments.

As with the Macquarie model, the SiFi model is interesting, but, so far, untested.

5.2.2.3 Symmetrical Networks

In Symmetrical Networks' version of this model, Symmetrical and its partners will build the network, which will be operated by an ISP chosen by the public sector partner. That operator may be an ISP that is a partner to Symmetrical, it may be the public sector entity itself, or it may be any other qualified network operator.

Symmetrical does not follow the multiple-ISP open-access approach anticipated by SiFi and Macquarie; rather, it intends that open access will happen "over the top" (OTT), when consumers select their own application providers over an unfettered data connection with no data cap.

Symmetrical will build, finance, and provide turnkey construction for an FTTP network, and the public sector partner will make a lease payment to Symmetrical that will cover the company's debt service, operating costs, and margin. The public sector entity will, in turn, be paid by the ISP; in Symmetrical's modeling, the ISP will pay the locality an amount equal to the locality's obligations to Symmetrical.

Symmetrical believes that this model is viable based on a minimum community-wide take rate of 35 percent. To reduce the public sector partner's risk, Symmetrical will not undertake a project unless city-wide, aggregated commitments at this level have been secured in advance.

As with the SiFi and Macquarie models, the viability of this model hinges on the selected ISP's ability to generate sufficient revenues to cover its required payment to the public sector entity (which equals the locality's required payment to Symmetrical), its costs, and, presumably, an acceptable operating margin. While Symmetrical is confident that this model is viable, it is also quite frank that the public sector entity bears the risk in the event that network revenues fall short of the obligated levels.

5.2.3 Model 3: Shared Investment and Risk (Dark FTTP Partnership)

A public–private partnership model based on shared investment and risk plays to the strengths of both the public and private sector partners. Most localities consider FTTP deployment not as a moneymaker, but as a powerful tool for education and economic development. Thus in a shared investment model, the risk is shared but the community still receives 100 percent of the benefits it seeks—recognizing that the benefits do not all appear on the project's financial statements. For the private partner, a shared investment means less upfront capital (risk), with an opportunity for future revenues.

Among other enormous benefits to this model, cities can not only provide fiber to the private sector—for compensation and to get gigabit and beyond service to the public—but can also secure extensive fiber throughout their communities for internal uses, including municipal and municipal utility operations, public safety, and emerging Smart City and Internet of Things (IoT) applications.

This model will provide an institutional or public sector network of the future—more extensive than any network that served city or county needs in the past, because the fiber will go everywhere in the community. It will have the potential to serve every conceivable application, from traffic signal control to air quality monitoring, from robust and secure public safety communications to high-end videoconferencing between universities and schools.

This benefit is ancillary to the core benefit of enabling a competitive gigabit (and beyond) product over fiber to every home and business in the community—but, in the long run, it has the potential to enable transformative public sector use and services. And indeed, local governments' track record of securing considerable savings and enormous operational capabilities over fiber is already demonstrated.[80]

We note, however, that while this model offers an extraordinary opportunity for innovation, it is in no way a sure thing for communities. We do not have the data points to develop the best practices necessary for success. At the moment, early actors are developing new and exciting partnerships to bring next-generation broadband to their communities. We describe some of those projects in the brief case studies below.

5.2.3.1 Case Study: Westminster, MD

The City of Westminster, Maryland, is a bedroom community of both Baltimore and Washington, D.C. where 60 percent of the working population leaves in the morning to work elsewhere.[81] The area has no major highways and thus, from an economic development perspective, has limited options for creating new jobs. Incumbents have also traditionally underserved the area with broadband.

The city began an initiative 12 years ago to bring better fiber connectivity to community anchor institutions through a middle-mile fiber network. In 2010, the State of Maryland received a large award from the federal government to deploy a regional fiber network called the Inter-County Broadband Network (ICBN) that included infrastructure in Westminster.[82]

Westminster saw an opportunity to expand the last mile of the network to serve residents. At the time, though, it did not have any clear paths to accomplish this goal. City leaders looked around at other communities and quickly realized that they were going to have to do something unique. Unlike FTTP success stories such as Chattanooga, Tennessee, they did not have a municipal electric utility to tackle the challenge. They also did not have the resources, expertise, or political will to develop from scratch a municipal fiber service provider to compete with the incumbents. As a result, they needed to find a hybrid model.

As the community evaluated its options, it became clear that the fiber infrastructure itself was the city's most significant asset. All local governments spend money on durable assets with long lifespans, such as roads, water and sewer lines, and other infrastructure that is used for the public good. The leaders asked, "Why not think of fiber in the same way?" The challenge then

[80] *See, for example:* "Community Broadband Creates Public Savings," Fact Sheet, Institute for Local Self-Reliance, https://goo.gl/kCEZeC.

[81] Case study is based in part on a presentation by Dr. Robert Wack, President, Westminster (Maryland) City Council, during a webinar hosted by the Fiber to the Home Council and facilitated by CTC Technology & Energy. *See*: http://goo.gl/x82Ro7 (password required). See also: Robert Wack, "The Westminster P3 Model," *Broadband Communities Magazine* (Nov./Dec. 2015), http://goo.gl/op1XpH.

[82] "The Project," Inter-County Broadband Network, http://goo.gl/GjBC26.

was to determine what part of the network implementation and operations the private sector partner would handle and what part could be the city's responsibility.

The hybrid model that made the most sense required the city to build, own, and maintain dark fiber, and to look to partners that would light the fiber, deliver service, and handle the customer relationships with residents and businesses. The model would keep the city out of network operations, where a considerable amount of the risk lies in terms of managing technological and customer service aspects of the network.

The city solicited responses from potential private partners through a request for proposals (RFP). Its goal was to determine which potential partners were both interested in the project and shared the city's vision.

The city eventually selected Ting Internet, an upstart ISP with a strong track record of customer service as a mobile operator. Ting shared Westminster's vision of a true public–private partnership and of maintaining an open access network. Ting has committed that within two years it will open its operations up to competitors and make available wholesale services that other ISPs can then resell to consumers.

Under the terms of the partnership, the city is building and financing all of the fiber (including drops to customers' premises) through a bond offering. Ting is leasing fiber with a two-tiered lease payment. One monthly fee is based on the number of premises the fiber passes; the second fee is based on the number of subscribers Ting enrolls.

Based on very preliminary information, given that this is a market in development as we write, we believe this is a highly replicable model.

What is so innovative about the Westminster model is how the risk profile is shared between the city and Ting. The city will bond and take on the risk around the outside plant infrastructure, but the payment mechanism negotiated is such that Ting is truly invested in the network's success.

Because Ting will pay Westminster a small monthly fee for every home and business passed, Ting is financially obligated to the city from day one, even if it has no customers. This structure gives the city confidence that Ting will not be a passive partner, because Ting is highly incented to sell services to cover its costs.

Ting will also pay the city based on how many customers it serves. Initially, this payment will be a flat fee—but in later years, when Ting's revenue hits certain thresholds, Ting will pay the city a small fraction of its revenue per user. That mechanism is designed to allow the city to share in some of the upside of the network's success. In other words, the city will receive a bit of entrepreneurial reward based on the entrepreneurial risk the city is taking.

Perhaps most significantly, there is also a mechanism built into the contract that ensures that the two parties are truly sharing risk around the financing of the outside plant infrastructure. In any quarter in which Ting's financial obligations to the city are insufficient to meet the city's debt service, Ting will pay the city 50 percent of the shortfall. In subsequent quarters, if Ting's fees to the city exceed the debt service requirements, Ting will be reimbursed an equivalent amount. This element of the financial relationship made the deal much more attractive to the city because it is a clear demonstration of the fact that its private partner is invested with it.

5.2.3.2 Case Study: Santa Cruz, CA

In what we believe is the first of many similar projects to come nationwide, the City of Santa Cruz has adopted a variation on the Westminster model (see Section 5.2.3.1 above). In December 2015, the City Council in Santa Cruz signed an agreement that potentially delivers tremendous value to local residents while sharing risk between the public and private sector.

The Santa Cruz City Council approved an agreement between the city and a local ISP, Cruzio. The city will build, own, and maintain a fiber network; Cruzio, which is a DSL reseller, will migrate many of its DSL customers over to the city's fiber network—and will actively pursue additional new customers to buy broadband services over the fiber. As in the Westminster agreement, Cruzio will pay the city both a per-passing and a per-subscriber fee for its use of the city's fiber.

Cruzio is a small company, which creates a certain amount of partnership risk for the city. But from the city's standpoint, it is a very attractive partner—a locally based, locally owned company that employs Santa Cruz residents. In fact, the name of the company incorporates the city's name.

For Santa Cruz, identifying a local partner was a key factor in its negotiations. Cruzio's localism was so important to the city that in early 2015, the Council directed city staff to negotiate exclusively with Cruzio.

Cruzio has operated in the city since the early days of the Internet when it was a dialup ISP. In the broadband era, it migrated to some wireless service and to reselling phone company DSL. The logical next step is for Cruzio to migrate to fiber—which is what the relationship with the city will enable it to do.

The benefits of the partnership to the city include not only owning a next-generation network—and all the positive externalities that come with such a network—but also supporting and enabling an important local employer and longtime partner in the community.

5.2.3.3 Case Study: Garrett County, MD

The case studies presented above are incredibly promising, but those projects may be more challenging to replicate in rural communities, where the cost of fiber deployment, even in a shared-investment scenario, may still be prohibitive. The shared investment and shared risk strategy, however, is still applicable to rural communities—perhaps using other technologies that secure the benefits of broadband even if they do not result in the kinds of speeds that fiber enables.

For example, Garrett County, in far western Maryland, is a relatively remote Appalachian community bordered by West Virginia and Pennsylvania. The county has struggled to get broadband in a number of its remote, mountainous areas. Where broadband is available, it is inadequate DSL service that does not meet the Federal Communications Commission's (FCC) new speed benchmark for broadband service, let alone the requirements for home-based businesses or home schooling. The incumbent provider has not made any plans to expand or upgrade service offerings.

Though mobile broadband is available in some parts of the county, data caps mean that it is not viable for economic or educational activities. (Parents who home-school their children can run through their monthly bandwidth allotment in one day of downloading educational videos.) Beyond these challenges for residents, the county has struggled to attract and retain businesses and teleworkers.

In response, the county has gradually and incrementally built out fiber in some areas, with a focus on connecting specific institutions. And in September 2015, the County Council approved a contract with a private partner to leverage some of that fiber and additional public funding to support the deployment of a fixed-wireless broadband network that will serve up to 3,000 currently unserved homes in the most remote parts of the county. The private partner, Declaration Networks Group (DNG), will also put its own capital toward the construction of the network, and will apply its technical and operational capabilities to managing the network.

The partnership involves cost to the county, but also massive benefit for residents and businesses in the newly served areas.

The county's outlay of funds will be $750,000, which will be matched by a grant from the Appalachian Regional Commission (ARC)—and which will be more than matched by DNG's commitment of both capital and operating funds. That relatively modest county contribution (which was then leveraged for the ARC economic development funding) made the economics of this opportunity very attractive to DNG, and secured a broadband buildout for an area that would otherwise not be attractive for private sector broadband investment.

From an economic development perspective, the county's investment represents enormous value for the dollar. This investment will enable residents in 3,000 homes to buy cost-effective broadband service that they cannot access now, and that will make possible telework, home-based businesses, and home schooling. This investment will also enable the county to close the homework gap for many students in the county schools who do not currently have broadband in their homes—an increasingly critical lack of service.

As the network is deployed over the next few years, the county will reduce to nearly zero the number of homes in the county that do not have access to some kind of broadband communications options. These options may be modest—not the robust speeds available in metro markets—but they are significantly better than nothing, and a huge economic development achievement from the county's standpoint.

5.3 Additional Strategic Considerations for Public–Private Partnerships

As public sector entities of all sizes and capabilities evaluate potential models for public–private partnerships, it is important to approach each proposal with a healthy dose of common sense. Next-generation fiber deployment, particularly on a large scale to reach all residences and businesses in a community, is a valuable and future-proof investment. But it will not be cheap or easy. If anyone tells you otherwise, or claims that they will deliver enormous benefits at little or no cost or risk, ask for examples of projects where they have accomplished what they are promising. If it were easy, we would already have seen enormous private investment in FTTP across the country. Communities should be skeptical of rosy projections.

It is also critical to look for private sector partners that are interested in developing meaningful partnerships to deploy next-generation infrastructure. A significant risk around economic development incentives and other measures to facilitate investment is that private companies will request that localities take on additional costs as a condition of the private investment. For example, a private partner might ask the local government to hire dedicated inspectors and provide free access to real estate—and provide in return only tacit commitments for new services or technological upgrades. The goal of these partnerships is not simply to shift private sector costs to the public sector. If a company is a true partner, it will be willing to make firm commitments to invest in the community in return for the actions the locality takes to lower the cost of deploying infrastructure.

In addition, partners and partnerships will differ in different parts of the country, and with the size of a community. A primary challenge for localities seeking buildout to every residence and business is that the larger the community, the more difficult it may be for a private partner to deploy its service universally. By taking on the risk of fiber construction and finding a partner to light the network and provide service, a locality can increase the potential for a universal fiber buildout to every location.

Finally, do not underestimate the importance of the political element in tackling these challenges. Political concerns will play a huge role in finding solutions. Community and political leaders must jointly decide to pursue a project of this scope, to solve the problems that may arise along the way, and to bring fiber and its benefits to the community.

6 Engineering Analysis: FTTP Network Requirements and Design

The City of Madison recognizes the importance of deploying a robust, scalable FTTP[83] network infrastructure that can support a wide range of applications and services. This section describes many of the applications and services that the City's proposed FTTP network will need to support, as well as the general requirements of the FTTP network design. We present high-level cost estimates for a potential deployment of a gigabit FTTP network in Section 7.

6.1 Field Survey Methodology for Network Design and Cost Estimate

A CTC OSP engineer performed a preliminary survey of Madison via Google Earth Street View to develop estimates of per-mile cost for aerial construction in the power space and communications space, and per-mile costs for underground construction in areas where poles are not available.

A CTC engineer then conducted a brief on-site field study of representative portions of the City. The engineer reviewed available green space, necessary make-ready on poles, and pole replacement—all of which have been factored in to our design and cost estimate.

Figure 74 illustrates the areas reviewed during the field survey, while Table 17 summarizes each. Both the map and the table refer to the four types of population densities and existing utilities we used in our cost estimation model—high, medium aerial, medium underground, and low. (See Section 7.1 for more details.)

[83] FTTP is a network architecture in which fiber optics are used to provide broadband services all the way to each subscriber's premises.

Figure 74: Map of Field Survey Areas

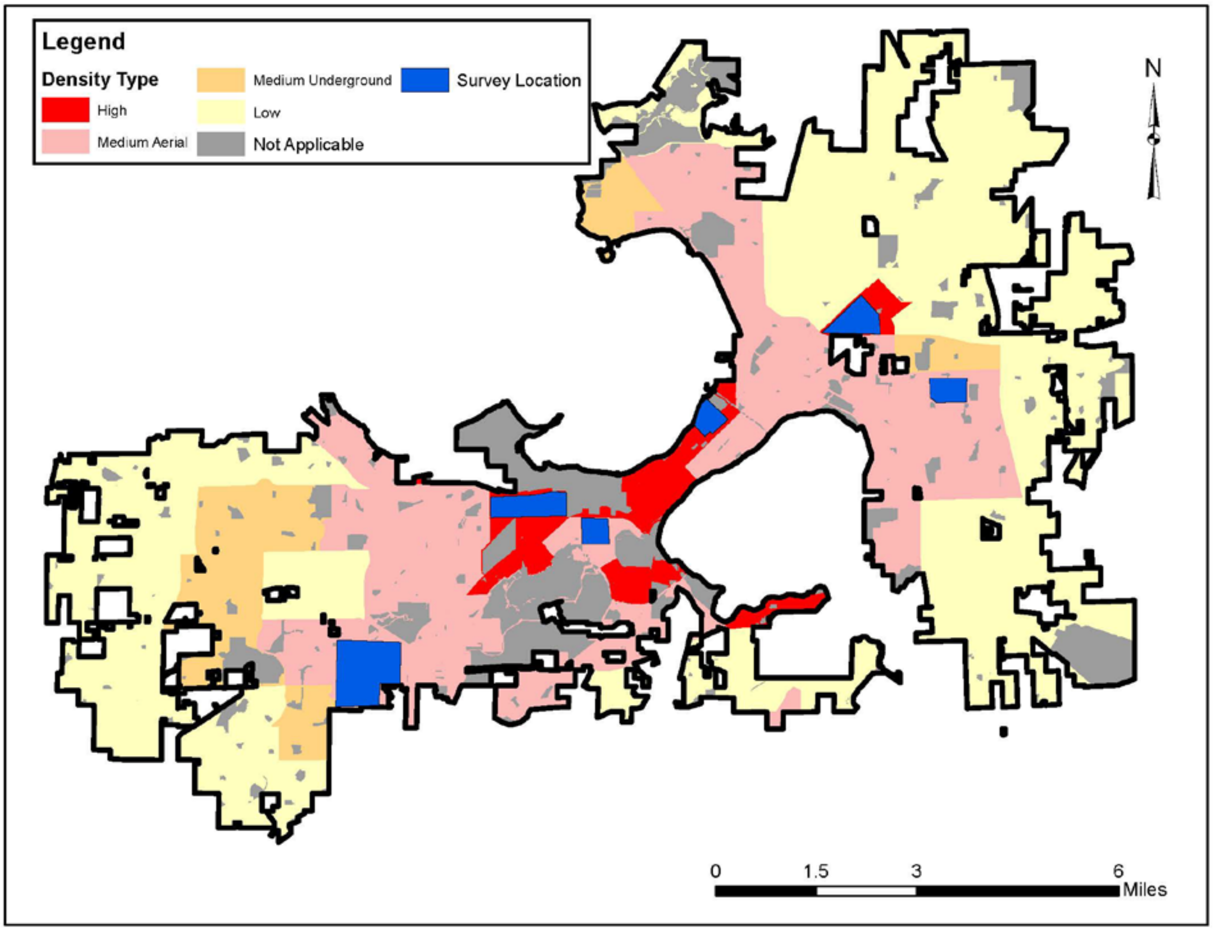

Table 17: Field Survey Findings[84]

	High Density	Medium Density Aerial	Medium Density Underground	Low Density
Aerial Construction	70%	70%	0%	0%
Poles per Mile	35	35	NA	NA
Moves per Pole	2.5	2.5	NA	NA
Poles Requiring Make-Ready	30%	30%	NA	NA
Poles Requiring Replacement	6%	5%	NA	NA
Intermediate Rock[85]	10%	5%	5%	5%
Hard Rock	2%	1%	1%	1%

[84] NA fields corresponds to underground areas, where utility poles are not part of the analysis.
[85] Higher percentages of intermediate and hard rock were used to simulate the tougher underground construction in the high-density downtown areas.

CTC's OSP engineer noted that the quality of the poles and pole attachments in Madison varied, as they do in many cities—but that overall, many poles would be capable of supporting an additional communications attachment with moderate make-ready.

6.2 FTTP Network Requirements

To explain why our analysis focuses on FTTP technology, we describe in this section the services and applications that the City's network must be able to support, the nature of the technologies we chose for the network, and the user groups we anticipate will use the network or subscribe to services.

6.2.1 User Applications and Services

The City's network must be able to support "triple play" services—high-quality data, video, and voice—that residential customers have grown accustomed to having in their homes, although this does not mean that the City or a given partner will be the entity that *directly* provides telephone or cable television services. As Internet technology has improved and network speeds have increased, voice and video services have become available as applications delivered by hundreds of providers over an Internet Protocol (IP)[86] data network connection.

The City and a potential partner can enable residential and small business customers to purchase voice, video, and other over-the-top (OTT)[87] services by providing them with unfettered,[88] reliable, high-speed Internet access with connections at a minimum of 1 Gbps.[89] In other words, the City and its partner would become an IP data network provider, either directly or through partnership(s), and would enable its citizens to purchase services—without the City acting as a gatekeeper.

6.2.1.1 Internet Access

Internet access is the fundamental service that most residents and small business owners will expect from a fiber connection, and is the prerequisite service for all of the applications described below. The retail provider on the FTTP network will also need one or more peering connections with upstream Internet service providers (ISP), reducing wholesale Internet costs and improving service delivery.

As described in detail below, the FTTP network will support a baseline service level (e.g., 1 Gbps) suitable for residential and small business customers. It will also be capable of supporting

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[86] Internet Protocol, or "IP," is the method by which computers share data on the Internet.

[87] "Over-the-top" (OTT) content is delivered over the Internet by a third-party application or service. The ISP does not provide the content (typically video and voice) but provides the Internet connection over which the content is delivered.

[88] Meaning that access to websites offering OTT services is not blocked, restricted, or rate-limited.

[89] Rate is a best-effort basis, not a guaranteed speed. Further, it is important to note that with the proposed architecture the retail provider(s) would provide a 1 Gbps baseline service and 10 Gbps and beyond on a case-by-case basis. The baseline can be increased to 10 Gbps and beyond by upgrading the network electronics

higher residential speeds—10 Gbps and beyond—and a range of business and enterprise services.[90]

6.2.1.2 IP Telephony (VoIP) and Video Conferencing

Voice over IP (VoIP) is a voice telephony service delivered over an IP data network.[91] In the context of an FTTP access network, VoIP generally refers to an IP-based alternative to Plain Old Telephone Service (POTS) over copper wiring from a Local Exchange Carrier (LEC).[92] With VoIP, both the live audio (voice) and the call control (signaling) portions of the call are provided through the IP network. Numerous third parties offer this type of full-service VoIP, which includes a transparent gateway to and from the Public Switched Telephone Network (PSTN).[93]

Because VoIP runs over a shared IP network instead of a dedicated pair of copper wires from the LEC, extra design and engineering are necessary to ensure consistent performance. This is how the VoIP services delivered by Comcast (which provides Quality of Service, or QoS,[94] on its network underneath the VoIP services) typically have the same sound and feel as traditional wireline voice calls. In contrast, VoIP services without QoS (such as Skype) will have varied performance, depending on the consistency of the Internet connection. For voice and other real-time services such as video conferencing, network QoS essentially guarantees the perceivable quality of the audio or video transmission.

From a networking perspective, IP-based video conferencing services are fundamentally similar to VoIP. While IP video conferencing is currently less common as a residential application, small and medium-sized businesses in the FTTP domain can be assured that QoS for IP-video conferencing can also be supported, as with VoIP.

6.2.1.3 Streaming Video

The variety of online video available through service providers like Amazon, HBO Go, Hulu, Netflix, YouTube, and others continues to attract users and challenge cable providers' traditional business models. These are all examples of OTT[95] video available over the Internet to users at home or on mobile devices like a smartphone or tablet.

Traditional cable television providers (also known as linear multi-channel video services) can also deliver content over a fiber connection rather than through a separate coaxial cable connection to users' homes.

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[90] Network can support faster connection speeds and other guaranteed service levels to a portion of end users.
[91] In this context, voice services are delivered over a data connection.
[92] A LEC is a public telephone company that provides service to a local or regional area.
[93] The PSTN is the copper-wire telephone networks that connect landline phones.
[94] QOS is a network's performance as measured on a number of attributes.
[95] OTT refers to voice, video, and other services provided by a third-party over the Internet rather than through a service provider's own dedicated network. OTT is also known as "value added" service.

All of these video services can be supported by the proposed FTTP network—as will be locally produced content from a Media Center and public service videos or documentaries filmed by students, community groups, or others which can be streamed to residents directly from a school, library, or government building that is on the network. The avenues through which consumers can access content are broadening while the process becomes simpler.

Because of the migration of video to IP format, we do not see a need for the FTTP network to support the Radio Frequency (RF) based video cable television service, an earlier technology used by some providers to carry analog and digital television in native form on a fiber system.

Early municipal providers like Lafayette Utilities System (LUS) and Chattanooga's Electric Power Board (EPB) found that a data product alone was not strong enough to obtain the necessary market share to make the endeavor viable. Even when Google Fiber entered the Kansas City market in 2011, it found that if it wanted to get people to switch providers, it *had* to offer cable, deviating from its original plan and introducing more cost and complexity than the simple data service it had anticipated. If an OTT cable offering were available when early municipal providers began offering service and when Google entered the Kansas City market, they may have found that offering traditional cable television was unnecessary. More recent municipal FTTP efforts, like Longmont, Colorado, are successfully gaining market share without providing video services.

6.2.1.4 Cloud Access

"Cloud services" refers to information technology services, such as software, virtualized computing environments, and storage, available "in the cloud" over a user's Internet connection. Enterprise and residential customers alike increasingly use cloud services. With their mobile devices like smartphones and tablets, consumers want access to their photos, videos, and music from anywhere. And businesses want employees to have access to important information to keep operations running smoothly, even when they are away from the office.

The business drivers behind cloud computing are ease of use and, in theory, lower operating costs. For example, if you are a business owner, the "cloud" theoretically allows you to use large-scale information services and technologies—without needing hardware or staff of your own to support it.

Cloud services eliminate the need to maintain local server infrastructure and software, and instead allow the user to log into a subscription-based cloud service through a Web browser or software client. The cloud is essentially a shift of workload from local computers in the network to servers managed by a provider (and that essentially make up the cloud). This, in turn, decreases the end user's administrative burden for Information Technology (IT) services.

Typically, cable modem and DSL services are not symmetrical—thus incumbent network transfer rates to upload to the cloud are significantly slower than download rates. This can cause significant delays uploading to cloud services.

There are also numerous other cloud services that customers frequently use for non-business purposes. These include photo storage services like Flickr and Shutterfly, e-mail services like Gmail and Hotmail, social media sites like Facebook and Twitter, and music storage services like iTunes and Amazon Prime.

By enabling retail ISP(s) to reliably serve residents and small businesses with high-speed services, the City's FTTP network will increase their options to use the cloud. Improving on less robust connections (e.g., cellular broadband or cable modem services), the City's network will also enable teleworkers and home-based knowledge workers in Madison to access cloud-based development environments, interact with application developers (both local and remote), and access content delivery network (CDN) development and distribution channels.[96]

6.2.1.5 Over-the-Top (OTT) Programming

As we noted, OTT programming typically refers to streaming content delivered via a consumer's Internet connection on a compatible device. Consumers' ubiquitous access to broadband networks and their increasing use of multiple Internet-connected devices has led to OTT being considered a disruptive technology for video-based entertainment. The OTT market, which includes providers like Netflix, Hulu, Amazon Instant Video, and iTunes, was expected to grow from about $3 billion in 2011 to $15 billion, by 2016.[97] New projections anticipate that the industry could grow to $17 billion by 2017[98] and $19 billion by 2019.[99]

In order to provision content, OTT services obtain the rights to distribute TV and movie content, and then transform it into IP data packets that are transmitted over the Internet to a display platform such as a TV, tablet, or smartphone. Consumers view the content through a Web-based portal (i.e., a browser) or an IP streaming device (e.g., Google Chromecast, Roku, Apple TV, Xbox 360, or Internet-enabled TV/Smart TV).

One potential difference in the delivery of OTT video content to consumers compared to other data traffic is OTT video's high QoS requirement. QoS prioritizes the delivery of video packets

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[96] See, for example: "Amazon CloudFront," *Amazon Web Services,* accessed May 3, 2016, http://aws.amazon.com/cloudfront/.

[97] Dr. Karim Taga and Clemens Schwaiger, "Over-the-Top-Video – "First to Scale Wins," *Arthur D Little*, accessed May 3, 2016, http://www.adlittle.com/downloads/tx_adlreports/TIME_2012_OTT_Video_v2.pdf.

[98] "Over-the-top content revenue worldwide from 2008 to 2017," *Statista*, accessed May 3, 2016, http://www.statista.com/statistics/260179/over-the-top-revenue-worldwide/.

[99] Wayne Friedman, "Over-the-Top TV Revenues Forecast to hit $19B In 2019," *Media Post,* last modified June 11, 2015, http://www.mediapost.com/publications/article/251798/over-the-top-tv-revenues-forecast-to-hit-19b-in-2.html.

over other data where uninterrupted delivery is not as critical, which ultimately translates to a high quality viewing experience for customers. Content buffering and caching for streamed content reduces the need for QoS. Network QoS is designed for and driven by the need to support real-time services such as VoIP and video conferencing.

OTT providers typically have to use the operators' IP bandwidth to reach many of their end users. At the same time, they are a major threat to cable television programming, often provided by the very same cable operators, due to their low-cost video offerings. As a result, many cable operators have introduced their own OTT video services to reach beyond the constraints of their TV-oriented platforms and to facilitate multi-screen delivery.[100]

Even Comcast seemed to embrace OTT by launching its "Streampix" in 2012,[101] though that service was less than successful and was ultimately removed as a standalone offering. In 2015, Comcast announced another attempt at providing OTT content in the form of its "Stream" package,[102] however subscribers must also sign up for Xfinity Internet to access "Stream" content.

While the nature of OTT video lends itself nicely to video-on-demand (VoD), time-shifted programming, and sleek user interfaces, OTT providers have limited control over the IP transport of content to users, which can cause strains on network bandwidth due to the unpredictable nature of video demand. Cable operators have experimented with rate limiting and bandwidth caps,[103] which would reduce subscribers' ability to access streaming video content. It is also technically possible for cable operators to prioritize their own traffic over OTT video streams, dial down capacity used by OTT on the system, or stop individual OTT streams or downloads.

Some cable operators have attempted to manage OTT on their networks by incorporating the caching of OTT video content from third-party providers (e.g., Netflix) in their data centers in order to improve QoS and reduce congestion on the cable provider's backbone network. This serves as a means for improving the quality of OTT video for video hosted in the data center.

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[100] "Cable operators embrace over-the-top video, but studios thwart Netflix, Hulu options," *FierceCable*, last modified July 2, 2013, http://www.fiercecable.com/special-reports/cable-operators-embrace-over-top-video-studios-thwart-netflix-hulu-options.

[101] John Cook, "Comcast unveils $4.99 per month Streampix service, taking aim at Netflix," *GeekWire,* last modified February 21, 2012, http://www.geekwire.com/2012/comcast-unveils-499-month-streampix-service-aim-netflix-hulu/.

[102] Heather Newman, "Why Comcast Is Still Betting On Bundles with Stream," *Forbes,* last modified July 27, 2015, http://www.forbes.com/sites/hnewman/2015/07/27/why-comcast-is-still-betting-on-bundles-with-stream/#2416cfcb72e6.

[103] Jeff Baumgartner, "Comcast tests new usage based internet tier in Fresno," *Multichannel News*, last modified August 1, 2013, http://www.multichannel.com/distribution/comcast-test-new-usage-based-internet-tier-fresno/144718.

6.2.2 Network Design Considerations

This section provides a high-level overview of certain functional requirements used to prepare the conceptual FTTP design and cost estimate. It also presents the technical details of an FTTP network in terms of performance, reliability, and consumer perceptions based on providers' marketing.

Google changed the industry discussions and customer perceptions of data access when it introduced its plans to deploy an FTTP network and offer a 1 Gbps data connection for $70 per month in Kansas City, beginning in 2012.[104] Until Google entered the FTTP market, cable operators such as Comcast questioned the need for 1 Gbps speeds and typically indicated that 10 Mbps was sufficient for residential and small business users. (Gigabit speeds were available in a few localities, such as Chattanooga, Tennessee, but Google's brand name meant that Google Fiber had a bigger impact on national awareness around this type of connection.) Since Google's entry, Comcast and other providers have slowly increased their data offering speeds—moving to 25 Mbps, 50 Mbps, and finally gigabit fiber services in selected markets.

Charter has not indicated plans to offer a 1 Gbps service in Madison; however, it has indicated plans for a demonstration of a 1 Gbps service in Louisville, Kentucky as part of a franchise agreement transfer in that city.[105]

Other cable operators have been more aggressive. For example, Comcast already advertises its 2 Gbps "Gigabit Pro" service in several markets—though that service is only available in locations that are less than one-third of a mile from its existing fiber infrastructure, and requires users to pay at least $1,000 in activation and installation fees. Comcast has also announced plans to upgrade its existing hybrid fiber-coaxial (HFC) network to DOCSIS 3.1 across its entire service area by 2018. Initially, it will offer 1 Gbps service, but DOCSIS 3.1 is capable of offering as much as 10 Gbps service. Comcast has not yet released pricing for DOCSIS 3.1-based services.[106]

It is important to note that Internet access speed represents only one portion of the overall Internet experience, and measuring a network's overall performance on one metric is incomplete. Further, "advertised speed" for residential services is a best-effort commitment, not a guarantee, and does not necessarily reflect actual performance. For example, the

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[104] "Plans and Pricing," *Google Fiber,* accessed May 3, 2016, https://fiber.google.com/cities/kansascity/plans/.

[105] Daniel Frankel, "Charter takes over TWC's Louisville charter, agrees to free Wi-Fi, 1 Gbps conditions," *FierceCable*, last modified October 23, 2015, http://www.fiercecable.com/story/charter-takes-over-twcs-louisville-charter-agrees-free-wi-fi-1-gbps-conditi/2015-10-23.

[106] Mike Dano, "Comcast: We'll cover our entire network with 10 Gbps-capable DOCSIS 3.1 tech as soon as 2018," *FierceCable*, last modified August 21, 2015, http://www.fiercecable.com/story/comcast-well-cover-our-entire-footprint-10-gpbs-capable-docsis-31-tech-soon/2015-08-21.

advertised speed does not delineate a minimum speed or a guarantee that any given application, such as Netflix, will work all the time.

6.2.2.1 Why Fiber Optics

For several decades, fiber optic networks have consistently outpaced and outperformed other commercially available physical layer technologies, including countless variants of copper cabling and wireless technologies. The ranges of current topologies and technologies all have a place and play important roles in modern internetworking.[107] The evolution of Passive Optical Network (PON) technology has made FTTP architecture extremely cost-effective for dense (and, more recently, even lower and medium-density) population areas.

The specifications and the performance metrics for FTTP networks continue to improve and outperform competing access technologies. In fact, from the access layer up through all segments of the network (the distribution layer and the core, packet-, and circuit-switched transports, and even into the data center), and for almost all wireless "backhaul" communications, optical networking is the standard wireline technology.

Compared to other topologies, fiber-based optical networks will continue to provide the greatest overall capacity, speed, reliability, and resiliency. Fiber optics are not subject to outside signal interference, can carry signals for longer distances, and do not require amplifiers to boost signals in a metropolitan area broadband network.[108]

If an ISP were to build new with no constraints based on existing infrastructure, it would likely begin with an FTTP access model for delivery of all current services; compared to other infrastructure, an FTTP investment provides the highest level of risk protection against unforeseen future capacity demands. In cases where a provider does not deploy fiber for a new route, the decision is often due to the provider's long-term investment in copper OSP infrastructure, which is expensive to replace and may be needed to support legacy technologies.

6.2.2.2 Fiber Routes and Network Topology

FTTP architecture must be able to support a phased approach to service deployment. Phased deployments can help support strategic or tactical business decisions of where to deploy first, second, or even last. Phasing also allows for well-coordinated marketing campaigns to specific geographic areas or market segments, which is often a significant factor in driving initial acceptance rates and deeper penetration. This is the "fiberhood" approach used by Google and others.

[107] An internetwork is a network of interconnected networks.

[108] Maximum distances depend on specific electronics—10 to 40 km is typical for fiber optic access networks.

A fiber backbone brings the fiber near each neighborhood, and fiber can be extended as service areas are added in later phases of deployment. This allows for the fiber in individual neighborhoods to be lit incrementally,[109] with each new neighborhood generating incremental revenue.

The proposed Gigabit passive optical network (GPON) FTTP architecture supports this capability once the core network electronics are deployed and network interconnections are made. GPON is the most commonly provisioned FTTP service—used, for example, by Verizon (in its FiOS systems), Google Fiber, and Chattanooga Electric Power Board (EPB). GPON uses passive optical splitting, which is performed inside fiber distribution cabinets (FDCs), to connect fiber from the optical line terminals (OLTs)[110] to multiple customer premises over a single GPON port. The GPON architecture is discussed further in Section 6.2.2.3 and Section 6.3 below.

In addition to these core considerations, we note that designing the network to support mobile backhaul may allow the City or its partners to generate additional revenue from mobile carriers, as well as improve mobile broadband service in the city. Given that this is a longer-term consideration our financial model does not currently include revenue earned from leasing excess network capacity to cellular providers for mobile backhaul use.

6.2.2.3 Passive Optical Network—Specifications and Technology Roadmap

The first PON specification to enjoy major commercial success in the U.S. is Gigabit-capable Passive Optical Network (GPON). This is the standard commonly deployed in today's commercial FTTP networks and it is inherently asymmetrical. Providers from Google Fiber to Chattanooga's EPB offer 1 Gbps asymmetrical GPON service with relatively high oversubscription rates (albeit far less than non-FTTP competitors). Our suggested network design allows for provision of symmetrical services ranging from typical levels of oversubscription to dedicated symmetrical capacity per subscriber.

The GPON standard (defined by ITU-T G.984.1) was first established and released in 2004, and while it has since been updated, the functional specification has remained unchanged. There are network speed variants within the specification, but the one embraced by equipment manufacturers and now widely deployed in the U.S. provides asymmetrical network speeds of 1.24 Gbps upstream and 2.49 Gbps downstream.

Since the release of the ITU-T G.984.1 GPON specification, research and testing toward faster PON technologies has continued. The first significant standard after GPON is known by several names: XG-PON, 10GPON, or NG-PON1. The NG-PON1 specification offers a four-fold performance increase over the older GPON standard. Although NG-PON1 has been available

[109] As the name implies, "lit fiber" is no longer dark—it is in use on a network, transmitting data.
[110] The OLT is the upstream connection point (to the provider core network) for subscribers.

since 2009, it was not adopted by equipment manufacturers and has not been deployed in provider networks. We expect the version released in 2015, NG-PON2, to evolve as the de facto next-generation PON standard.

These new standards can be implemented through hardware or software (electronics) upgrades, and are "backward compatible" with the current generation, so all variants can continue to operate on the same network.

The optical layer of the NG-PON2 standard is quite different from GPON. The specification uses a hybrid system of new optical techniques, time division multiplexing (TDM) / wave division multiplexing (WDM) PON (TWDM-PON), that basically multiplexes four 10 Gbps PONs onto one fiber, to provide 40 Gbps downstream. This is a 16-fold performance increase over the current GPON standard.

While efforts continue on an ongoing basis by the standards-development community and hardware manufacturers to deliver a WDM-based solution leveraging wavelength-tunable optics to significantly surpass the 10 Gbps barrier, the more recently announced XGS-PON represents an interim solution to facilitate true symmetrical 10 Gbps services (the "S" in "XGS"). The ITU-T announced simultaneously on March 1, 2016 the approval of an amendment to the NG-PON2 standards with the first-stage approval the "XGS-PON" standard.

The XGS-PON physical layer is based on XG-PON specifications (and likely eliminates any potential demand there might have been for XG-PON), operating within the same windows using fixed wavelength optics. Final approval of the standard is expected later in 2016, and some manufacturers expect widespread commercial deployments to begin in 2017—well before NG-PON2 hardware will be widely available or affordable—enabling providers to deliver symmetrical 10 Gbps services over their PON infrastructure while operating in parallel with existing GPON services.

At minimum, the upgrade pathway for existing GPON deployments will require new enhanced small form-factor pluggable (SFP+) modules on the OLT side within the hub building or equipment cabinet, and a new optical network terminal (ONT) device at the customer premises, with software and firmware upgrades on the FTTP electronics. The migration to WDM-based technologies, like NG-PON2, also require the addition of coexistence elements ("CEx") between the OLT and the PON splitters, which can consist of a range of configurations of passive wavelength filters and couplers. Final details are yet to be announced and will vary by manufacturer, but the NG-PON2 specification requires a migration path and backward compatibility with GPON, facilitated by a coordinated wavelength plan that allows each of these standards to operate over common fiber strands without interfering. FTTP equipment manufacturers are actively testing upgrade steps and strategies for migrating from GPON to NG-PON2.

Table 18: PON Standards

Year	Standard
1994	pi-PON. 50 Mb/s, 1310nm bidirectional, circuit switched
1999	A/B-PON. 622/155 Mb/s, 1550nm down, 1310nm up, ATM-based
2004	G-PON. 2.4/1/2Gb/s, 1490nm down, 1310nm up, packet-based G-PON (2.5)
2009	NG-PON1. 10/2.5Gb/s, 1577nm down, 1270nm up, packet-based XG-PON (10)
2015	NG-PON2. 40G+ capacity XLG-PON (40)
2016	XGS-PON. 10/10 Gb/s, 1577nm down, 1270 up

6.2.2.4 Managing Network Demand

Perhaps the most fundamental problem solved by IP packet data networking is how to cost-effectively design, build, and operate a network to manage unpredictable demands and bursts of network traffic.

The earliest transport networks (and many of the major Internet backbone segments today) are circuit switched. This means that each network leg is a fixed circuit, running at a fixed speed all the time. Fixed-circuit networks are less flexible and scalable, and utilize capacity far less efficiently than packet-switched networks; they must be precisely designed and planned in advance, because there are fewer mechanisms to deal with unplanned traffic surges or unexpected growth in demand.

"Dial-up" modems provide an example of circuit-switched technology. Copper POTS lines were in huge demand as residential and business customers purchased fax machines and accessed the Internet over modems. Because the POTS technologies could not support all of these uses at the same time, and were limited to slower speeds, phone companies were only able to serve that demand by installing more copper lines.

The packet-switched DSL, cable modem, fiber, and wireless technologies that replaced POTS addressed the limitations of fixed-circuit technologies because the flow of network traffic is determined on a per packet basis, and the network provides robust mechanisms for dealing with unexpected bursts of traffic. The trade-off for flexibility, resiliency, and ease of use is that network speed will vary, depending mainly on the amount of traffic congestion.

6.2.2.4.1 Oversubscription

An important balancing act in packet networks is between network performance (speed) and network utilization (efficiency). The primary method of achieving this balance is *oversubscription*. Because the vast majority of network users are not actually transmitting data at any given moment, the network can be designed to deliver a certain level of performance based on assumptions around actual use.

Oversubscription is necessary in all packet-switched network environments and is generally beneficial—by enabling the network operator to build only as much capacity as necessary for most scenarios. By way of comparison, the electric industry uses a demand factor to estimate generation requirements. Similarly, a road that has enough capacity to keep most traffic moving at the speed limit most of the time will get congested during peak travel times—but building a road large enough to handle all of the traffic at peak times would be too expensive. Most drivers most of the time have enough room to go the speed limit, but when a lot of users want to be on the road at the same time, everyone has to slow down.

The retail provider(s) using the City FTTP network will need to evaluate and manage its subscription levels to deliver the optimal balance of performance and efficiency. Although the goal of providing symmetrical *dedicated*[111] 1 Gbps data to all subscribers is admirable and technically possible, it may not be very practical or affordable. By comparison, Google's 1 Gbps offering is technically neither symmetrical nor dedicated.

Services may be burstable, meaning that users may experience the advertised data rates at times, but the average speed will vary greatly based on the traffic being generated over the provider's distribution network. Performance parameters on a burstable service are rarely publicized or realized. Often a network operator cannot change this parameter without changing the network's physical connections.

When looking at FTTP requirements, it is important to understand that the speeds and performance stated in marketing material for consumer services are not the same as a network's actual technical specifications. Actual speeds and performance will depend on the activity of other users on the network. Generally, all residential and small business Internet services are delivered on a best-effort basis and have oversubscription both on the network and in the network's connection to the Internet.

First, let's look at network oversubscription. Today's GPON standard supports FTTP network speeds of up to 2.4 Gbps downstream (to the consumers) and 1.2 Gbps upstream (from the consumers) from a given OLT. Each OLT interface is typically connected to passive optical splitters configured to support up to 32 premises.[112] That is, up to 32 users will share the 2.4 Gbps downstream and 1.2 Gbps upstream.[113] Given that not all users will demand capacity at

[111] As its name implies, service is "dedicated" when the link runs directly from the ISP to the user.
[112] Can be deployed in 8 to 1, 16 to 1, and 32 to 1 configurations. Lower rations reduce the number of subscribers sharing the capacity, but increases the number of FDCs and fiber strands.
[113] In an HFC network as used by Comcast, the network capacity is shared among 250 to 500 users.

the same time and that very few applications today actually use 1 Gbps, a provider can reasonably advertise delivery of a symmetrical 1 Gbps service on a best-effort basis and most consumers will have a positive experience. This level of oversubscription at the GPON "access" layer is quite low compared to most modern cable modem networks, which typically share 150 Mbps – 300 Mbps among several hundred users, even while offering service tiers that "burst" to 150 Mbps.

NG-PON2 (described above) will likely enable support of 40 Gbps downstream. In four or so years, the NG-PON2 platform should become standard, and although it will initially be somewhat more expensive, pricing will likely quickly match levels similar to today's 2.4 Gbps platform.

Even with today's 2.4 Gbps GPON platform, the network can be designed to support 10 Gbps, 100 Gbps, or other symmetrical speeds. This can be accomplished with a hybrid approach using Active Ethernet (AE)[114] and GPON, or by deploying a full AE network, which would require placing active electronics inside FDCs in the field.

The next level of oversubscription is generally in the distribution network between the OLT and the service provider's core network. This portion of the network varies drastically between networks of different size, and is specific to the architecture of a particular network. Most OLT hardware provides 10 Gigabit Ethernet (10 GE) interfaces for uplinks to aggregation switches, frequently with multiple 10 GE interfaces supporting dozens of GPON interfaces (each supporting 16 or 32 customers)—perhaps on the order of 500 or 1,000 customers supported over a pair of redundant 10 GE links. While substantially more oversubscription than at the access layer in a GPON network, most OLT hardware is modularly scalable so that oversubscription can be managed by augmenting uplink capacity as demands grow. Moreover, this layer of the network can generally be upgraded less expensively and, indeed over-engineered in the initial deployment without significantly impacting costs in a relative sense, as the number of network devices and interfaces are far fewer than at the access layer.

The next level of oversubscription is with the network's access to the Internet. Again, since not all users demand capacity at the same time, there is no need to supply dedicated Internet bandwidth to each residential or small business customer. In fact, it would be cost prohibitive to do so: Assuming a DIA cost of $0.50 per Mbps per month, the network operator would pay $500 per month for 1 Gbps of DIA. But an operator with a residential and small business 1 Gbps service could easily use an oversubscription of 500 to 1,000 on DIA today. Then, as users

[114] This is a technology that provides a symmetrical (upload/download) Ethernet service and does not share optical wavelengths with other users. For subscribers that receive AE service—typically business customers that request a premium service or require greater bandwidth—a single dedicated fiber goes directly to the subscriber premises with no optical splitting.

require more bandwidth, the operator simply subscribes to more bandwidth. The preferential approach is to reduce the traffic over the Internet, which is accomplished by peering to other networks, placing servers (such as Netflix) on the City's FTTP network (referred to as on-net), and caching.[115]

All of the applications that the City has identified are possible with 1:32 GPON architecture and reasonable oversubscription. If a bottleneck occurs at the Internet access point, the retail provider(s) can simply increase the amount of commodity bandwidth (DIA) it is purchasing or bring servers such as Netflix on-net. Customers looking for greater than 1 Gbps or who require Committed Interface Rates (CIR) can be served via a higher priced Ethernet service rather than the GPON-based 1 Gbps service.

6.2.2.4.2 Rate Limiting

In some networks, unexpected bursts of network traffic slow things down to unacceptable speeds for everyone using the network. Thus there needs to be a mechanism in place to manage these events for the greater good of everyone sharing the network.

One technique for controlling this is called rate-limiting. It can be implemented in many different ways, but the net result is that it prevents over-congestion on a network during the busiest usage times.

Most consumer Internet services today provide subscribers with a "soft" rate for their data connections. This may allow for some extra speed and capacity during times when the network is uncongested, but it may also mean that the "soft" rate may not be achievable during times when the network is the most congested. Providers need to have this flexibility to cost effectively manage the networks overall performance and efficiency and they do this with subscription levels and rate limiting.

6.2.2.5 Internet Protocol (IP) Based Applications

The FTTP design will be an all-IP platform that provides a scalable and cost-effective network in the long run. This will allow the City and its partners to minimize ongoing costs; increase economies of scale with other network, communications, and media industries; and operate a uniform and scalable network. For example, with an IP-based data network, there would not need to be a separate set of video transport equipment in the headend or hubs, nor a set of dedicated video channels. The transport equipment and the spectrum would become uniform and converge to a single IP platform. Thereafter, network upgrades could be carried out solely based on the evolution of high-speed networking architecture, independent of video processing capabilities often inherent in incumbent provider networks.

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[115] Network server or service that saves Web pages or other Internet content locally.

6.2.2.6 Migration from IPv4 to IPv6 Protocol

The Internet is in the process of migrating from the IPv4 to the IPv6 protocol. This upgrade will include several improvements in the operation of the Internet. One of the most notable is the increase in available device addresses, from approximately four billion to 3×10^{38} addresses. IPv6 also incorporates other enhancements to IP networking, such as better support for mobility, multicasting, security, and greater network efficiency; it is being adopted across all elements of the Internet, such as equipment vendors, ISPs, and websites.

Support of IPv6 is not unique to the proposed City FTTP network. Many cable operators have begun migrating their services to IPv6.

Customers with access to IPv6 can connect IPv6-aware devices and applications through their data connection and no longer need to use network address translation (NAT) software and hardware to share the single IP address from the ISP among multiple devices and applications. Each device can have its own address, be fully connected, and (if desired) be visible to outside networks.

One way to think of removing NAT is that it is the IP equivalent of moving from a world of cumbersome telephone systems with a main number and switchboard extension (e.g., 608-555-0000 extension 4422) to one where each individual has a unique direct number (e.g., 608-555-4422). Devices and applications that will particularly benefit from IPv6 include interactive video, gaming, and home automation, because NAT (and other IPv4 workarounds to share limited address space) makes connecting multiple devices and users more complex to configure, and IPv6 will eliminate that complexity and improve performance. With IPv6, each device and user can potentially be easily found, similar to how a phone is reached by dialing its phone number from anywhere in the world.

6.2.2.7 Multicasting—IP Transport of Video Channels

Traditional Internet video can waste capacity, especially in a “channel” video environment, because it sets up a new stream from the source to each viewer. Even if many people are watching the same program at the same time, a separate copy is streamed all the way from the server (or source) to the user. *Multicasting* is a method of transmitting data to multiple destinations by a single transmission operation in an IP network.

Using multicasting, a cable operator (leveraging the proposed FTTP network) can send a program to multiple viewers in a more efficient way. A multicast-aware network sends only a single copy of any given video stream from its source through the various network routers and switches within the network. When a viewer selects the program, the viewer’s device (set-top converter or computer) requests the multicast stream, a copy of which is then provided to that customer by the underlying network—rather than the originating video server or encoder sending a dedicated unicast stream to that customer, as is the case with OTT video services and other Internet-based video applications. Thus, the stream exists only once over any given segment of the network upstream from the access layer, so even if many neighbors are viewing the same stream, multicast video services can never occupy more capacity than the sum of one copy of each video stream (see Figure 75 and Figure 76).

Figure 75: Unicast IP Network Carries Multiple Copies of Single Video Channel

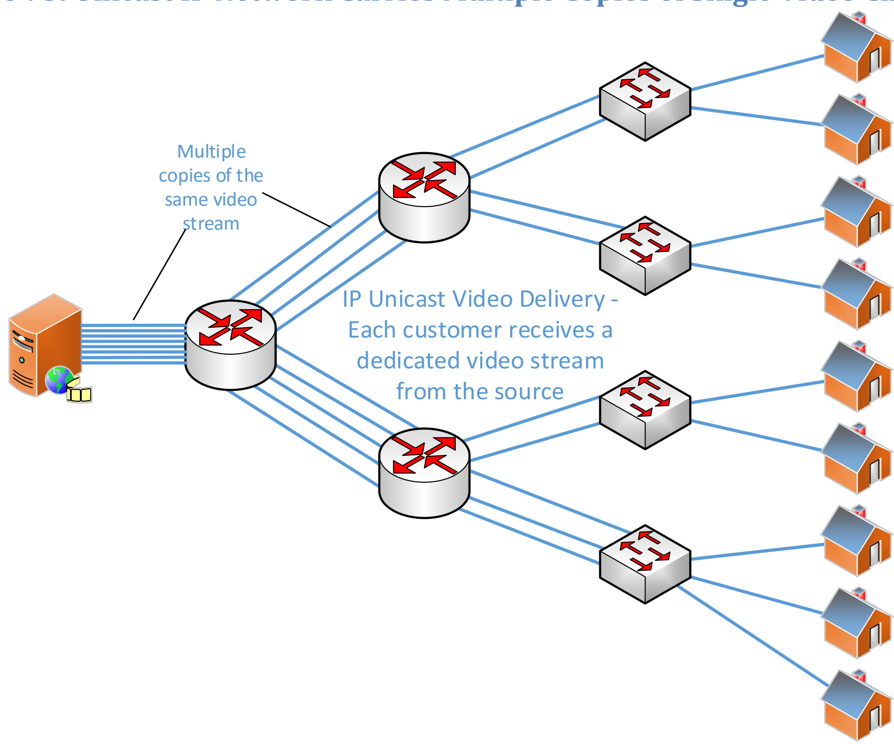
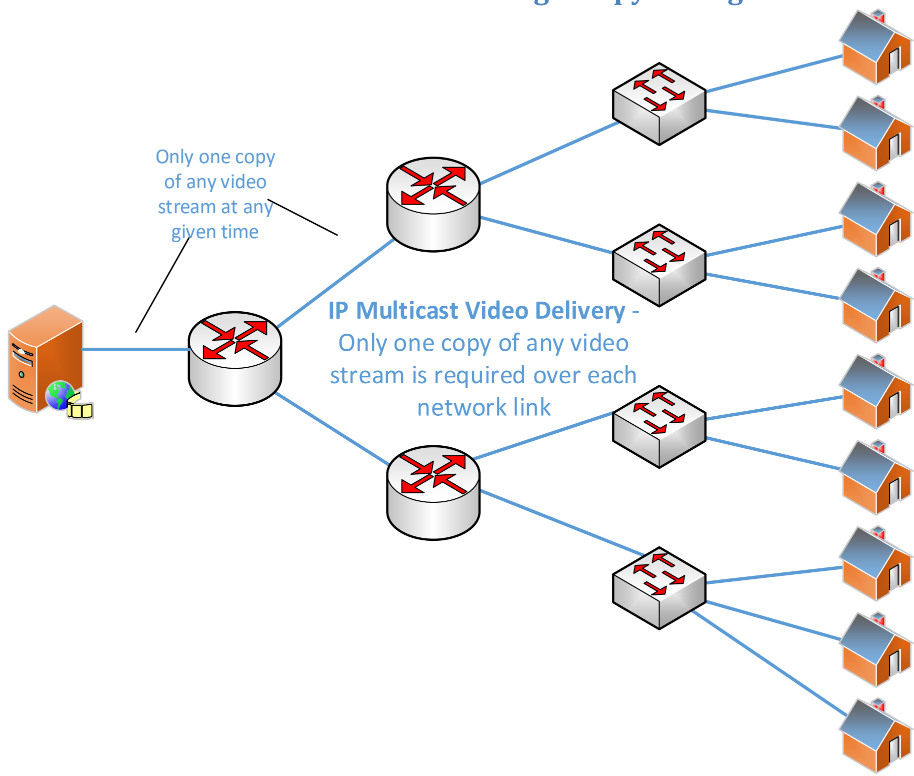


Figure 76: Multicast IP Network Carries Single Copy of Single Video Channel



Multicast is a feature that was optional in IPv4 but standard (and better executed) in IPv6. As multicast-capable and multicast-aware routers and set-top converters become standard, a cable operator and OTT video providers leveraging the City's FTTP network could consider an all-IP video programming offering, and not just VoD, as multicast provides a means to carry traditional channels over IP without wasting the backbone capacity.

6.2.3 Target User Groups

Based on our discussions with City staff, we identified two primary categories of potential network users (in addition to the City):

- Residents
- Small businesses and enterprise users

To analyze the user groups, we first estimated the possible number of "passings"—the number of households and businesses the fiber could potentially pass (potential customers). Based on data provided by the City, there are a total of 61,000 land parcels (structures) in the City and a total of 915 street miles.

The City's property database, PLGEO—which is used for assessments and to generate property tax bills—estimates that there are 114,680 residential households in the City of Madison. See Table 19 below.

Table 19: Total Potential Residential Customers Passed

Dwellings in Structures on Property	Dwelling Units
1-unit, detached	46,320
2 units	6,849
3 or 4 units	6,032
5 to 9 units	4,278
10 to 19 units	2,830
20 or more units[116]	48,371
Residential Total	**114,680**

We typically treat MDUs with 20 or more units on a case-by-case basis because the potential customers there may not be accessible to the City. For example, many large building owners are locked into long-term contracts with a single provider to offer services to all the units in the building. For this analysis, we included 50 percent of households in MDUs with 20 or more units—thus, we estimate that there are 90,494 residential households in Madison.

Table 20: Total Residential Passings

Residential Total	114,680
Less 50% of households in 20 or more units	24,186
Total residential household market base	**90,494**

To determine the number of total businesses, we used data from InfoUSA,[117] which has records for 10,331 businesses in Madison. See Table 21 below.

[116] The 20-or-more unit category is the total dwellings in all structures on the property vs. the census data category is for the total units in a given structure. With census data, CTC treats larger MDUs on a case-by-case basis and the households in these units are not considered in the market potential. The OSP fiber estimate includes a connection to the building, but does not include costs for internal wiring. All other MDUs are treated as a single family unit for the OSP, drop, and CPE estimates. For the PLGEO data we recommend treating 50 percent of units in the 20-plus category on a case-by-case basis and the remaining units as single family units.

[117] See www.InfoUSA.com.

Table 21: Total Potential Business Customers Passed

Total Employees	Total Businesses
1 to 4	5,356
5 to 9	1,896
10 to 19	1,417
20 to 49	1,014
50 to 99	373
100 to 249	191
250 to 499	59
500 to 999	15
1,000 to 4,999	9
5,000 to 9,999	-
10,000 or more	1
Business Total	**10,331**

To estimate potential business passings, we assume that businesses with 100 or more employees are likely to purchase a high-end service such as Metro Ethernet, thus excluding them from the total business market base. Of the 10,331 for which InfoUSA has data, we identified 275 businesses with 100 or more employees.

For the remaining 10,056 businesses, we assume the ratio of businesses that are likely located in office complexes is similar to that of residential units located in large MDUs. Like residential MDUs with 20 or more units, office complexes are treated on a case-by-case business and are excluded from the potential passings we derive and use in our analysis. We use residential census data to produce assumptions about what percentage of businesses are likely located in office complexes. While we used the City's tax database to derive residential passings, we relied on census data to project potential business passings. According to census, just over 21 percent of residential units are in MDUs with 20 or more units. Using this number, we estimate that there are 7,895 businesses in complexes of under 20 units across the City. See Table 22 below.

Table 22: Total Business Passings

Business Total	10,331
Less businesses with 100 or more employees	275
Net Business Total	10,056
Less estimated businesses in office complexes	2,161
Total business GPON market base	**7,895**

Given this, we assume that the City's total passings, or market base, is 98,389 (Table 23).

Table 23: Total Residential and Business Passings

Total residential household market base	90,494
Total business GPON market base	7,895
Total residential and business passings	**98,389**

6.2.3.1 Residents

The largest potential user group for a City FTTP network is the residential market. Residents will require a diverse range of speeds and capabilities—from simple, reliable connectivity at low cost, to extremely-high-speed, symmetrical services that can support hosting and research and development applications. The fiber network will provide the capability to offer a range of services through the same physical medium, requiring only an upgrade of electronics or software at user premises, rather than custom physical connections, to deliver higher-capacity services.

6.2.3.2 Small Businesses and Enterprise Users

In terms of their broadband needs, small businesses are often more similar to high-capacity residential users than to large enterprise customers. They may need more than just a basic connection, but do not typically require the speeds, capacity, or guaranteed service levels that a large organization or high-end data user needs.

The FTTP network must support small businesses and be capable of supporting select institutions and enterprise users. It is important to emphasize that the suggested network design will have enough fiber capacity to provide either AE service or PON service to any business or resident. Our design and cost estimates provide for a conservative business analysis with sufficient fiber strands and network electronics capacity to meet near-term demands at nearly any take rate, and includes AE (dedicated symmetrical gigabit) hardware support for approximately 10 percent of all business passings. With the recommended network in place, the City or another ISP will be able to sell customized service to enterprise customers on a case-by-case basis.

6.3 FTTP Network Design

6.3.1 Network Architecture

OSP (layer 1, also referred to as the physical layer) is both the most expensive part of the network and the longest lasting. The architecture of the physical plant determines the network's scalability for future uses and how the plant will need to be operated and maintained; the architecture is also the main determinant of the total cost of the deployment.

Figure 77 (below) shows a logical representation of the high-level FTTP network architecture we recommend. This design is open to a variety of architecture options. The figure illustrates the primary functional components in the FTTP network, their relative position to one another, and the flexibility of the architecture to support multiple subscriber models and classes of service.

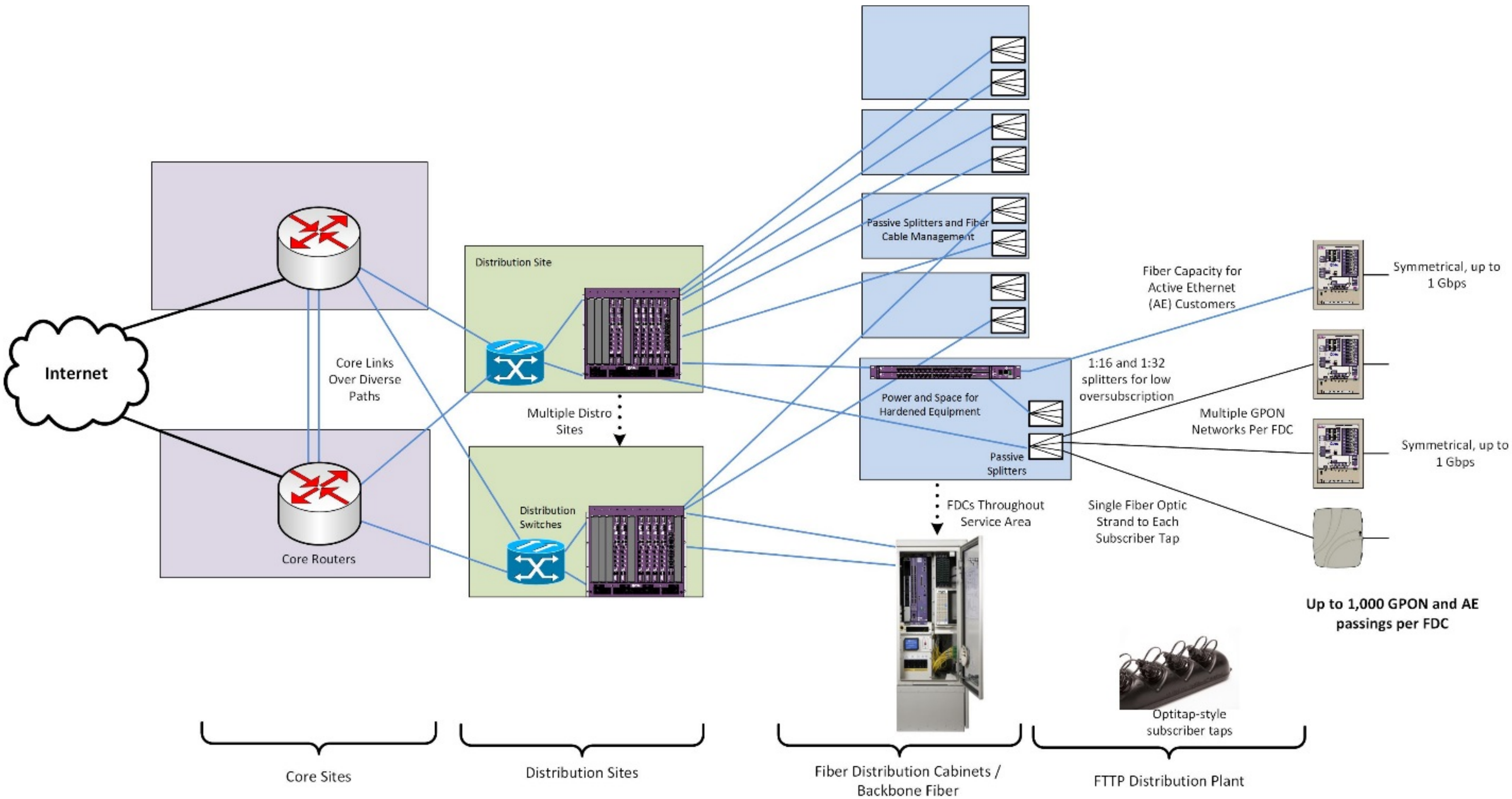
The recommended architecture is a hierarchical data network that provides critical scalability and flexibility, both in terms of initial network deployment and accommodating the increased demands of future applications and technologies. The network characteristics are:

- Capacity – ability to provide efficient transport for subscriber data, even at peak levels
- Availability – high levels of redundancy, reliability, and resiliency; ability to quickly detect faults and re-route traffic
- Diversity – physical path diversity to minimize operational impact resulting from fiber or equipment failure
- Efficiency – no traffic bottlenecks; efficient use of resources
- Scalability – ability to grow in terms of physical service area and increased data capacity, and to integrate newer technologies
- Manageability – simplified provisioning and management of subscribers and services
- Flexibility – ability to provide different levels and classes of service to different customers; can support an open access or single-provider network; can provide separation between service providers on the physical layer (separate fibers) or logical layer (separate virtual local area network (VLAN or VPN)
- Security – controlled physical access to all equipment and facilities, plus network access control to devices

This architecture offers scalability to meet long-term needs. It is consistent with best practices for an open access network model that might potentially be required to support multiple network operators, or at least multiple retail service providers requiring dedicated connections to certain customers. This design would support a combination of GPON and direct AE services (with the addition of electronics at the FDCs), which would enable the network to scale by migrating to direct connections to each customer, or reducing splitter ratios, on an as-needed basis.

The design assumes placement of manufacturer-terminated fiber tap enclosures within the ROW or easements. This provides water-tight fiber connectors for customer drop cables and eliminates the need for service installers to perform splices in the field. This is an industry-standard approach to reducing the customer activation times and the potential for damage to distribution cables and splices. The model also assumes the termination of standard lateral fiber connections within larger multi-tenant business locations and MDUs.

Figure 77: High-Level FTTP Architecture



6.3.2 The Role of the Metropolitan Unified Fiber Network (MUFN)

The Metropolitan Unified Fiber Network (MUFN) is a quasi-public consortium of public and private partners that collaboratively sought a federal grant in 2009 to construct a dark fiber network in the Madison area. Through the MUFN consortium, a robust backbone network was funded with approximately $5.1 million through the Broadband Technology Opportunities Program (BTOP), a federal grant program administered by the National Telecommunications and Information Administration (NTIA).

At the end of the grant period, a sub-recipient agreement allowed the City to take ownership of the MUFN fiber and conduit within Madison's corporate limits. As the cost estimate in Section 7 notes, use of MUFN to support an FTTP network in the City would likely decrease the project's overall cost. The MUFN fiber extends to all areas of the City and can provide connectivity into many of the City's neighborhoods.

Though there would be BTOP requirements to satisfy, and the NTIA would likely have to grant permission, the City might be able to give control of the existing MUFN to a private partner through a lease or indefeasible right of use (IRU). The City will have to take into consideration any requirements to which MUFN is beholden as a BTOP recipient, and how to navigate those.[118]

For example, one condition of its BTOP funding is that the MUFN consortium is required to offer commercial service in addition to dark fiber leasing, so the consortium took on two partners to provide commercial service: SupraNet and the Wisconsin Independent Network (WIN).[119,120] This particular stipulation benefits the City—one component of the City's facilities use agreement with WIN is that the City can take ownership of any conduit placed by the private entity. This means that the City's access to conduit for its own use expands as the WIN network grows, which could mean that the City has greater opportunities to leverage existing facilities and infrastructure for FTTP deployment, whether directly or through a partnership. But this also means that there are contractual relationships for the City to consider, and these may impact the terms of a public–private partnership.

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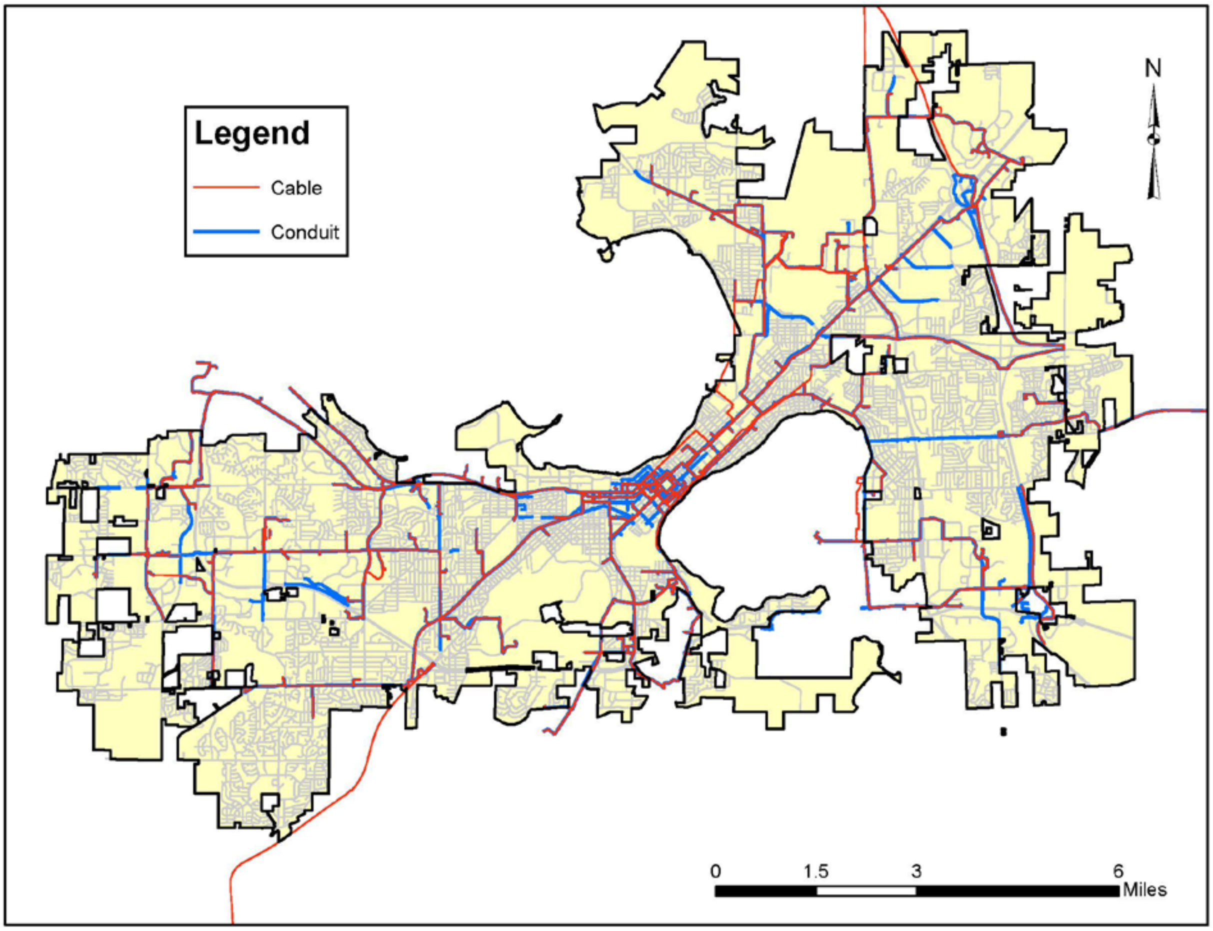
[118] This analysis does not anticipate or provide guidance about all that is required of BTOP recipients. The City should work with its legal counsel and the NTIA to determine how best to manage these requirements.

[119] http://www.supranet.net/, accessed April 2016.

[120] https://wins.net/, accessed April 2016.

Figure 78: Map of MUFN Showing Its Suitability as an FTTP Backbone Network



Alternatively, the City could maintain ownership of the MUFN and expand it to meet the needs of a citywide FTTP deployment and to satisfy its portion of a partnership. As we outline below, we believe that retaining ownership of the fiber assets—both the existing network and any potential expansion—is likely to be in the City's best interest as it moves forward with considering an FTTP build-out. Assuming the City can legally retain ownership of its assets, we believe this structure would help mitigate the City's risk and create a good balance between the City and a potential partner.

MUFN fiber also extends to nearby suburbs, including three municipalities that are within the City. Although in-depth analysis about localities outside the City is beyond the scope of this report, these locations could potentially be eventual targets for the City's private partner(s). It may be prudent for the City to work collaboratively with nearby local governments to the greatest extent possible under the state law to facilitate the greatest use of the MUFN fiber in the area.

6.3.3 Network Design Assumptions

The network design and cost estimates assume the City will:

- Identify and procure space at two core facilities to house network electronics and provide backhaul to the Internet;
- Use existing MUFN locations for eight distribution hub facilities with adequate environmental and backup power systems to house network electronics;
- Use the existing MUFN fiber optics to connect core sites to distribution hubs
- Use the existing MUFN fiber and construct additional fiber to connect the distribution hubs to FDCs;
- Construct fiber optics from the FDCs to each residence and business (i.e., from termination panels in the FDC to tap locations in the ROW or on City easements); and
- Construct fiber laterals into large, multi-tenant business facilities and/or residential MDUs.

Leveraging MUFN would decrease the costs associated with both constructing a backbone and identifying locations to house electronics that are attached to the backbone ring. The use of MUFN would also allow the City to conduct FTTP pilot programs or begin deployment in neighborhoods where demand is greatest.

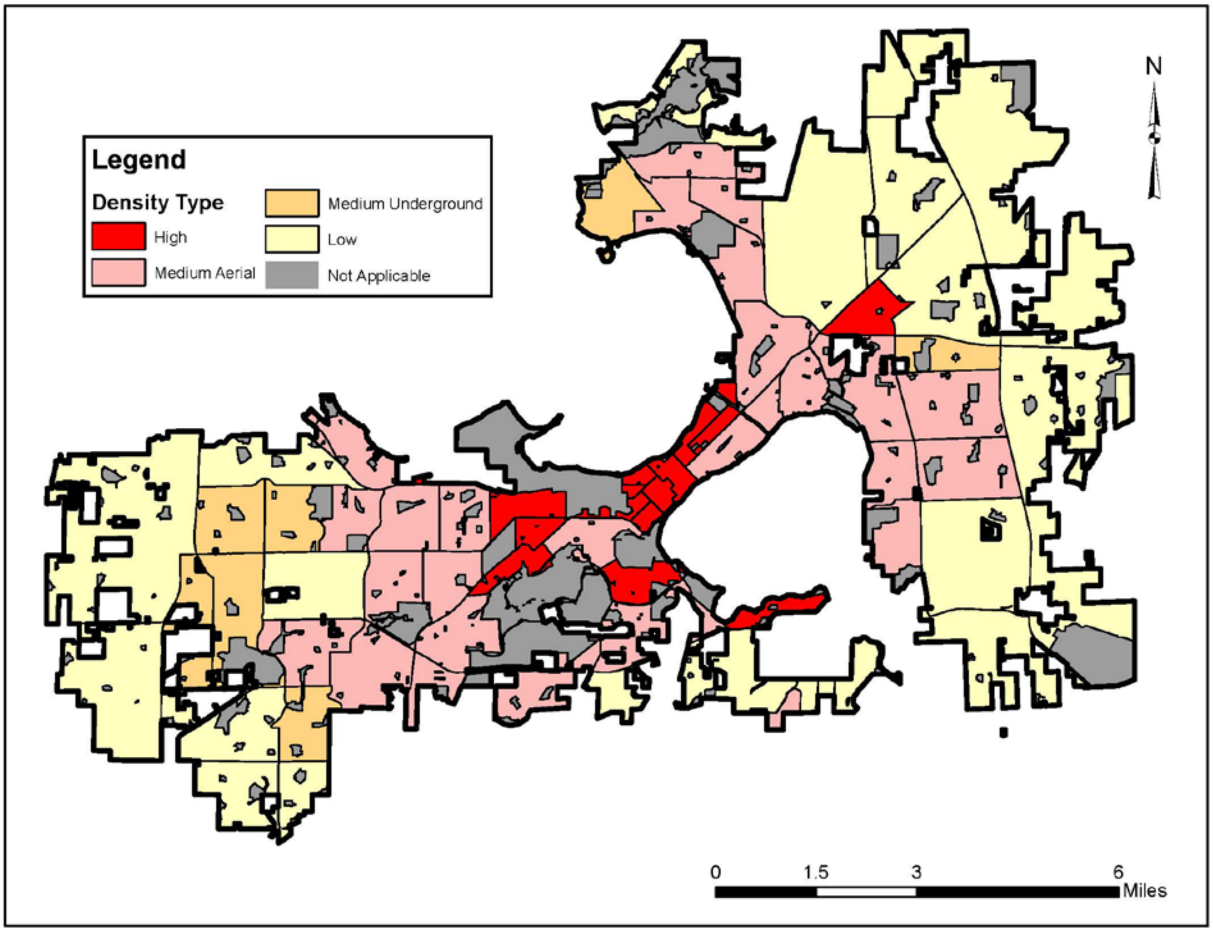
The FTTP network and service areas were defined based on the following criteria:

- Targeting 256 to 512 passings per FDC;
- Service areas defined by passing density and existing utilities, and are broken into the categories of high, medium aerial, medium underground, and low densities;
- Service areas served by multiple FDCs;
- FDCs suitable to support hardened network electronics, providing backup power and an active heat exchange;[121] and
- Avoiding the need for distribution plant to cross major roadways and railways.

[121] These hardened FDCs reflect an assumption that the City's operational and business model will require the installation of provider electronics in the FDCs that are capable of supporting open access among multiple providers. We note that the overall FTTP cost estimate would decrease if the hardened FDCs were replaced with passive FDCs (which would house only optical splitters) and the providers' electronics were housed only at hub locations.

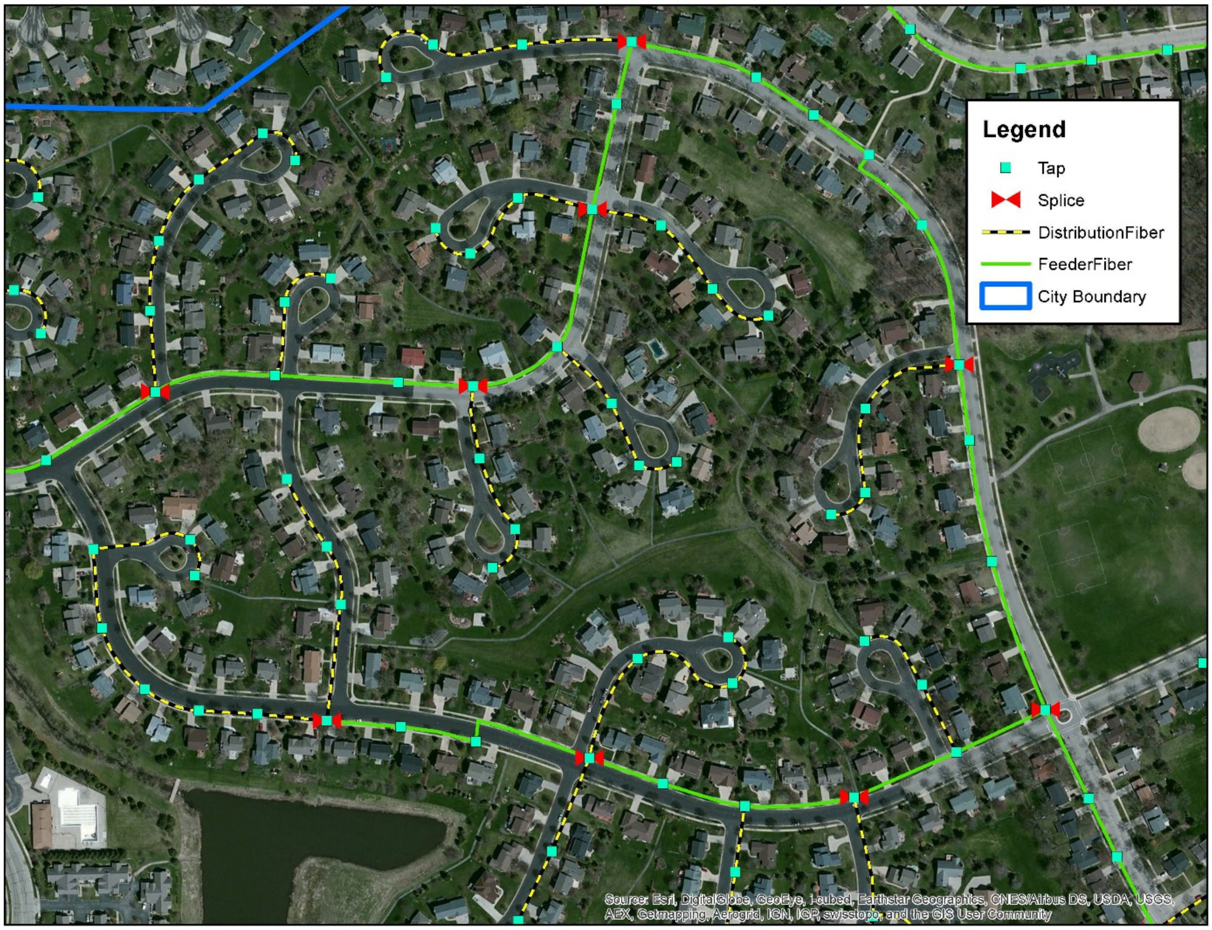
Coupled with an appropriate network electronics configuration, this fiber design serves to greatly increase the reliability of services provided to customers as compared to that of more traditional cable and telephone networks. The backbone design minimizes the average length of non-diverse distribution plant between the network electronics and each customer, thereby reducing the probability of service outages caused by a fiber break.

Figure 79: FTTP Service Areas



The access layer of the network, encompassing the fiber plant from the FDCs to the customers, dedicates a single fiber strand from the FDC to each passing (i.e., potential customer address). This traditional FTTP design allows either network electronics or optical splitters in the FDCs. See Figure 80 below for a sample design.

Figure 80: Sample FTTP Access Layer Design



This architecture offers scalability to meet long-term needs. It is consistent with best practices for an open access network model that might potentially be required to support multiple network operators, or at least multiple retail service providers requiring dedicated connections to certain customers.

6.3.4 Network Core and Hub Sites

The core sites are the bridges that link the FTTP network to the public Internet and deliver all services to end users. The proposed network design includes two core locations, based on the network's projected capacity requirements and the need for geographical redundancy (i.e., if one core site were to fail, the second core site would continue to operate the network).

The location of core network facilities also provides physical path diversity for subscribers and all upstream service and content providers. For our design and cost estimates, we assume that the Madison core sites will be housed in secure locations with diverse connectivity to the Internet and MUFN.

The core locations in this plan will house providers' Operational Support Systems (OSS)[122] such as provisioning platforms, fault and performance management systems, remote access, and other OSS for FTTP operations. The core locations are also where any business partner or content / service providers will gain access to the subscriber network with their own point-of-presence. This may be via remote connection, but collocation is recommended.

The core locations are typically run in a High Availability (HA) configuration, with fully meshed and redundant uplinks to the public Internet and/or all other content and service providers. It is imperative that core network locations are physically secure and allow unencumbered access 24x7x365 to authorized engineering and operational staff.

The operational environment of the network core and hub locations is similar to that of a data center. This includes clean power sources, UPS batteries, and diesel power generation for survival through sustained commercial outages. The facility must provide strong physical security, limited/controlled access, and environmental controls for humidity and temperature. Fire suppression is highly recommended.

Equipment is to be mounted securely in racks and cabinets, in compliance with national, state, and local codes. Equipment power requirements and specification may include 48-volt DC and/or 120/240 volts AC. All equipment is to be connected to conditioned / protected clean power with uninterrupted cutover to battery and generation.

For the cost estimate, we assumed that the core and distribution hubs will be located within existing City facilities connected to MUFN.

6.3.5 Distribution and Access Network Design

The distribution network is the layer between the hubs and the FDCs, which provide the access links to the taps. The distribution network aggregates traffic from the FDCs to the core. Fiber cuts and equipment failures have progressively greater operational impact as they happen closer to the network core, so it is critical to build in redundancies and physical path diversities in the distribution network, and to seamlessly re-route traffic when necessary.

The distribution and access network design proposed in this report is flexible and scalable enough to support two different architectures:

1. Housing both the distribution and access network electronics at the hubs, and using only passive devices (optical splitters and patches) at the FDCs; or

[122] The OSS includes a provider's provisioning platforms, fault and performance management systems, remote access, and other OSS for FTTP operations. The network's core locations house the OSS.

2. Housing the distribution network electronics at the hubs and pushing the access network electronics further into the network by housing them at the FDCs.

By housing all electronics at the hubs, the network will not require power at the FDCs. Choosing a network design that only supports this architecture may reduce costs by allowing smaller, passive FDCs in the field. However, this architecture will limit the redundancy capability from the FDCs to the hubs.

By pushing the network electronics further into the field, the network gains added redundancy by allowing the access electronics to connect to two hub sites. In the event one hub has an outage the subscribers connected to the FDC would still have network access. Choosing a network design that only supports this architecture may reduce costs by reducing the size of the hubs.

Selecting a design that supports both of these models would allow the City to accommodate many different service operators and their network designs. This design would also allow service providers to start with a small deployment (i.e., placing electronics only at the hub sites) and grow by pushing electronics closer to their subscribers.

6.3.5.1 Access Network Technologies

FDCs can sit on a curb, be mounted on a pole, or reside in a building. Our model recommends installing sufficient FDCs to support higher than anticipated levels of subscriber penetration. This approach will accommodate future subscriber growth with minimal re-engineering. Passive optical splitters are modular and can be added to an existing FDC as required to support subscriber growth, or to accommodate unanticipated changes to the fiber distribution network with potential future technologies.

Our FTTP design also includes the placement of indoor FDCs and splitters to support MDUs. This would require obtaining the right to access the equipment for repairs and installation in whatever timeframe is required by the service agreements with the customers. Lack of access would potentially limit the ability to perform repairs after normal business hours, which could be problematic for both commercial and residential services.

In this model we assume the use of GPON electronics for the majority of subscribers and AE for a small percentage of subscribers (typically business customers) that request a premium service or require greater bandwidth. GPON is the most commonly provisioned FTTP service—used, for example, by Verizon (in its FiOS systems), Google Fiber, and Chattanooga EPB.

Furthermore, providers of gigabit services typically provide these services on GPON platforms. Even though the GPON platform is limited to 1.2 Gbps upstream and 2.4 Gbps downstream for the subscribers connected to a single PON, operators have found that the variations in actual subscriber usage generally means that all subscribers can obtain 1 Gbps on demand (without provisioned rate-limiting), even if the capacity is aggregated at the PON. Furthermore, many GPON manufacturers have a development roadmap to 10 Gbps and faster speeds as user demand increases.

GPON supports high-speed broadband data, and is easily leveraged by triple-play carriers for voice, video, and data services. The GPON OLT uses single-fiber (bi-directional) SFP modules to support multiple (most commonly less than 32) subscribers.

GPON uses passive optical splitting, which is performed inside FDC, to connect fiber from the OLTs to the customer premises. The FDCs house multiple optical splitters, each of which splits the fiber link to the OLT between 16 to 32 customers (in the case of GPON service).

AE provides a symmetrical (up/down) service that is commonly referred to as Symmetrical Gigabit Ethernet. AE can be provisioned to run at sub-gigabit speeds, and like GPON easily supports legacy voice, voice over IP, and video. AE is typically deployed for customers who require specific service level agreements that are easier to manage and maintain on a dedicated service.

For subscribers receiving AE service, a single dedicated fiber goes directly to the subscriber premises with no splitting. Because AE requires dedicated fiber (home run) from the OLT to the CPE, and because each subscriber uses a dedicated SFP on the OLT, there is significant cost differential in provisioning an AE subscriber versus a GPON subscriber.

Our fiber plant is designed to provide AE service or PON service to all passings. The network operator selects electronics based on the mix of services it plans to offer and can modify or upgrade electronics to change the mix of services.

6.3.5.2 Expanding the Access Network Bandwidth

GPON is currently the most commonly provisioned FTTP technology, due to inherent economies when compared with technologies delivered over home-run fiber[123] such as AE. The cost differential between constructing an entire network using GPON and AE is 40 percent to 50 percent.[124] GPON is used to provide services up to 1 Gbps per subscriber and is part of an evolution path to higher-speed technologies that use higher-speed optics and wave-division multiplexing.

This model provides many options for scaling capacity, which can be done separately or in parallel:

[123] Home run fiber is a fiber optic architecture where individual fiber strands are extended from the distribution sites to the premises. Home run fiber does not use any intermediary aggregation points in the field.
[124] "Enhanced Communications in San Francisco: Phase II Feasibility Study," CTC report, October 2009, at p. 205.

1. Reducing the number of premises in a PON segment by modifying the splitter assignment and adding optics. For example, by reducing the split from 16:1 to 4:1, the per-user capacity in the access portion of the network is quadrupled.

2. Adding higher speed PON protocols can be accomplished by adding electronics at the FDC or hub locations. Since these use different frequencies than the GPON electronics, none of the other CPE would need to be replaced.

3. Adding WDM-PON electronics as they become widely available. This will enable each user to have the same capacity as an entire PON. Again, these use different frequencies than GPON and are not expected to require replacement of legacy CPE equipment.

4. Option 1 could be taken to the maximum, and PON replaced by a 1:1 connection to electronics—an AE configuration.

These upgrades would all require complementary upgrades in the backbone and distribution Ethernet electronics, as well as in the upstream Internet connections and peering—but they would not require increased fiber construction.

6.3.5.3 Customer Premises Equipment (CPE) and Subscriber Services

In the final segment of the FTTP network, fiber runs from the FDC to customers' homes, apartments, and office buildings, where it terminates at the subscriber tap—a fiber optic housing located in the ROW closest to the premises. The service installer uses a pre-connectorized drop cable to connect the tap to the subscriber premises without the need for fiber optic splicing.

The drop cable extends from the subscriber tap (either on the pole or underground) to the building, enters the building, and connects to CPEs.

7 FTTP Cost Estimates

The cost estimates presented here are highly conservative projections based on a City-funded, ubiquitous FTTP deployment. These estimates include costs the City is likely to incur if it opts to construct and own the fiber network; these costs include outside plant (OSP) construction labor, materials, engineering, permitting, and pole attachment licensing. This analysis shows what we anticipate the City might have to spend on an FTTP deployment with no partnership with the private sector to help share the financial burden.

7.1 OSP Cost Estimation Methodology

As with any utility, the design and associated costs for construction vary with the unique physical layout of the service area—no two streets are likely to have the exact same configuration of fiber optic cables, communications conduit, underground vaults, and utility pole attachments. Costs are further varied by soil conditions, such as the prevalence of subsurface hard rock; the condition of utility poles and feasibility of "aerial" construction involving the attachment of fiber infrastructure to utility poles; and crossings of bridges, railways, and highways.

To estimate costs for a citywide network, we extrapolated the costs for strategically selected sample designs on the basis of street mileage and passings. Specifically, we developed sample FTTP designs to generate costs per passing for four types of population densities and existing utilities—high, medium aerial, medium underground, and low.[125]

Our observations determined that for the medium underground and low-density areas, utilities are primarily underground, but the low-density areas require more construction of fiber to reach a smaller number of homes in an area.

High- and medium-density urban areas tend to have underground utilities; utilities are predominantly aerial in urban residential areas (although the poles there tend to require more make-ready). Medium-density areas tend to have the greatest variation in the percentages of aerial versus underground construction. Generally, the newest subdivisions and developments tend to be entirely underground (medium underground areas), whereas older neighborhoods have a mixture of aerial and underground construction (medium aerial areas). Many areas also tend to have rear easements for utilities, which can increase the cost of construction due to restricted access to the utility poles.

The assumptions, sample designs, and cost estimates were used to extrapolate a cost per passing for the OSP. This number was then multiplied by the number of households in each area based on the City's GIS data. The actual cost to construct FTTP to every premises in the

[125] The sample design was 13 percent of the total City street mileage.

City could differ from the estimate due to changes in the assumptions underlying the model. For example, if access to the utility poles is not granted or make-ready and pole replacement costs are too high, the network would have to be constructed underground—which could significantly increase the cost of construction. Alternatively, if the City were able to partner with a local telecommunications provider and overlash to existing pole attachments, the cost of the build could be significantly lower. Further and more extensive analysis would be required to develop a more accurate cost estimate across the entire City.

7.2 FTTP Cost Estimate Components

Actual costs may vary due to unknown factors, including: 1) costs of private easements, 2) utility pole replacement and make-ready costs, 3) variations in labor and material costs, 4) subsurface hard rock, and 5) the City's operational and business model (including the percentage of residents and businesses who subscribe to the service, otherwise known as the penetration rate or the "take rate"). We have incorporated suitable assumptions to address these items based on our experiences in similar markets.

The technical operating costs for this model are outlined in Section 7.3.4 (not including non-technical operating costs such as marketing, legal services, and financing costs). The total cost of operations will vary with the business model chosen and the level of existing resources that can be leveraged by the City and any potential business partners.

The cost components for OSP construction include the following tasks:

- ***Engineering*** – includes system level architecture planning, preliminary designs and 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.

- ***Quality Control / Quality Assurance*** – includes expert quality assurance field review of final construction for acceptance.

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

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

- ***Backbone and Distribution Plant Splicing*** – includes all labor related to fiber splicing of outdoor fiber optic cables.
- ***Backbone Hub, Termination, and Testing*** – consists of the material and labor costs of placing hub shelters and enclosures, terminating backbone fiber cables within the hubs, and testing backbone cables.
- ***FTTP Service Drop and Lateral Installations –*** consists of all costs related to fiber service drop installation, including outside plant construction on private property, building penetration, and inside plant construction to a typical backbone network service "demarcation" point; also includes all materials and labor related to the termination of fiber cables at the demarcation point. A take-rate of 35 percent was assumed for standard fiber service drops.

7.3 Cost Estimate for Fiber, Network Electronics, Service Drops, and CPEs

This section provides a summary of cost estimates for construction of a citywide FTTP network to all City residents and businesses. This estimate encompasses some costs that we anticipate the City will likely share with a partner—such as network electronics,[126] service drop installation,[127] customer premises equipment (CPE),[128] and testing.

With a retail model, assuming a 35 percent take rate, this deployment will cost more than $194 million—inclusive of OSP construction labor, materials, engineering, permitting, pole attachment licensing, network electronics, drop installation, CPEs, and testing.

Table 24: Breakdown of Estimated Total Cost with Electronics (combination aerial and underground construction)

Cost Component	Total Estimated Cost
OSP	$136 million
Central Network Electronics	8 million
CPE	22 million
FTTP Service Drop and Lateral Installations	28 million
Total Estimated Cost:	$194 million

[126] These is the electronic equipment that "lights" the dark fiber network.
[127] A service drop, or "drop," is the fiber connection from an optical tap in the ROW to the customer premises.
[128] This is the electronic equipment installed at a subscriber's home or business.

7.3.1 OSP

7.3.1.1 Cost of Constructing the Network – Aerial and Underground

In terms of OSP, the estimated cost to construct the proposed FTTP network is $136 million, or $1,380 per passing.[129] As discussed above, our model assumes a mixture of aerial and underground fiber construction, depending on the construction of existing utilities in the area as well as the state of any utility poles and existing infrastructure. Table 25 provides a breakdown of the estimated OSP costs by type of area. (Note, the costs have been rounded.)

Table 25: Estimated OSP Costs for FTTP

Area	Distribution Plant Mileage	Total Cost	Passings	Cost per Passing	Cost Per Plant Mile
High Density	100	$18.7 million	19,400	$960	$184,000
Medium Density Aerial	425	$54.3 million	43,400	$1,250	$128,000
Medium Density Underground	80	$12.1 million	9,300	$1,300	$146,000
Low Density	350	$50.8 million	26,300	$1,935	$143,000

Costs for aerial and underground placement were estimated using available unit cost data for materials and estimates on the labor costs for placing, pulling, and boring fiber based on construction in comparable markets.

The material costs were generally known with the exception of unknown economies of scale and inflation rates, and barring any sort of phenomenon restricting material availability and costs. The labor costs associated with the placement of fiber were estimated based on similar construction projects.

Aerial construction entails the attachment of fiber infrastructure to existing utility poles, which could offer significant savings compared to all-underground construction, but increases

[129] The passing count includes individual single-unit buildings and units in small multi-dwelling and multi-business buildings as single passings. It treats larger buildings as single passings.

uncertainty around cost and timeline. The utility pole owners can impose costs related to pole remediation and “make-ready” construction that can make aerial construction cost-prohibitive in comparison to underground construction.

While generally allowing for greater control over timelines and more predictable costs, underground construction is subject to uncertainty related to congestion of utilities in the public ROW and the prevalence of subsurface hard rock—neither of which can be fully mitigated without physical excavation and/or testing. While anomalies and unique challenges will arise regardless of the design or construction methodology, the relatively large scale of this project is likely to provide ample opportunity for variations in construction difficulty to yield relatively predictable results on average.

We assume underground construction will consist primarily of horizontal, directional drilling to minimize ROW impact and to provide greater flexibility to navigate around other utilities. The design model assumes a single two-inch, High-Density Polyethylene (HDPE) flexible conduit over underground distribution paths, and dual two-inch conduits over underground backbone paths to provide scalability for future network growth.

Underground construction costs may potentially be reduced in some high-density corridors, primarily downtown, by using Madison Gas & Electric conduit in conduit bank, although there would be lease costs for use of the conduit. Conduit is not available in all bank areas and more detailed survey work is required to determine how much is feasible to use, and the degree of cost savings.

7.3.1.2 Cost of Constructing the Network Entirely Underground

The City’s existing middle mile fiber that supports MUFN is constructed entirely underground for reliability reasons and to avoid negotiating pole access with the utility owners. As part of our FTTP analysis, we developed a cost estimate assuming that the entire FTTP network were to be constructed underground. An all-underground network would cost more than $212 million. The following is a breakdown of the all-underground cost estimate.

Table 26: Breakdown of Estimated Total Cost with Electronics for an All Underground Network

Cost Component	Total Estimated Cost
OSP	$141 million
Central Network Electronics	8 million
FTTP Service Drop and Lateral Installations	41 million
CPE	22 million
Total Estimated Cost:	$212 million

The cost increase is due to the added cost of constructing the outside plant as well as the increased costs for fiber optic drops, which are significantly more expensive than aerial drops.

7.3.2 Central Network Electronics Costs

Central network electronics will cost an estimated $8 million, or $80 per passing, based on an assumed take rate of 35 percent.[130] (These costs may increase or decrease depending on take rate, and the costs may be phased in as subscribers are added to the network.) The central network electronics consists of the electronics to connect subscribers to the FTTP network at the core, hubs, and cabinets. Table 27 below lists the estimated costs for each segment.

Table 27: Estimated Central Network Electronics Costs

Network Segment	Subtotal	Passings	Cost per Passing
Core and Distribution Electronics	$3 million	98,000	$30
FTTP Access Electronics	$5 million	98,000	$50
Central Network Electronics Total	**$8 million**	**98,000**	**$80**

7.3.2.1 Core Electronics

The core electronics connect the hub sites and connect the network to the Internet. The core electronics consist of high performance routers, which handle all of the routing on both the FTTP network and to the Internet. The core routers should have modular chassis to provide high availability in terms of redundant components and the ability to be "hot swappable"[131] line cards and modular in the event of an outage. Modular routers also provide the ability to expand the routers as demand for additional bandwidth increases.

[130] The take rate affects the electronics and drop costs, but also may affect other parts of the network, as the city may make different design choices based on the expected take rate. A 35 percent take rate is typical of environments where a new provider joins the telephone and cable provider in a city.

[131] Hot swappable means that the line cards or modular can be removed and reinserted without the entire device being powered down or rebooted. The control cards in the router should maintain all configurations and push them to a replaced line card without the need for reconfirmation.

The cost estimate design envisions redundant rings between the core sites running networking protocols such as hot standby routing protocol (HSRP) to ensure redundancy in the event of a core failure. Additional rings can be added as network bandwidth on the network increases. The core sites would also tie to both hubs using 10 Gbps links. The links to the hubs can also be increased with additional 10 Gbps and 40 Gbps line cards and optics as demand grows on the network. The core networks will also have 40 Gbps to ISPs that connect the FTTP network to the Internet.

The cost of the core routing equipment for the two core sites is $1.5 million. These costs do not include the service provider’s OSS such as provisioning platforms, fault and performance management systems, remote access, and other OSS for FTTP operations. The services providers and/or their content providers may already have these systems in place.

7.3.2.2 Distribution Electronics

The distribution network electronics at the two hub sites aggregate the traffic from the FDCs and send it to the core sites to access the Internet. The core sites consist of high performance aggregation switches, which consolidate from the traffic from the many access electronics and send it to the core for route processing. The distribution switches typically are large modular switch chassis that can accommodate many line cards for aggregation. The switches should also be modular to provide redundancy in the same manner as the core switches.

The cost estimate assumes that the aggregation switches connect to the access network electronics with 10 Gbps links to each distribution switch. The aggregation switches would then connect to the core switches over single or multiple 10 Gbps links as needed to meet the demand of the FTTP users in each service area.

The cost of the distribution switching equipment for the distribution hubs is $1.5 million. These costs do not include any of the service provider’s OSS or other management equipment.

7.3.2.3 Access Electronics

The access network electronics at the FDCs connect the subscribers’ CPEs to the FTTP network. We recommend deploying access network electronics that can support both GPON and AE subscribers to provide flexibility within the FDC service area. We also recommend deploying modular access network electronics for reliability and the ability at add line cards as more subscribers join in the service area. Modularity also helps reduce initials capital costs while the network is under construction or during the roll out of the network.

The cost of the access network electronics for the network is $5 million. These costs are based on a take rate of 35 percent and include optical splitters at the FDCs for that take rate.

7.3.3 Customer Premises Equipment and Service Drop Installation (Per Subscriber Costs)

CPEs are the subscriber's interface to the FTTP network. For this cost estimate, we selected CPEs that provide only Ethernet data services (however, there are a wide variety of CPEs offering other data, voice, and video services). Using the estimated take rate of 35 percent, we estimated the CPE for residential and business customers will be $22 million.

Each activated subscriber would also require a fiber drop installation and related electronics, which would cost roughly $1,240 per subscriber, or $50 million total (assuming a 35 percent take rate).

The drop installation cost is the biggest variable in the total cost of adding a subscriber. A short aerial drop can cost as little as $250 to install, whereas a long underground drop installation can cost upward of $2,000. (We estimate an average of $610 per drop installation for the City's deployment.)

The other per subscriber expenses include the cost of the optical network terminal (ONT) at the premises, a portion of the optical line termination (OLT) costs at the hub, the labor to install and configure the electronics, and the incidental materials needed to perform the installation. The numbers provided in the table below are averages and will vary depending on the type of premises and the internal wiring available at each premises.

Table 28: Per Subscriber Cost Estimates

Construction and Electronics Required to Activate a Subscriber	Estimated Average Cost
Drop Installation and Materials	$610
Subscriber Electronics (ONT and OLT)	330
Electronics Installation	200
Installation Materials	100
Total	**$1,240**

7.3.4 Operating Cost Considerations

This section outlines some of the key technical operating expenditures that a citywide FTTP network would incur. Costs for technical operations of the FTTP network include staffing (technicians, program manager), OSP maintenance, electronics maintenance, and customer support.

The costs discussed in this section are not meant to be inclusive of all operating costs such as marketing, legal, and financial costs. Further the magnitude of total cost of operations will vary with the business model chosen, balance of added new staff versus using contractors, the level of existing resources that can be leveraged by the City, and any potential business partners.

In the Financial Analysis we outline the estimated costs for the dark FTTP lease model. This model does not require electronic costs, vendor maintenance fees, or other costs associated beyond maintaining a dark fiber network.

7.3.4.1 Technical Operational Expenditures

If the City were to offer a retail data service, we estimate that the City would likely initially purchase 10 Gbps of Internet capacity. This is an estimated number for the beginning of the network deployment and can be expected to grow as, video streaming and other cloud applications grow in importance. Depending upon the contract terms Internet bandwidth we would estimate costs in the $0.50 per Mbps per month to $1.00 per Mbps per month range in Madison. We recommend that the Internet access be purchased from multiple Internet providers and be load balanced to ensure continuity during an outage.

The operating costs also include maintenance contracts on the core network electronics. These contracts ensure that the City has access to software support and replacement of critical network electronics that would be cost-prohibitive to store as spares. Where cost effective such as the distribution aggregation switches and the FTTP electronics, we recommend storing spares to reduce the total costs of maintenance contracts. We estimate hardware maintenance contracts and sparing at 15 percent of the total electronics cost.

In addition, we recommend planning for an annual payment into a depreciation operating reserve account based on the equipment replacement cost to help limit risk. This reserve fund should never go negative; the balance that accrues in this account will fund the capital needs for ongoing capital replenishments.

7.3.4.1.1 Fiber Maintenance Costs

The City would need to augment its current fiber staff or contractors with the necessary expertise and equipment available to maintain the fiber optic cable in a citywide FTTP network. Typical maintenance costs can exceed 1 percent of the total fiber OSP construction cost per year and includes a mix of City staff and contracted services.

Fiber optic cable is resilient compared to copper telephone lines and cable TV coaxial cable. The fiber itself does not corrode, and fiber cable installed over 20 years ago is still in good condition. However, fiber can be vulnerable to accidental cuts by other construction, traffic accidents, and severe weather. In other networks of this size, we have seen approximately 80 outages per 1,000 miles of plant per year.

The fiber optic redundancy from the hubs to the FDCs in the backbone network will facilitate restoring network outages while repair of the fiber optic plant is taking place.

Depending on the operational and business models established between the City and service providers, the City may be responsible for adds, moves, and changes associated with the network as well as standard plant maintenance. These items may include:

- Adding and/or changing patching and optical splitter configurations at FDCs and hubs;
- Extending optical taps and laterals to new buildings or developments;
- Extending access to the FTTP network to other service providers;
- Relocating fiber paths due to changes such as the widening of roadways;
- Participating in the moving of utilities due to pole replacement projects; and
- Tree trimming along the aerial fiber optic path.

The City would need to obtain contracts with fiber optic contractors that have the necessary expertise and equipment available to maintain a citywide FTTP network. These contracts should specify the service level agreements the City needs from the fiber optic contractors in order to ensure that the City can meet the service level agreements it has with the network service providers. The City should also ensure that it has access to multiple fiber optic contractors in the event that one contractor is unable to meet the City's needs. The fiber optic contractors should be available 24x7 and have a process in place for activating emergency service requests.

7.3.4.1.2 Fiber Locating

The City will be responsible for locating and marking all underground conduit for excavation projects according to Wisconsin's One-Call System statutes. Locating involves receiving and reviewing excavation tickets to determine whether the area of excavation may impact the City's underground FTTP infrastructure. If the system is impacted, the City must mark its utilities in the manner and within the allotted timeframe provided by the statute.

Locating is either done in-house or by contractors who specialize in utility locating. The City may be able to leverage its existing utility locating personnel, processes, or contractors to reduce the cost of utility locating for the FTTP network.

7.3.4.1.3 Pole Attachment Fees

The City will need to pay utility pole owners an annual fee per pole to attach its fiber optic cables to the poles. Pole attachment fees can be thought of a rent for using the pole. Pole attachment fees are set by the pole owner and would be outlined in the City's pole attachment agreement with the owner, which will be negotiated with MGE.

7.3.4.2 Technical Staffing Requirements

Additional staffing will be required to perform the maintenance and operation responsibilities of a Citywide FTTP network. The staffing levels and the responsibility for that staffing will vary greatly with the various potential business models. The following sections outline the technical groups that will be required maintain and operate the network.

7.3.4.2.1 Outside Plant

The OSP group will be responsible for the maintenance, operations, and expansion of the City's telecommunications infrastructure including conduit, fiber, pole attachments, and splice enclosures. During construction, the OSP group will be responsible for tracking and overseeing the construction of new infrastructure. Once the network is constructed, the OSP group will oversee any future adds, moves, or changes to the network.

The OSP group may use contractors to perform activities such as construction, repair, and locating. Management of contractors will be a responsibility of an OSP manager with OSP technicians assisting with project oversight and quality assurance and quality control. The OSP manager will also assist with engineering and design of any adds, moves, and changes that occur on the network.

The OSP group will have responsibility for general field operations. This group will include OSP technicians to perform locates, and contracted support to provide repair services. Tasks will include management of the One Call process, fiber locates, response and troubleshooting of Layer 1 troubleshooting, and fleet management. Additionally, it is critical that while many of OSP jobs may be outsourced, that the OSP group be equipped with the proper locate and testing equipment.

Our estimate includes one OSP manager and up to two OSP technicians to operate the network, depending on what roles are contracted and what capabilities already exist within the City for locates.

7.3.4.2.2 Network Engineering

The network engineering group develops and maintains the network architecture, responds to high-level troubleshooting requests, manages network electronics and makes sure the network delivers to the end user a reliable service.

The network engineering group is responsible for making architecture decisions that will determine how the network is capable of delivering services to users. The network engineering group will also be responsible for change management and architectural review to ensure that network continuity is ensured after changes.

The network engineering group will also be responsible for vendor selections when new hardware, technologies, or contractor support is needed to support the network. The network engineering team will perform regular maintenance of the network as well as provision, deploy, test, and accept any electronics to support new sites or services.

Network technicians will be responsible for troubleshooting issues with network electronics and responding to customer complaints.

To operate network electronics (if required by the business model) we estimate a staffing requirement of two network managers, six network engineers, and seven network technicians that could be a combination of personnel as well as contracted support.

7.3.4.2.3 Network Operations Center and Customer Service

The network will require individuals to perform monitoring and oversight of the network electronics. The group will be responsible for handling technical calls from users, actively monitoring the health of the network, and escalating issues to the proper operations groups. The group is also required to develop and monitor network performance parameters to ensure that the network is meeting its obligations to its user's as defined in the network service level agreements (SLAs).

Often network operations require a 24x7 customer service helpdesk and tools for network monitoring, alerting, and provisioning.

7.4 Cost Estimate for Dark FTTP

The cost estimate is based on a ubiquitous fiber deployment, in which the network is constructed to every building in the community. The estimate provides a breakdown of costs that enables inputs to a range of business models—from a City overbuild,[132] to various public–private partnerships. To illustrate the broad range of potential costs, we present a complete FTTP estimate (fiber and electronics) assuming a 35 percent take rate, which is the percentage of subscribers who purchase broadband service from the FTTP enterprise. We also present a graphic that shows how take rate impacts the total cost.

Any FTTP deployment will require significant capital investment—whether by the City, a private partner, or some combination. It makes sense to think of the cost estimate, which includes everything from dark fiber to network electronics to customer premises equipment (CPE), as a "worst-case scenario." It is unlikely that the City will construct, operate, and maintain the fiber,

[132] In a City overbuild model, the City would construct, own, and maintain the dark fiber; purchase and maintain the network electronics required to "light" the fiber; and purchase and maintain the CPEs.

and offer retail services over the network. However, this feasibility study aims to consider a range of ownership possibilities, as well as risk and reward tradeoffs.

We recommend a dark FTTP partnership model. In this model, the City constructs and owns the fiber network, and the private partner leases the fiber from the City; purchases and maintains network electronics required to "light" the fiber; purchases and maintains CPEs; and directly serves the end user. Unlike the public overbuild model, which includes the substantial capital and operating expense for network electronics, a dark FTTP partnership requires the City to invest in only the fiber outside plant (OSP) capital and operating costs.

The financial analysis below is based on a dark FTTP partnership where the City would construct, own, and operate *only* the fiber assets, not including the drop cable that connects the customer's home to the network.[133] In this model, the cost to own, maintain, and replenish network electronics and CPEs, and to install the drop cable, is passed on to the City's private partner.

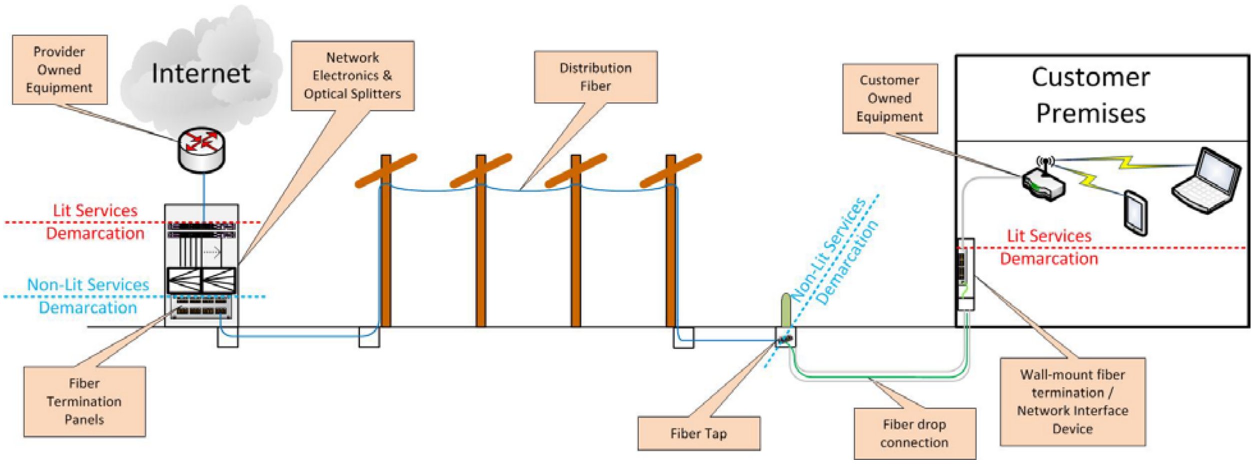
7.4.1 Cost Implications of Dark FTTP Partnership

Many of the assumptions in our analysis could change through negotiation with a private partner—for example, the City may elect to install and retain ownership of drop cables. We have chosen the assumptions in the financial analysis for the base case scenario because we believe this approach presents a reasonable balance of costs, control, and risk for the City. (City ownership of the drops, for example, would increase the City's control, but also significantly increase the City's costs.)

The financial analysis in Section 8 assumes that the City constructs and owns the dark FTTP infrastructure up to a demarcation point at the optical tap near each residence and business, and leases the dark fiber backbone and distribution fiber to a private partner. As we noted, this means the private partner would be responsible for all network electronics, fiber drops to subscribers, and CPEs—as well as network sales, marketing, and operations.

[133] The City can potentially negotiate with its chosen partner(s) about ownership of the customer drop cable.

Figure 81: Demarcation Between City and Partner Network Elements



The precise demarcation point that makes sense for the City and its partner is negotiable, and will have to be determined through discussions between the City and its potential partner(s). For example, some network operators suggest that the network's optical splitters should be a part of the Layer 1 or dark fiber assets. We caution against this approach. The network operator (i.e., the City's partner) should maintain the splitters because, as operator of the electronics, it must determine and control the GPON network split ratio to meet the network's performance standards. This may involve moving power users to GPON ports with lower split ratios, or moving users to different splitters to manage the capacity of the GPON ports. The City should not be involved in this level of network management. Also, the City should not have to inventory various sized splitters or swap them as the network operator makes changes. Even if the City were to decide to purchase some of the optical splitters for the network, we believe it should be the network operator's responsibility to manage and maintain the splitters.

7.4.2 Dark FTTP Cost Estimate – No Network Electronics, Service Drops, or CPEs

While the cost estimate in Section 7.1 anticipates the full range of potential City costs, this section shows the project cost to deploy *only* the FTTP OSP infrastructure.[134] This is the total capital cost for the City to build a dark FTTP network for lease to a private partner—it is the City's projected OSP cost in a dark FTTP partnership.

The City has historically avoided aerial construction when deploying new fiber because of concerns about ice storms and other weather-related incidents that could cause mass outages due to downed aerial lines. In light of this, we estimated costs to place all fiber underground. We based these estimates on two potential construction scenarios: all-underground and a combination of underground and aerial.

[134] This is the physical portion of a network (also called "layer 1") that is constructed on utility poles (aerial) or in conduit (underground).

7.4.2.1 Combination of Aerial and Underground Construction

Assuming a combination of aerial and underground construction, the citywide dark FTTP network deployment will cost more than $143 million—including OSP construction labor, materials, engineering, permitting, and pole attachment licensing. Again, this estimate does not include any electronics, subscriber equipment, drops, or CPEs. Section 7.1 shows estimated costs for fiber, network electronics, drops, and CPES, and include all underground construction, as well as a combination of aerial and underground.

Table 29: Breakdown of Estimated Dark FTTP Cost – Combination of Aerial and Underground Construction

Cost Component	Total Estimated Cost
OSP Engineering	$14.7 million
Quality Control/Quality Assurance	5.4 million
General OSP Construction Cost	99.3 million
Special Crossings	0
Backbone and Distribution Plant Splicing	5 million
Backbone Hub, Termination, and Testing	11.4 million
FTTP Lateral Installations	7.7 million
Total Estimated Cost (aerial and underground):	**$143.5 million**

7.4.2.2 All Underground Construction

Assuming that all construction is underground, the citywide dark FTTP network deployment will cost more than $149 million, inclusive of outside plant (OSP) construction labor, materials, engineering, permitting, and pole attachment licensing. Again, this estimate *does not* include any electronics, subscriber equipment, or drops—and it includes no aerial fiber.

The projected cost to construct all underground is only about $5.6 million more than the cost for a combination of aerial and underground fiber. This difference is notably minimal; underground construction costs can sometimes be much higher than aerial, but our projections indicate that it would not add a major financial burden if the City opts to construct the dark FTTP network entirely underground.

Table 30: OSP Cost Estimate Summary (Underground Construction)

Cost Component	Total Estimated Cost
OSP Engineering	$14,706,000
Quality Control/Quality Assurance	5,429,000
General OSP Construction Cost	104,883,000
Special Crossings	-
Backbone and Distribution Plant Splicing	4,955,000
Backbone Hub, Termination, and Testing	11,406,000
FTTP Lateral Installations	7,741,000
Total Estimated OSP Cost (all underground)	**$149,120,000**

8 Financial Analysis of Dark FTTP Network

The financial analysis for all scenarios presented here represents a minimum requirement for the City of Madison to break even each year, excluding any potential revenue from other dark fiber lease opportunities that may be available to the City.

This analysis assumes that the City will construct, own, and maintain the dark fiber network over which one or more private partners will provide lit retail service to end users. In this dark FTTP partnership model, the financial responsibility for deploying core electronics to "light" the network falls to the private partner. We also assume the partner is responsible for CPEs, and installing the drop cable to the customer. This model assumes that maintenance and replenishments for electronics are the partner's responsibility.

The base case financial analysis assumes all-underground construction. An all-underground network would increase the ongoing costs for fiber locates and ticketing, while eliminating the pole maintenance costs. Using the all-underground cost estimate for the fiber outside plant (OSP), and in order for the City to maintain positive cash flow, the City's private partner will need to pay a minimum fee of $15 per passing per month. This payment assumes there are no upfront or balloon payments. Based on an assumption that the City will deploy a ubiquitous FTTP network, the financial model applies the fee to all residential and business premises in the City. The current model keeps the $15 per passing fee constant, although the City and its partner should negotiate periodic increases on the portion of the fee covering operational and maintenance costs.

The financial analysis for the base case scenario is as follows:

Table 31: Base Case Financial Analysis

Income Statement	1	5	10	15	20
Total Revenues	$ 88,550	$ 17,710,020	$ 17,710,020	$ 17,710,020	$ 17,710,020
Total Cash Expenses	(856,190)	(2,316,120)	(2,316,120)	(2,316,120)	(2,316,120)
Depreciation	(2,274,200)	(7,494,600)	(7,494,600)	(7,494,600)	(7,494,600)
Interest Expense	(2,430,000)	(7,754,950)	(6,023,970)	(3,866,860)	(1,178,750)
Taxes	-	-	-	-	-
Net Income	$ (5,471,840)	$ 144,350	$ 1,875,330	$ 4,032,440	$ 6,720,550
Cash Flow Statement	**1**	**5**	**10**	**15**	**20**
Unrestricted Cash Balance	$ 209,360	$ 613,770	$ 3,410,190	$ 6,207,970	$ 9,006,860
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	2,430,000	-	-	-	-
Debt Service Reserve	2,700,000	9,325,000	9,325,000	9,325,000	9,325,000
Total Cash Balance	$ 5,339,360	$ 10,084,900	$ 12,931,870	$ 15,779,960	$ 18,629,160

Please note that we used a "flat-model" in the analysis. In a "flat-model," inflation and operating cost increases (including salaries) are not used in the analysis because it is assumed that operating cost increases will be offset by increases in operator lease payments over time (and likely passed on to subscribers in the form of increased prices). We anticipate that the City will apply an inflation factor, typically based on a Consumer Price Index (CPI), to the portion of the per subscriber fee covering projected operating expenses during negotiations with a private partner. Please note that it is not appropriate to apply a CPI to the entire passing fee because the majority of the fee is to support the principal and interest on the debt service. This is discussed further in Section 8.5.

This section presents an overview of the financial analysis; we have provided the City with a complete financial model in Excel format. Because the Excel spreadsheets can be manipulated to show the impact of changing assumptions (much as we have done in the scenarios in Section 8.6 below), it will be an important tool for the City to use as it negotiates with a private partner.

8.1 FTTP Financing Options

A key consideration for any FTTP network deployment is how to finance upfront capital construction costs. These costs represent a large expenditure that is generally slow to yield a return; the lack of a quick return on investment (ROI) sheds some light on why the private sector is not clamoring to upgrade existing legacy networks with fiber infrastructure, or to build new FTTP networks.

The City can seek bonding, or borrow funds, to cover construction costs to expand its fiber network, and in consideration of operations and maintenance (O&M) costs. Municipal bonds may also factor into a public–private partnership. While not every partnership will require the City to pursue bonding, all potential private partners will likely request some contribution from the City. One partnership structure that may be particularly desirable to the City entails the City owning and operating the infrastructure while a private partner lights the fiber and offers retail services over it. In this scenario, the likelihood of bonding is much greater because the City would likely be responsible for funding the construction of the network.

The City will likely be required to finance[135] some portion of an FTTP network, even if it engages a partner, and especially if it opts to retain ownership and control of the network, which is a desirable approach for the City. The City of Madison has a great credit rating and a low cost for bond financing, which gives it an advantage and makes it attractive to potential partners. There are also a variety of bonding avenues the City may be able to explore, such as working through the Community Development Authority (CDA) to secure bond financing.

[135] The term "financing" generally refers to any borrowing required or investments provided. The amount financed requires repayment, typically with interest—such as through a bond or loan. By comparison, "funding" means resources that can include subscriber revenues, taxes, or other sources of capital that are used to cover operation, maintenance, debt service, and other expenses. Federal or state grants, such as the BTOP grant that was used to construct the MUFN, are an example of funding. Funding does not require repayment.

We discuss here some of the common types of bonds that municipalities typically rely on for capital projects, and the advantages and disadvantages of each. Please note that the following is a summary, does not include every financing mechanism available to the City, and does not offer any legal or tax advice.

8.1.1 General Obligation Bonds

General obligation bonds are directly tied to the City's credit rating and ability to tax its citizens. This type of bond is not tied to revenues from any specific municipal projects, but is connected instead to citywide taxes and revenues can be used to repay this debt.

City leadership is likely very familiar with this type of bonding, as general obligation bonds are commonly sought in municipal organizations to fund capital improvement projects. Based on conversations with staff, the City is at approximately one-third of its borrowing capacity, as borrowing has increased in recent years due to infrastructure investments.

General obligation bonds can be politically challenging because they generally require a public approval process. These bonds are usually issued for projects that will clearly serve the needs of the entire community, such as roadway improvements. While it is our opinion that a fiber enterprise serving the public clearly meets this condition, incumbent opposition is likely. The City will need to develop a clear vision for its messaging to clearly convey to the community that it intends for the fiber network to serve all members of the community, and to serve all citizens' needs. The pilot project may factor in to demonstrating the City's commitment to serving the entire community, and help with public approval.

Further, a clearly and publicly stated goal of network ubiquity may help ease the process of general obligation bond approval. That is, if the City is willing and able to commit to expanding the network to serve *all* members of the community, it may be politically palatable to request approval of general obligation bonds. In addition, a model which opens fiber access to multiple providers enables new and existing providers to offer new service and give Madison consumers a choice and alternatives. Given the City's dedication to deploying a ubiquitous network, general obligation bonds could be a reasonable option for Madison.

It may be especially helpful if the City can work within existing initiatives and with other public, quasi-public, and private institutions to demonstrate how the fiber network can effectively benefit the entire community. For example, the City may want to consider tapping into the knowledge and resources of its Community Development and Economic Development Divisions to show a fiber network's role in economic development. This, coupled with a concerted effort to ensure the network passes every potential customer in the City so that anyone may potentially access service, could illustrate fiber's potential as a community resource.

8.1.2 Revenue Bonds

Revenue bonds are directly tied to a specific revenue source to secure the bond and guarantee repayment of the debt. For example, the revenue stream from a municipality's electric, natural gas, or water utility may be used to secure a revenue bond.

Theoretically, any municipal service that generates some sort of revenue that could be used to pay back the debt might potentially be used to secure a revenue bond—municipally owned public transportation or hospitals, for example. In light of this, it might make sense that the revenues generated from owning a fiber optic network and leasing it to providers could be used to guarantee a revenue bond, but this is typically not an accepted practice within the bonding community. Municipal broadband projects without a proven revenue stream are usually viewed as high-risk in the bonding community, and the projected revenues from the network will likely be viewed as too uncertain to support repayment of the loan.

If the City wishes to pursue revenue bonds, it may find that other utilities departments' revenues are more likely to be approved as an acceptable stream to support a revenue bond. These bonds are less politically challenging than general obligation bonds, but the City will still need to be prepared to explain why it must pursue this form of bond to help support FTTP network deployment.

8.2 Cost Implications of FTTP Technical Model

The financial analysis in this section assumes that the City constructs and owns the FTTP infrastructure up to a demarcation point at the optical tap near each residence and business, and leases the dark fiber backbone and distribution fiber to a private partner. The private partner would be responsible for all network electronics, fiber drops to subscribers, and customer premises equipment (CPE)—as well as network sales, marketing, and operations.

Using a mix of 38 percent aerial and 62 percent underground construction the citywide dark FTTP network deployment will cost more than $143 million, inclusive of outside plant (OSP) construction labor, materials, engineering, permitting, and pole attachment licensing. This estimate does not include and electronics, subscriber equipment, or drops. The average drop cost with the above mix of aerial and underground construction is $607.

Table 32: Breakdown of Estimated Dark FTTP Cost – Combination of Aerial and Underground Construction

Cost Component	Total Estimated Cost
OSP Engineering	$14.7 million
Quality Control/Quality Assurance	5.4 million
General OSP Construction Cost	99.3 million
Special Crossings	0
Backbone and Distribution Plant Splicing	5 million
Backbone Hub, Termination, and Testing	11.4 million
FTTP Lateral Installations	7.7 million
Total Estimated Cost:	$143.5 million

The City or its partner(s) may aim to place all newly constructed fiber underground to avoid weather-related concerns (e.g., ice storms and other weather incidents that could cause outages due to downed aerial lines), and challenges with obtaining pole attachments. Because all-underground construction is a possibility, we estimated costs to place all fiber underground. We estimate that it will cost more than $149 million to construct an all-underground dark FTTP network, inclusive of outside plant (OSP) construction labor, materials, engineering, permitting, and pole attachment licensing. This estimate does not include and electronics, subscriber equipment, or drops. For the cost estimate in this section we used the all-underground construction estimate.

The all-underground model also increases the average drop cost from $607 to $972—though this is potentially the private provider's cost.

Table 33: Breakdown of Estimated Dark FTTP Cost – All Underground Construction

Cost Component	Total Estimated Cost
OSP Engineering	$14.7 million
Quality Control/Quality Assurance	5.4 million
General OSP Construction Cost	104.9 million
Special Crossings	0
Backbone and Distribution Plant Splicing	5 million
Backbone Hub, Termination, and Testing	11.4 million
FTTP Lateral Installations	7.7 million
Total Estimated Cost:	$149.1 million

The ownership of the drops is an assumption that could be changed through negotiation with a private partner—as, indeed, could many of the assumptions underpinning this analysis. We have chosen this key parameter for the base case scenario because we believe this approach presents a reasonable balance of costs, control, and risk for the City. (City ownership of the drops, for example, would increase the City's control, but also increase the City's costs.)

In a related vein, we note that some network operators suggest that the network's optical splitters should be a part of the Layer 1 or dark fiber assets. We caution against this approach. The network operator (i.e., the City's partner) should maintain the splitters because, as operator of the electronics, it must determine and control the GPON network split ratio to meet the network's performance standards. This may involve moving power users to GPON ports with lower split ratios, or moving users to different splitters to manage the capacity of the GPON ports. The City should not be involved in this level of network management. Also, the City should not have to inventory various sized splitters or swap them as the network operator makes changes. Even if the City decides to purchase some of the optical splitters for the network, we believe it should be the network operator's responsibility to manage and maintain the splitters.

8.3 Financing Costs and Operating Expenses

This financial analysis assumes that the City will cover all of its capital requirements with general obligation (GO) bonds to maximize the benefits of the City's strong bond rating. We assume that the City's bond rate will be 4.5 percent, which represents a two-percentage-point premium over current non-taxable rates. (Because the network will have private users, the City will not be able to bond at a non-taxable rate.)

We expect that the City will take three 20-year bonds—one each in years one, two, and three—for a total of $186.5 million in financing. (The difference between the financed amount and the total capital costs—$149.3 million—represents the amount needed to maintain positive cash flow in the early years of network deployment.) The resulting principal and interest (P&I) payments will be the major factor in determining the City's long-term financial requirements; P&I accounts for about 86.5 percent of the City's annual costs in our base case model after the construction period.

We project that the bond issuance costs will be equal to 1.0 percent of the principal borrowed. For the bond, a debt service reserve account is maintained at 5.0 percent of the total issuance amount. An interest reserve account will be maintained for the first two years. Principal repayment on the bonds will start in year two.

The model assumes a straight-line depreciation of assets, and that the outside plant and materials will have a 20-year life span. Because we assume the City's partner will be responsible for network electronics and CPE, we have not included depreciation or replacement costs for that equipment (although we note that, typically, network equipment would be replaced after 10 years, while CPE and last-mile infrastructure would be depreciated over five years). The model plans for a depreciation reserve account starting in year three to fund future replacements and upgrades.

Table 34 shows the income statement for years one, five, 10, 15, and 20.

Table 34: Income Statement

		Year 1	Year 5	Year 10	Year 15	Year 20
Income Statement						
a. Revenues						
Per Passing		$ 88,550	$ 17,710,020	$ 17,710,020	$ 17,710,020	$ 17,710,020
	Total	$ 88,550	$ 17,710,020	$ 17,710,020	$ 17,710,020	$ 17,710,020
c. Operating Costs						
Operation Costs		$ 705,690	$ 1,770,120	$ 1,770,120	$ 1,770,120	$ 1,770,120
Labor Costs		150,500	546,000	546,000	546,000	546,000
	Total	$ 856,190	$ 2,316,120	$ 2,316,120	$ 2,316,120	$ 2,316,120
d. EBITDA		$ (767,640)	$ 15,393,900	$ 15,393,900	$ 15,393,900	$ 15,393,900
e. Depreciation		2,274,200	7,494,600	7,494,600	7,494,600	7,494,600
f. Operating Income (EBITDA less Depreciation)		$ (3,041,840)	$ 7,899,300	$ 7,899,300	$ 7,899,300	$ 7,899,300
g. Non-Operating Income						
Interest Income		$ -	$ 23,800	$ 23,800	$ 23,930	$ 24,060
Interest Expense (10 Year Bond)		-	-	-	-	-
Interest Expense (20 Year Bond)		(2,430,000)	(6,047,770)	(6,047,770)	(3,890,790)	(1,202,810)
Interest Expense (Loan)		-	-	-	-	-
	Total	$ (2,430,000)	$ (6,023,970)	$ (6,023,970)	$ (3,866,860)	$ (1,178,750)
h. Net Income (before taxes)		$ (5,471,840)	$ 144,350	$ 1,875,330	$ 4,032,440	$ 6,720,550
i. Facility Taxes		$ -	$ -	$ -	$ -	$ -
j. Net Income		$ (5,471,840)	$ 144,350	$ 1,875,330	$ 4,032,440	$ 6,720,550

Table 35 shows the cash flow statement for years one, five, 10, 15, and 20. The unrestricted cash balance is approximately $209,000 in year one and $3.4 million in year 10. By year 15, the unrestricted cash balance is approximately $6.2 million and it is $9 million by year 20.

Table 35: Cash Flow Statement

	Year 1	Year 5	Year 10	Year 15	Year 20
Cash Flow Statement					
a. Net Income	$ (5,471,840)	$ 144,350	$ 1,875,330	$ 4,032,440	$ 6,720,550
b. Cash Outflows					
Debt Service Reserve	$ (2,700,000)	$ -	$ -	$ -	$ -
Interest Reserve	(4,860,000)	-	-	-	-
Depreciation Reserve	-	(48,710)	(48,710)	(48,710)	(48,710)
Financing	(540,000)	-	-	-	-
Capital Expenditures	(44,923,000)	-	-	-	(3,000)
Total	$ (53,023,000)	$ (48,710)	$ (48,710)	$ (48,710)	$ (51,710)
c. Cash Inflows					
Interest Reserve	$ 2,430,000	$ -	$ -	$ -	$ -
Depreciation Reserve	-	-	-	-	3,000
Grants (infrastructure)	-	-	-	-	-
10-Year Bond/Loan Proceeds	-	-	-	-	-
20-Year Bond Proceeds	54,000,000	-	-	-	-
Loan Proceeds	-	-	-	-	-
Total	$ 56,430,000	$ -	$ -	$ -	$ 3,000
d. Total Cash Outflows and Inflows	$ 3,407,000	$ (48,710)	$ (48,710)	$ (48,710)	$ (48,710)
e. Non-Cash Expenses - Depreciation	$ 2,274,200	$ 7,494,600	$ 7,494,600	$ 7,494,600	$ 7,494,600
f. Adjustments					
Proceeds from Additional Cash Flows (10 Year Bond)	$ -	$ -	$ -	$ -	$ -
Proceeds from Additional Cash Flows (20 Year Bond)	$ (54,000,000)	$ -	$ -	$ -	$ -
Proceeds from Additional Cash Flows (Loan)	$ -	$ -	$ -	$ -	$ -
g. Adjusted Available Net Revenue	$ (53,790,640)	$ 7,590,240	$ 9,321,220	$ 11,478,330	$ 14,166,440
h. Principal Payments on Debt					
10 Year Bond Principal	$ -	$ -	$ -	$ -	$ -
20 Year Bond Principal	-	7,030,840	8,761,700	10,918,680	13,606,660
Loan Principal	-	-	-	-	-
Total	$ -	$ 7,030,840	$ 8,761,700	$ 10,918,680	$ 13,606,660
j. Cash Balance					
Unrestricted Cash Balance	$ 209,360	$ 613,770	$ 3,410,190	$ 6,207,970	$ 9,006,860
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	2,430,000	-	-	-	-
Debt Service Reserve	2,700,000	9,325,000	9,325,000	9,325,000	9,325,000
Total Cash Balance	$ 5,339,360	$ 10,084,900	$ 12,931,870	$ 15,779,960	$ 18,629,160

Significant network expenses—known as “capital additions”—are incurred in the first few years during the construction phase of the network. These represent the equipment and labor expenses associated with building a fiber network. (Again, because the City’s responsibility will be limited to OSP, we have not included any costs for core network equipment, drops, or CPE.) This analysis projects that capital additions in year one will total approximately $44.9 million. These costs will total approximately $74.6 million in year two, and $29.8 million in year three. This totals just over $149.3 million in capital additions[136] for years one through three.

8.4 Operating and Maintenance Expenses

The cost to deploy an FTTP network goes far beyond fiber implementation. Network deployment requires sales and marketing, network maintenance and technical operations, and

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136 Includes the FTTP OSP plus vehicles, computers, and test equipment required to maintain the OSP.

other functions. In this model, we assume that the City's partner will be responsible for lighting the fiber and selling services, so the City's financial requirements are limited to expenses related to OSP infrastructure and network administration.

These expanded responsibilities will require the addition of new staff. We assume the City will add a total of four full-time-equivalent (FTE) positions within the first three years, and will then maintain that level of staffing. Our assumptions include one FTE for OSP management and HR/administrative support, and two FTEs for fiber plant maintenance and operations. Salaries and benefits are based on estimated market wages, and benefits are estimated at 40 percent of base salaries.

Locates and ticket processing will be significant ongoing operational expenses for the City. Based on our experience in other cities, we estimate that a contract for locates will cost $133,600 in year one, increase to $267,200 in year two, and increase to $546,000 from year three on. (If the City decides to perform this work in-house, the contract expense would be eliminated—but staffing expenses would increase.)

Additional key operating and maintenance assumptions include the following:

- Insurance is estimated to be $50,000 in year one and $75,000 from year two on.
- Office expenses are estimated to be $2,400 annually.
- Contingency expenses are estimated at $10,000 in year one and $25,000 in subsequent years.
- Legal fees are estimated to be $100,000 in year one, $50,000 in year two, and $25,000 from year three on.
- Consulting fees are estimated at $100,000 in year one and $20,000 from year two on.

Fiber network maintenance costs are calculated at 0.5 percent of the total construction cost, per year. This is estimated based on a typical rate of occurrence in an urban environment, and the cost of individual repairs. This is in addition to staffing costs to maintain fiber.

Table 36 lists the City's projected operating expenses for years one, five, 10, 15, and 20.

Table 36: Operating Expenses

	Year 1	Year 5	Year 10	Year 15	Year 20
Operating Expenses					
Insurance	$ 50,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000
Office Expenses	2,400	2,400	2,400	2,400	2,400
Locates & Ticket Processing	216,600	866,200	866,200	866,200	866,200
Contingency	10,000	25,000	25,000	25,000	25,000
Fiber & Network Maintenance	223,680	745,600	745,600	745,600	745,600
Legal and Lobby Fees	100,000	25,000	25,000	25,000	25,000
Consulting	100,000	20,000	20,000	20,000	20,000
Education and Training	3,010	10,920	10,920	10,920	10,920
Pole Attachment Expense	-	-	-	-	-
Sub-Total	$ 705,690	$ 1,770,120	$ 1,770,120	$ 1,770,120	$ 1,770,120
Labor Expenses	$ 150,500	$ 546,000	$ 546,000	$ 546,000	$ 546,000
Sub-Total	$ 150,500	$ 546,000	$ 546,000	$ 546,000	$ 546,000
Total Expenses	$ 856,190	$ 2,316,120	$ 2,316,120	$ 2,316,120	$ 2,316,120
Principal and Interest	$ (4,860,000)	$ -	$ -	$ -	$ -
Facility Taxes	-	-	-	-	-
Sub-Total	$ (4,860,000)	$ -	$ -	$ -	$ -
Total Expenses, P&I, and Taxes	$ (4,003,810)	$ 2,316,120	$ 2,316,120	$ 2,316,120	$ 2,316,120

8.5 Revenue

The base case scenario assumes that the City's private partner will pay a fee of $15 per passing per month, with no upfront or balloon payments. Based on an assumption that the City will deploy a ubiquitous FTTP network, the financial model applies the fee to all residential and business premises in the City. The current model keeps that $15 per passing fee constant, although the City and its partner could negotiate periodic increases.

Operating and maintenance expenses account for approximately 13.5 percent of the City's total annual costs. (P&I payment on debt is the remaining amount.) At a minimum, then, 13.5 percent of the per-passing fee should be increased by a CPI each year.

In the scenarios below, we show how changing certain assumptions related to financing will affect that fee. (We note, too, that the fee will be just one element of the City's negotiations with a private partner.)

8.6 Sensitivity Scenarios

This section demonstrates the sensitivity of the financial projections to changes in various assumptions. For comparison, we repeat the base case scenario—with a per-passing fee of $15 per month—here:

Table 37: Base Case Financial Analysis

Income Statement	1	5	10	15	20
Total Revenues	$ 88,550	$ 17,710,020	$ 17,710,020	$ 17,710,020	$ 17,710,020
Total Cash Expenses	(856,190)	(2,316,120)	(2,316,120)	(2,316,120)	(2,316,120)
Depreciation	(2,274,200)	(7,494,600)	(7,494,600)	(7,494,600)	(7,494,600)
Interest Expense	(2,430,000)	(7,754,950)	(6,023,970)	(3,866,860)	(1,178,750)
Taxes	-	-	-	-	-
Net Income	$ (5,471,840)	$ 144,350	$ 1,875,330	$ 4,032,440	$ 6,720,550

Cash Flow Statement	1	5	10	15	20
Unrestricted Cash Balance	$ 209,360	$ 613,770	$ 3,410,190	$ 6,207,970	$ 9,006,860
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	2,430,000	-	-	-	-
Debt Service Reserve	2,700,000	9,325,000	9,325,000	9,325,000	9,325,000
Total Cash Balance	$ 5,339,360	$ 10,084,900	$ 12,931,870	$ 15,779,960	$ 18,629,160

8.6.1 Adding a One-Time, $10 Million Payment from the City's Partner

In this section, we demonstrate the impact of a one-time payment from the City's partner on the financial model. A $10 million upfront payment from the private partner would enable the City to reduce its bond requirement by $12.5 million—which, in turn would lower the required per-passing fee to $14.10.

Table 38: A $10 Million Upfront Payment Reduces the City's Borrowing by $12.5 Million

Income Statement	1	5	10	15	20
Total Revenues	$ 10,083,240	$ 16,647,420	$ 16,647,420	$ 16,647,420	$ 16,647,420
Total Cash Expenses	(856,190)	(2,316,120)	(2,316,120)	(2,316,120)	(2,316,120)
Depreciation	(2,274,200)	(7,494,600)	(7,494,600)	(7,494,600)	(7,494,600)
Interest Expense	(2,115,000)	(7,244,610)	(5,631,970)	(3,622,350)	(1,118,010)
Taxes	-	-	-	-	-
Net Income	$ 4,837,850	$ (407,910)	$ 1,204,730	$ 3,214,350	$ 5,718,690

Cash Flow Statement	1	5	10	15	20
Unrestricted Cash Balance	$ 4,254,050	$ 644,730	$ 3,083,290	$ 5,523,210	$ 7,964,230
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	2,115,000	-	-	-	-
Debt Service Reserve	2,350,000	8,700,000	8,700,000	8,700,000	8,700,000
Total Cash Balance	$ 8,719,050	$ 9,490,860	$ 11,979,970	$ 14,470,200	$ 16,961,530

8.6.2 Increasing the City's Interest Rate

Because the City will be building and maintaining the OSP, but not lighting the fiber or selling retail services, the City's capital investment and financing are the key sensitivities in the model. As we noted above, about 86.5 percent of the City's annual cash outflow will cover P&I; only 13.5 percent of cash outflow will be for network operations and maintenance. If the City's interest rate were to increase by two percentage points, to 6.5 percent, the City would need to increase its borrowing by $7.5 million to cover the increased interest payments in early years, as well as to keep cash flow positive. The increased borrowing would, in turn, increase the required per-passing payment from $15 to $17.75 (a roughly 18 percent increase in that fee).

Table 39: Increasing the City's Interest Rate by 2 Percentage Points Increases Required Borrowing by $7.5 Million

Income Statement	1	5	10	15	20
Total Revenues	$ 104,790	$ 20,956,860	$ 20,956,860	$ 20,956,860	$ 20,956,860
Total Cash Expenses	(856,190)	(2,316,120)	(2,316,120)	(2,316,120)	(2,316,120)
Depreciation	(2,274,200)	(7,494,600)	(7,494,600)	(7,494,600)	(7,494,600)
Interest Expense	(3,672,500)	(11,818,740)	(9,513,410)	(6,354,930)	(2,027,600)
Taxes	-	-	-	-	-
Net Income	$ (6,698,100)	$ (672,600)	$ 1,632,730	$ 4,791,210	$ 9,118,540
Cash Flow Statement	**1**	**5**	**10**	**15**	**20**
Unrestricted Cash Balance	$ 90,600	$ 296,370	$ 3,017,930	$ 5,740,850	$ 8,464,870
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	3,672,500	-	-	-	-
Debt Service Reserve	2,825,000	9,700,000	9,700,000	9,700,000	9,700,000
Total Cash Balance	$ 6,588,100	$ 10,142,500	$ 12,914,610	$ 15,687,840	$ 18,462,170

In contrast to the scenario above, if the City were able to decrease its interest rate by two percentage points, to 2.5 percent, it would be able to reduce its borrowing by 6.5 million and the required per-passing cost to $12.50.

Table 40: Reducing the City's Interest Rate by 2 Percentage Points Reduces Required Borrowing

Income Statement	1	5	10	15	20
Total Revenues	$ 73,790	$ 14,758,350	$ 14,758,350	$ 14,758,350	$ 14,758,350
Total Cash Expenses	(856,190)	(2,316,120)	(2,316,120)	(2,316,120)	(2,316,120)
Depreciation	(2,274,200)	(7,494,600)	(7,494,600)	(7,494,600)	(7,494,600)
Interest Expense	(1,287,500)	(4,084,500)	(3,045,010)	(1,868,920)	(538,310)
Taxes	-	-	-	-	-
Net Income	$ (4,344,100)	$ 863,130	$ 1,902,620	$ 3,078,710	$ 4,409,320
Cash Flow Statement	**1**	**5**	**10**	**15**	**20**
Unrestricted Cash Balance	$ 129,600	$ 747,370	$ 2,744,180	$ 4,742,350	$ 6,741,620
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	1,287,500	-	-	-	-
Debt Service Reserve	2,575,000	9,000,000	9,000,000	9,000,000	9,000,000
Total Cash Balance	$ 3,992,100	$ 9,893,500	$ 11,940,860	$ 13,989,340	$ 16,038,920

8.6.3 Increasing the City's Bond Term to 30 Years

The illustrate the sensitivity of the City's financial model to bonding and borrowing terms, we increased the City's bond term from 20 years to 30 years. The per-passing fee required to maintain cash flow decreases from $15.00 to $12.15. However, the longer bond term increases the city's risk and increases the City's interest rate. Further, a longer bond term would require a longer contract with the private partner; given both the pace of change in the broadband industry, and the average lifespan of telecommunications companies.

Table 41: Increasing the City's Bond Term to 30 Years Decreases the Per-Passing Fee

Income Statement	1	5	10	15	20
Total Revenues	$ 71,730	$ 14,345,120	$ 14,345,120	$ 14,345,120	$ 14,345,120
Total Cash Expenses	(856,190)	(2,316,120)	(2,316,120)	(2,316,120)	(2,316,120)
Depreciation	(2,274,200)	(7,494,600)	(7,494,600)	(7,494,600)	(7,494,600)
Interest Expense	(2,430,000)	(7,926,270)	(7,063,630)	(5,988,670)	(4,649,100)
Taxes	-	-	-	-	-
Net Income	$ (5,488,660)	$ (3,391,870)	$ (2,529,230)	$ (1,454,270)	$ (114,700)

Cash Flow Statement	1	5	10	15	20
Unrestricted Cash Balance	$ 192,540	$ 860,210	$ 3,612,170	$ 6,365,460	$ 9,119,880
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	2,430,000	-	-	-	-
Debt Service Reserve	2,700,000	9,175,000	9,175,000	9,175,000	9,175,000
Total Cash Balance	$ 5,322,540	$ 10,181,340	$ 12,983,850	$ 15,787,450	$ 18,592,180

8.6.4 Reducing Operating Expenses by 25 Percent

Because the City will be borrowing to cover not only all of its capital requirements, but also a portion of its operating costs in the early years, decreasing the City's expenses would have a corresponding effect on the required per-passing fee. However, the impact is not linear. Decreasing operating expenses by 25 percent would only decrease the per-passing cost by 60 cents, to $14.40.

Table 42: Decreasing the City's Operating Expenses by 25 Percent Only Slightly Reduces the Per Passing Fee

Income Statement	1	5	10	15	20
Total Revenues	$ 85,010	$ 17,001,620	$ 17,001,620	$ 17,001,620	$ 17,001,620
Total Cash Expenses	(642,140)	(1,737,090)	(1,737,090)	(1,737,090)	(1,737,090)
Depreciation	(2,274,200)	(7,494,600)	(7,494,600)	(7,494,600)	(7,494,600)
Interest Expense	(2,430,000)	(7,712,430)	(5,990,490)	(3,844,680)	(1,170,620)
Taxes	-	-	-	-	-
Net Income	$ (5,261,330)	$ 57,500	$ 1,779,440	$ 3,925,250	$ 6,599,310

Cash Flow Statement	1	5	10	15	20
Unrestricted Cash Balance	$ 419,870	$ 748,770	$ 3,294,780	$ 5,842,120	$ 8,390,590
Depreciation Reserve	-	146,130	196,680	246,990	297,300
Interest Reserve	2,430,000	-	-	-	-
Debt Service Reserve	2,700,000	9,275,000	9,275,000	9,275,000	9,275,000
Total Cash Balance	$ 5,549,870	$ 10,169,900	$ 12,766,460	$ 15,364,110	$ 17,962,890

8.6.5 Construct Network with a Mix of Aerial and Underground Construction

The scenario below assumes a split of roughly 62 percent underground and 38 percent aerial fiber for construction of the City's network (as opposed to the base case and other scenarios, which assume all-underground construction). The mixed construction model also decreases the average drop cost from $972 to $607—though this would be the private provider's cost. In this scenario, the required per-passing fee would increase slightly, to $14.50.

Table 43: Mix of Aerial and Underground Construction Slightly Decreases Per-Passing Fee

Income Statement	1	5	10	15	20
Total Revenues	$ 85,600	$ 17,119,690	$ 17,119,690	$ 17,119,690	$ 17,119,690
Total Cash Expenses	(814,560)	(2,288,200)	(2,288,200)	(2,288,200)	(2,288,200)
Depreciation	(2,190,320)	(7,215,000)	(7,215,000)	(7,215,000)	(7,215,000)
Interest Expense	(2,340,000)	(7,484,820)	(5,814,200)	(3,732,350)	(1,138,000)
Taxes	-	-	-	-	-
Net Income	$ (5,259,280)	$ 131,670	$ 1,802,290	$ 3,884,140	$ 6,478,490

Cash Flow Statement	1	5	10	15	20
Unrestricted Cash Balance	$ 225,640	$ 882,260	$ 3,452,240	$ 6,023,480	$ 8,595,720
Depreciation Reserve	-	140,700	182,200	223,430	264,660
Interest Reserve	2,340,000	-	-	-	-
Debt Service Reserve	2,600,000	9,000,000	9,000,000	9,000,000	9,000,000
Total Cash Balance	$ 5,165,640	$ 10,022,960	$ 12,634,440	$ 15,246,910	$ 17,860,380

Appendix A – Common Community Objectives

This appendix is attached as a separate PDF file.

Appendix B – Best Practices for FTTP Deployment in Underserved Areas

This appendix is attached as a separate PDF file.

Appendix C – Residential Market Research Instrument

This appendix is attached as a separate PDF file.

Appendix D – Glossary of Terms

Access Fiber – The fiber in an FTTP network that goes from the FDCs to the optical taps that are located outside of homes and businesses in the ROW.

AE – Active Ethernet; a technology that provides a symmetrical (upload/download) Ethernet service and does not share optical wavelengths with other users. For subscribers that receive AE service—typically business customers that request a premium service or require greater bandwidth—a single dedicated fiber goes directly to the subscriber premises with no optical splitting.

CPE – Customer premises equipment; the electronic equipment installed at a subscriber's home or business.

Distribution Fiber – The fiber in an FTTP network that connects the hub sites to the fiber distribution cabinets.

Drop – The fiber connection from an optical tap in the ROW to the customer premises.

FDC – Fiber distribution cabinet; houses the fiber connections between the distribution fiber and the access fiber. FDCs, which can also house network electronics and optical splitters, can sit on a curb, be mounted on a pole, or reside in a building.

FTTP – Fiber-to-the-premises; a network architecture in which fiber optics are used to provide broadband services all the way to each subscriber's premises.

GPON – Gigabit passive optical network; the most commonly provisioned FTTP service—used, for example, by Verizon (in its FiOS systems), Google Fiber, and Chattanooga Electric Power Board (EPB). GPON uses passive optical splitting, which is performed inside FDCs, to connect fiber from the Optical Line Terminals (OLTs) to multiple customer premises over a single GPON port.

IP – Internet Protocol; the method by which computers share data on the Internet.

LEC – Local Exchange Carrier; a public telephone company that provides service to a local or regional area.

MDU – Multi-dwelling unit; a large building with multiple units, such as an apartment or office building.

OLT – Optical line terminal; the upstream connection point (to the provider core network) for subscribers. The choice of an optical interface installed in the OLT determines whether the network provisions shared access (one fiber split among multiple subscribers in a GPON architecture) or dedicated AE access (one port for one subscriber).

OSP – Outside plant; the physical portion of a network (also called “layer 1”) that is constructed on utility poles (aerial) or in conduit (underground).

OSS – Operational Support Systems (OSS); includes a provider’s provisioning platforms, fault and performance management systems, remote access, and other OSS for FTTP operations. The network’s core locations house the OSS.

OTT – Over-the-top; content, such as voice or video service, that is delivered over a data connection.

Passing – A potential customer address (e.g., an individual home or business).

POTS – “Plain old telephone service;” delivered over the PSTN.

PSTN – Public switched telephone network; the copper-wire telephone networks that connect landline phones.

QoS – Quality of service; a network’s performance as measured on a number of attributes.

ROW – Right-of-way; land reserved for the public good such as utility construction. ROW typically abuts public roadways.

VoIP – Voice over Internet Protocol; telephone service that is delivered over a data connection.