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Cost Estimates for FTTP Network Construction

Prepared for City of Santa Cruz, California
May 2015

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1 Executive Summary

This report documents a high-level design and cost estimate for the City of Santa Cruz's (City) deployment of a gigabit fiber-to-the-premises (FTTP) network.

1.1 Project Background

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

The CTC design and cost estimate are underpinned by data and insight gathered by CTC engineers through a number of related steps:

1. Discussions with City stakeholders
2. A limited field survey of outside plant in selected areas of the City
3. An extensive desk survey of candidate fiber routes

1.2 FTTP Cost Estimate

Based on these inputs and other guidance from the City, we developed a conceptual, high-level FTTP design that reflects the City's goals and is open to a variety of architecture options. This citywide FTTP network deployment will cost more than $50 million, inclusive of anticipated outside plant (OSP) construction labor, network electronics, materials, engineering, permitting, pole attachment licensing, drop installation, customer premises equipment (CPE), and testing.

Table 1: Breakdown of Estimated Total Cost

Cost Component	Total Estimated Cost
OSP	$32,000,000
FTTP Service Drop and Lateral Installations	$10,200,000
Central Network Electronics	$6,200,000
CPE	$3,500,000
Total Estimated Cost:	$51,900,000

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 California and elsewhere.

1.2.1 OSP

In terms of OSP, the estimated cost to construct the proposed FTTP network is $32 million, or $1,500 per passing.[1] As discussed in the report, our model assumes all underground fiber construction, because the cost of make-ready and pole replacement necessary for aerial construction in Santa Cruz makes underground construction significantly less expensive in most areas. (If the City were to construct the OSP with aerial fiber in areas where existing utilities are aerial, the cost per passing would be $1,600.) Table 2 summarizes the estimated OSP costs.

Table 2: Estimated OSP Costs for FTTP

Distribution Plant Mileage	Total Cost (with drops)	Total Cost (without drops)	Passings	Cost per Passing (Distribution Only)	Cost Per Plant Mile (Distribution Only)
137.3	**$42,200,000**	**$32,000,000**	**21,219**	**$1,500**	**$233,000**

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.

After discussions with the utility pole owners, and analyzing make-ready and pole replacement costs, CTC determined that the City's pole infrastructure would not cost-effectively support citywide FTTP and that underground construction was a more cost-effective option.

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.

[1] 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.

In addition to these construction 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 are 1 percent of the total construction cost per year—or roughly $425,000 annually.

1.2.2 Central Network Electronics

Central network electronics will cost an estimated $6.2 million, or $280 per passing. The central electronics costs are based on an assumed take rate of 35 percent.[2] 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 3 below lists the estimated costs for each segment.

Table 3: Estimated Central Network Electronics Costs

Network Segment	# of Sites	Cost Estimate	Subtotal	Passings	Cost per Passing
Core	2	$1,400,000	$2,800,000	22,100	$126
Hubs	2	$600,000	$1,200,000	22,100	$54
Distribution Cabinets	40	$56,000	$2,200,000	22,100	$100
		Central Electronics Total	**$6,200,000**	**22,100**	$280

1.2.3 Customer Premises Equipment

We also estimated the costs of installing customer premises equipment (CPE) at each subscriber. Using the same estimated take rate of 35 percent, we estimated an average CPE electronics and installation cost for both residential and business customers to be $455 per subscriber, or $3.5 million.

1.3 Other Deployment Opportunities

The City could potentially decrease the cost of fiber construction or ease into the fiber optic marketplace by leveraging fiber resources such as the Sunesys network. Sunesys has an extensive fiber optic network in the City which the company is currently expanding. Developing a partnership with Sunesys could provide the City with fiber resources that it could light to start serving customers in some neighborhoods in a "fiberhood" style. (This approach to network buildout, which some service providers have used, prioritizes neighborhoods where the most

[2] 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. In CTC's Task 2 business plan, we will examine how the feasibility of the project depends on a range of take rates.

residents have committed to buying service. This demand-driven approach ensures that the network operator has sufficient customers to justify the construction costs.)

This approach might also decrease the total cost of the FTTP network by using the Sunesys fiber as a significant portion of the fiber backbone. This assumes, of course, that the City and Sunesys are able to come to a reasonable agreement regarding fiber counts, service level agreements, cost, and other parameters.

2 Field Survey

A CTC outside plant (OSP) engineer performed a preliminary survey of Santa Cruz via Google Earth Street View to develop estimates of underground versus aerial percentages, per mile cost for aerial in the power space and communications space, and per mile costs for underground (where poles are not available).

Following that extensive desk survey, a CTC engineer conducted a brief field study of representative portions of the City on site. He reviewed available green space, necessary make-ready on poles, pole replacement, and guy replacement. He noted specific issues that will have an impact on construction—all of which have been factored in to our design and cost estimate.

Figure 1 illustrates the areas reviewed during the field survey (identified by Census tract numbers), while Table 4 summarizes each. (Field survey notes are attached as Appendix A.)

Figure 1: Map of Field Survey Areas

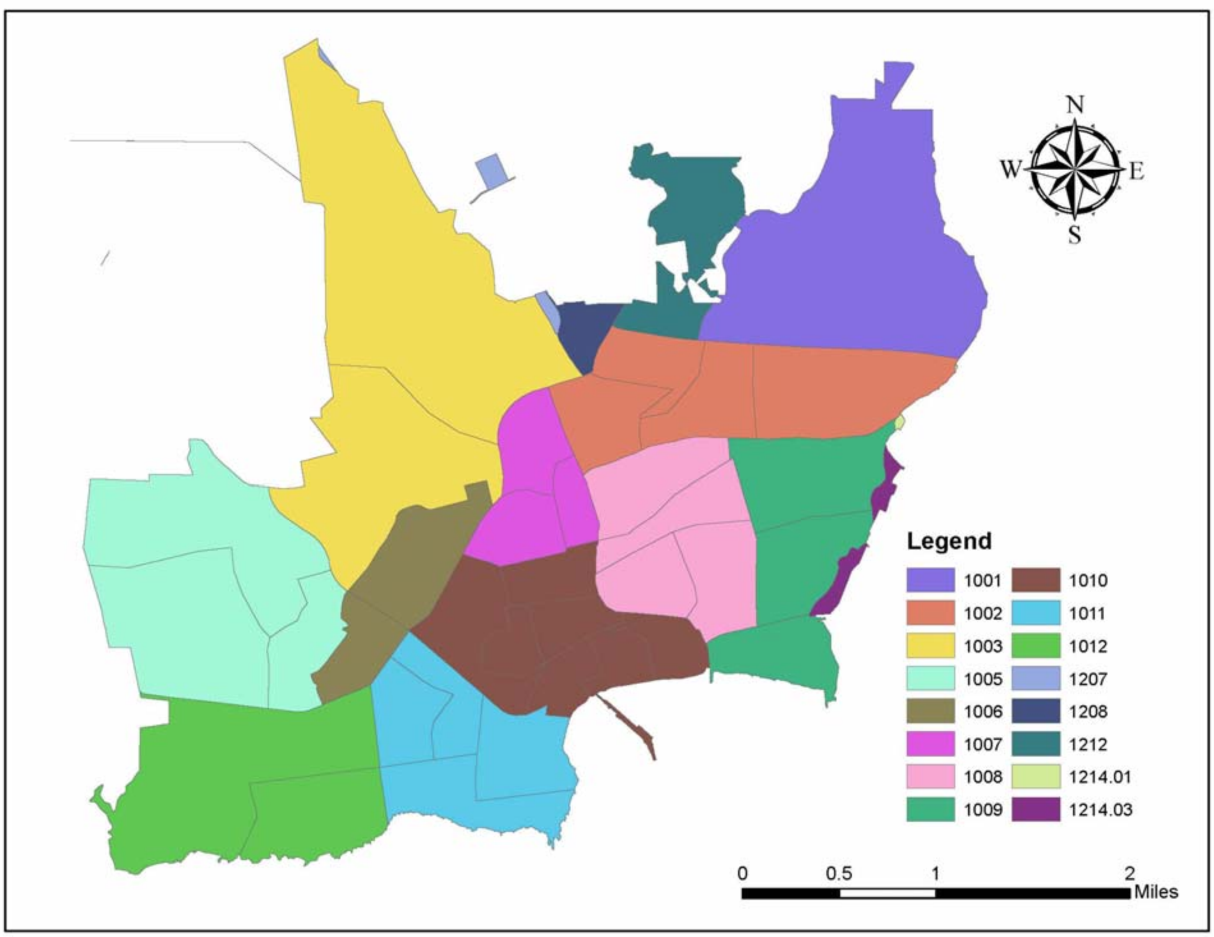


Table 4: Field Survey Findings

Service Area	Aerial vs. Underground	Front Easement vs. Rear Easement
Service Area 1001	95% / 5%	Rear Aerial: 60% Front Aerial: 40% Rear Buried: 100% Front Buried: 0%
Service Area 1002	95% / 5%	Rear Aerial: 65% Front Aerial: 35% Rear Buried: 0% Front Buried: 0%
Service Area 1003 (northeast)	70% / 30%	Rear Aerial: 50% Front Aerial: 50% Rear Buried: unknown Front Buried: unknown
Service Area 1003 (southwest)	95% / 5%	Rear Aerial: 45% Front Aerial: 55% Rear Buried: 100% Front Buried: 0%
Service Area 1005	50% / 50%	Rear Aerial: 30% Front Aerial: 70% Rear Buried: 90% Front Buried: 10%
Service Area 1006	90% / 10%	Rear Aerial: 85% Front Aerial: 15% Rear Buried: 100% Front Buried: 0%
Service Area 1007	20% / 80%	Rear Aerial: 35% Front Aerial: 75% Rear Buried: 20% Front Buried: 20% Underground: 60%
Service Area 1008 (north)	80% / 20%	Rear Aerial: 50% Front Aerial: 50% Rear Buried: 60% Front Buried: 20% Underground: 20%
Service Area 1008 (south)	85% / 15%	Rear Aerial: 35% Front Aerial: 65% Rear Buried: 60% Front Buried: 40%
Service Area 1009	80% / 20%	Rear Aerial: 20% Front Aerial: 80% Rear Buried: 10% Front Buried: 90%
Service Area 1010	70% / 30%	Rear Aerial: 20%

Service Area	Aerial vs. Underground	Front Easement vs. Rear Easement
		Front Aerial: 80% Rear Buried: 20% Front Buried: 80%
Service Area 1011	80% / 20%	Rear Aerial: 10% Front Aerial:90% Rear Buried: 10% Front Buried: 90%
Service Area 1012 (east)	60% / 40%	Rear Aerial: 10% Front Aerial: 90% Rear Buried: 5% Front Buried: 95%
Service Area 1012 (west)	50% / 50%	Rear Aerial: 20% Front Aerial: 80% Rear Buried: 90% Front Buried: 10%
Service Area 1207	10% / 90%	Rear Aerial: 0% Front Aerial: 100% Rear Buried: 0% Front Buried: 100%
Service Area 1208	25% / 75%	Rear Aerial: 100% Front Aerial: 0% Rear Buried: 0% Front Buried: 100%
Service Area 1212	30% / 70%	Rear Aerial: 15% Front Aerial: 85% Rear Buried: 0% Front Buried: 100%
Service Area 1214	0% / 100%	Rear Aerial: 0% Front Aerial: 0% Rear Buried: 100% Front Buried: 0%
Service Area 1214 (north)	n/a	n/a

CTC's OSP engineer noted that the quality of the poles and pole attachments in Santa Cruz varied widely, as they do in many cities—but that overall, many poles would need to be replaced because they are either too short or "under classed" to support a new attachment.

We corroborated our assessment of the poles in discussions with representatives of PG&E—who advised us that 25 percent of the utility poles would likely need to be replaced to support a new attachment. They quoted a cost of $20,000 per pole replacement—meaning that citywide aerial construction would be significantly more expensive than typical aerial construction where poles are newer and not under-classed.

Based on the estimated percentage of aerial and underground plant we identified in our field survey, we estimate that the difference between aerial and underground construction in Santa Cruz is more than $80,000 per mile, as shown in Table 5.

Table 5: Comparison of Estimated Aerial and Underground Construction Costs

Backbone Construction	Price per Mile
Underground (one conduit, labor, and materials)	$102,000
Aerial (new attachment, labor, and materials)	$185,000

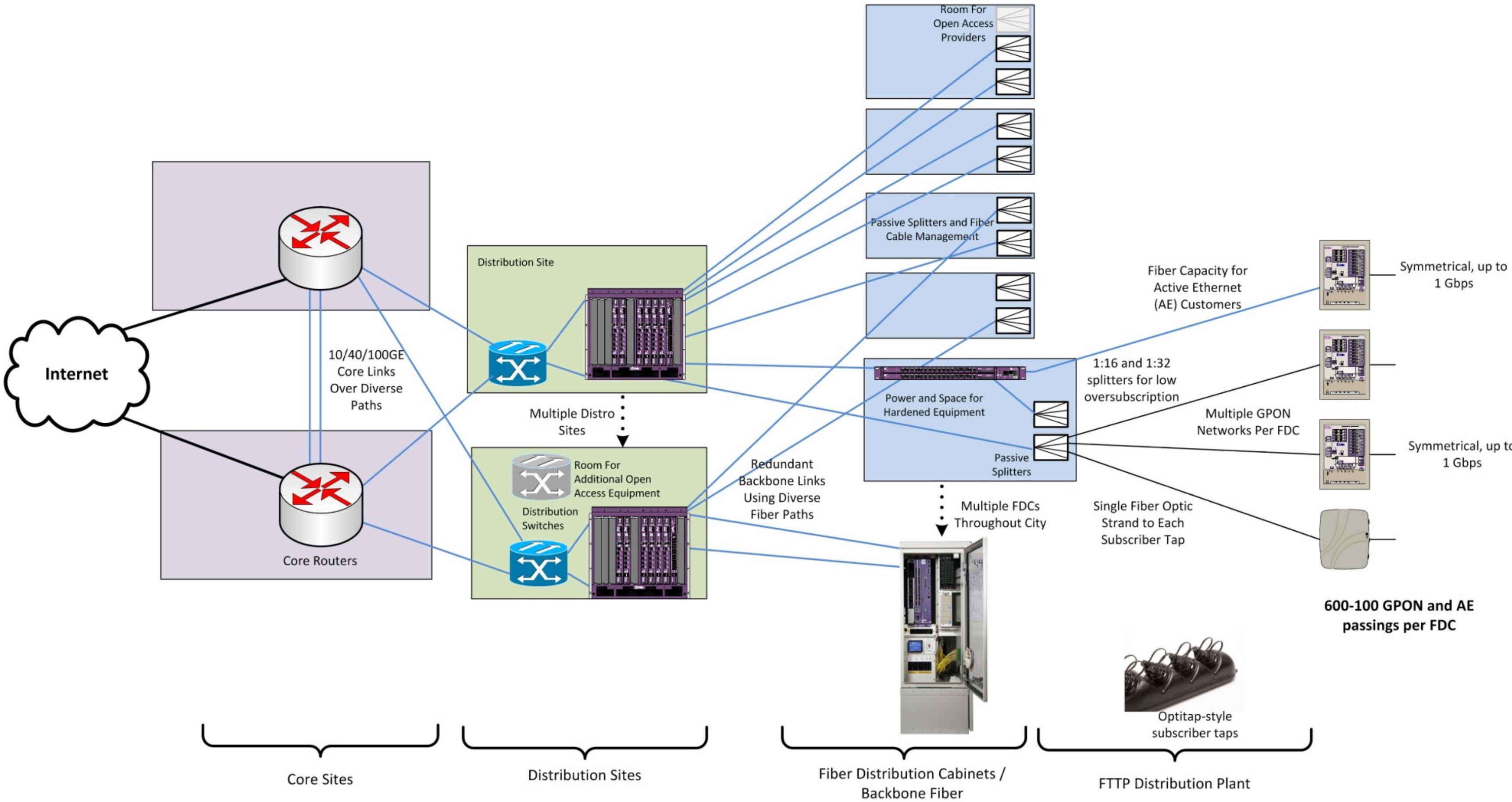
So while aerial plant is generally less expensive to build than underground plant, underground plant will be more cost-effective in Santa Cruz.

3 FTTP Network Design

The physical layer (layer 1, also referred to as outside plant or OSP) 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 initiative.

Figure 2 shows a logical representation of the high-level FTTP network architecture we recommend for the City. This design is open to a variety of architecture options. The drawing illustrates the primary functional components in the FTTP network, their relative position to one another, and the flexible nature of the architecture to support multiple subscriber models and classes of service.

Figure 2: High-Level FTTP Architecture



The recommended plan is a hierarchical data network that provides critical scalability and flexibility, both in terms of initial network deployment and capability to accommodate the increased demands of future applications and technologies. The characteristics of this hierarchical FTTP data network are:

- Capacity – ability to provide efficient transport for subscriber data, even at peak levels
- Availability – high levels of redundancy, reliability, and resiliency 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 or poor 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 into different customer environments. Can support an open access network or a single-provider network. Separation between service providers can be provided on the physical (separate fibers) or logical (separate VLAN or VPN) layers.
- Security – controlled physical access to all equipment and facilities, plus network access control to devices

3.1 Network Design

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;
- Construct two distribution hub facilities with adequate environmental and backup power systems to house network electronics;
- Construct backbone rings that connect core sites to distribution hubs, and distribution hubs to fiber distribution cabinets (FDC);

- Construct fiber optics from the FDCs to each residence and business (i.e., from termination panels in the FDC to tap locations in the right-of-way or on City easements); and
- Construct fiber laterals into large, multi-tenant business facilities and/or multi-dwelling units.

The backbone layer consists of approximately 19.7 miles of fiber paths and provides redundant connectivity between the core locations, the hub facilities, and the FDCs. Figure 3 (below) illustrates this backbone design, including service area boundaries.

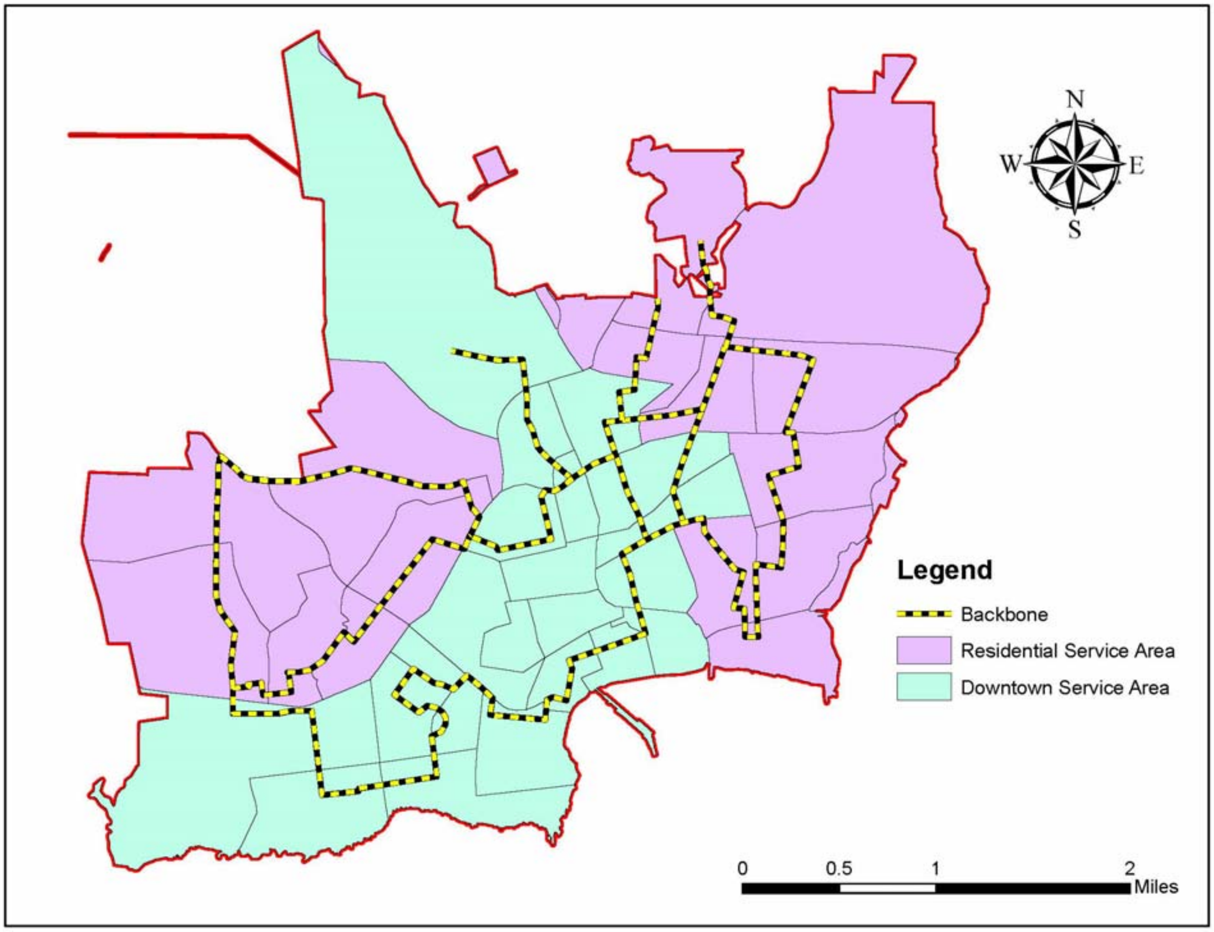
The backbone ring design and service areas were defined based on the following criteria:

- Allowing for complete backbone path diversity between the hubs and FDC locations;
- Targeting 600 to 1,000 passings per service area;
- Each FDC serves a single service area;
- FDCs suitable to support hardened network electronics, providing backup power and an active heat exchange;[3] and
- A dedicated fiber cable of at least 288-strand count; and
- Avoiding the need for distribution plant to cross major roadways and railways.

Coupled with an appropriate network electronics configuration, this design serves to greatly increase the reliability of fiber services provided to the customers 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.

[3] 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 fiber distribution cabinets (which would house only optical splitters) and the providers' electronics were housed only at hub locations.

Figure 3: FTTP Network Backbone and 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 (potential customer address). This traditional FTTP design allows either network electronics or optical splitters in the FDCs. See Figure 4 below for a sample design.

Figure 4: Sample FTTP Access Layer Design

This architecture offers scalability to meet long-term needs, and 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 Gigabit Passive Optical Network (GPON) and direct Active Ethernet 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 right-of-way or City easements, providing water-tight fiber connectors for customer service drop cables. This is an industry-standard approach to reduce customer activation times and the potential for damage to distribution cables and splices by eliminating the need for service installers to perform splices in the field. The model also assumes the termination of standard lateral fiber connections within larger multi-tenant business locations and multi-dwelling units.

3.2 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 Santa Cruz core sites will be housed in secure locations with diverse connectivity to the Internet.

The core locations in this plan will house providers' Operational Support Systems (OSS) such as provisioning platforms, fault and performance management systems, remote access, and other operational support systems 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.

Santa Cruz has a wide range of options for core locations. One possibility is collocating at Internet points of presence in the City, which might include higher education data centers, the current Cruzio colocation facility at 877 Cedar Street, or telecommunication carrier locations. Other options might include using City-owned facilities with robust physical security, diverse fiber entry, and reliable backup power.

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.

Figure 5: Sample Hub Facility

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 sites would be rented in collocation spaces. We recommend a locked cage space that can accommodate three to four racks of equipment. The collocation facility should provide redundant HVAC, utility power, and backup power systems. The collocation space should be able to supply cross-connects with Internet service providers (preferably Tier 1). If possible, we recommend using facilities that meet SOC2–Type 2 compliance.

We assumed that hub sites would be pre-fabricated concrete facilities located on public land. The facilities would be equipped with redundant HVAC and backup power systems. The hubs should be approximately 20 feet by 30 feet in size, and should have adequate height to support full-sized racks as well as overhead cable management raceways. The hub facilities should be equipped with remote monitoring and alarm capabilities for the environmental and security systems.

3.3 Distribution and Access Network Design

The distribution network is the layer between the hubs and the fiber distribution cabinets (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
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 both 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.

3.3.1 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 Active Ethernet 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 32) subscribers.

GPON uses passive optical splitting, which is performed inside fiber distribution cabinets (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).

Active Ethernet (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 easily supports legacy voice (GR-303 and TR-008) and Next Gen Voice over IP (SIP and MGCP). AE also supports video. Service distance (from the OLT) can extend as far as 75 km (about 46 miles).

For subscribers receiving Active Ethernet 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. This hardware cost differential is partially reflected in the CPE kit pricing for an AE subscriber, which includes the dedicated SFP module on the OLT. The GPON CPE ($455) costs less than half the CPE for Active Ethernet service ($976).

Our fiber plant is designed to provide Active Ethernet 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.

3.3.2 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[4] such as Active Ethernet. The cost differential between constructing an entire network using GPON and Active Ethernet is 40 percent to 50 percent.[5] 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:

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 ODC 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 Active Ethernet 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.

3.3.3 Customer Premises Equipment (CPE) and 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 right-of-way 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.

[4] 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.

[5] "Enhanced Communications in San Francisco: Phase II Feasibility Study," CTC report, October 2009, at p. 205.

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

We have specified three CPE kits to offer various features and capabilities and to meet subscriber budgets. Figure 6 lists the basic and premium kits for single-family unit (SFU) and multi-dwelling unit (MDU) subscribers, as well as the quantity of each estimated in our model. The primary distinction between the two subscriber classes is the cost of inside plant cabling. The basic CPE kit provides simple Ethernet on the subscriber LAN, whereas the premium CPE includes the fastest Wi-Fi available today (802.11ac).

Figure 6: CPE Kits

Name	Description
ONT Kit - Residential SFU - Basic	ONT, Enclosure, NID, 8hr UPS, Ethernet
ONT Kit - Residential SFU - Premium	ONT, Enclosure, NID, 8hr UPS, Ethernet, Advanced Wi-Fi
ONT Kit - Residential SFU - AE Access	ONT, Enclosure, NID, 8hr UPS, Ethernet, Advanced Wi-Fi, AE Access
ONT Kit - Residential MDU - Basic	ONT, Enclosure, NID, Indoor Cabling, 8hr UPS, Ethernet
ONT Kit - Residential MDU - Premium	ONT, Enclosure, NID, Indoor Cabling, 8hr UPS, Ethernet, Advanced Wi-Fi
ONT Kit - Residential MDU - AE Access	ONT, Enclosure, NID, Indoor Cabling, 8hr UPS, Ethernet, Advanced Wi-Fi, AE Access
ONT Kit - Business (SFU) - Basic	ONT, Enclosure, NID, 8hr UPS, Ethernet
ONT Kit - Business (SFU) - Premium	ONT, Enclosure, NID, 8hr UPS, Ethernet, Advanced Wi-Fi
ONT Kit - Business (SFU) - AE Access	ONT, Enclosure, NID, 8hr UPS, Ethernet, Advanced Wi-Fi, AE Access
ONT Kit - Business (MDU) - Basic	ONT, Enclosure, NID, Indoor Cabling, 8hr UPS, Ethernet
ONT Kit - Business (MDU) - Premium	ONT, Enclosure, NID, Indoor Cabling, 8hr UPS, Ethernet, Advanced Wi-Fi
ONT Kit - Business (MDU) - AE Access	ONT, Enclosure, NID, Indoor Cabling, 8hr UPS, Ethernet, Advanced Wi-Fi, AE Access

We recommend indoor CPE devices, which generally do not need to be configured or maintained by the operator after they are installed. Placing CPE devices outdoors unnecessarily increases cost by requiring hardened equipment.

4 FTTP Cost Estimate

This section provides a summary of cost estimates for construction of a citywide FTTP network to all City residents and businesses, including a detailed overview of the methodology upon which they are based.

4.1 Summary of Cost Estimates – OSP and Network Electronics

CTC estimates the total cost for the citywide FTTP network, including OSP, electronics, drops, and CPE, to be $51.9 million.

Table 6: Breakdown of Estimated Total Cost

Cost Component	Total Estimated Cost
OSP	$32,000,000
FTTP Service Drop and Lateral Installations	$10,200,000
Central Network Electronics	$6,200,000
CPE	$3,500,000
Total Estimated Cost:	$51,900,000

CTC estimates the total cost for the citywide FTTP OSP network infrastructure to be approximately $42.2 million with drops (assuming a 35 percent take rate), or $32 million without drops.

Table 7: Estimated OSP Costs for FTTP

Distribution Plant Mileage	Total Cost (with drops)	Total Cost (without drops)	Passings	Cost per Passing (Distribution Only)	Cost Per Plant Mile (Distribution Only)
137.3	**$42,200,000**	**$32,000,000**	**21,219**	**$1,500**	**$233,000**

The total estimated cost encompasses 137.3 miles of backbone, distribution, and access network plant (collectively referred to as "distribution plant") passing a total of approximately 21,200 addresses ("passings"). This entails the placement of fiber optic cable of varying strand counts, not including service drops to individual customers, and is independent of the take-rate for the offered services.

These cost estimates are based on all-underground construction. After discussions with the utility pole owners, and analyzing make-ready and pole replacement costs, ***CTC determined that the City's pole infrastructure would not support citywide FTTP and that underground construction was a more cost-effective option.***

Aerial construction entails the attachment of fiber infrastructure to existing utility poles, which could offer significant savings compared to all-underground construction, but increases 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 rights-of-way 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 right-of-way impact and to provide greater flexibility to navigate around other utilities. The design model assumes a single 2-inch, High-Density Polyethylene (HDPE) flexible conduit over underground distribution paths, and dual 2-inch conduits over underground backbone paths to provide scalability for future network growth.

4.2 OSP Costs

4.2.1 OSP Cost Estimation Methodology

Meeting the City's objective of reaching every residence and business will require building FTTP infrastructure along the vast majority of the roughly 200 miles of applicable roadways within City limits. 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. Our estimation methodology for the citywide network involves the extrapolation of estimated costs on the basis of street mileage for strategically selected sample designs, as well as field surveys to ascertain unique attributes of particular service areas.

We first developed a system-level backbone network design to serve as the basis for subdividing the City into these smaller service areas, each of which is likely to exhibit generally consistent construction attributes throughout. CTC surveyed a broad sampling of each service area to estimate averages for key metrics impacting construction methodology and cost, such as requirements for special crossings (bridges, railways, etc.), the number of utility poles per mile, and the estimated level of utility pole make-ready construction required to facilitate aerial construction of fiber.

Service areas were divided into two categories based on density and land use:

1. Residential (primarily home and subdivisions with some limited commercial areas)
2. Downtown (primarily commercial with higher density housing and a greater number of MDUs)

Additionally, CTC developed sample designs within each service area, selected to approximate the average density of passings per street mile of that entire service area (see Figure 3).

These sample designs, coupled with key metrics determined from field surveys, were used to extrapolate quantities for corresponding labor and material units. Where applicable, cost estimates are based on contract labor and material rates we have seen in other competitively bid fiber projects.

4.2.2 OSP Cost Estimate Breakdowns

Table 8 summarizes the estimated OSP costs, including drops.

Table 8: Breakdown of Estimated OSP Costs (Including Drops)

Cost Component	Total Estimated Cost
OSP Engineering	$2,200,000
Quality Control/Quality Assurance	$600,000
General OSP Construction Cost	$26,000,000
Special Crossings	$200,000
Backbone and Distribution Plant Splicing	$800,000
Backbone Hub, Termination, and Testing	$2,200,000

FTTP Service Drop and Lateral Installations	$10,200,000
Total Estimated Cost:	$42,200,000

The cost components itemized in the table above include the following scope of 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.[6]
- ***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.

[6] Note that because Santa Cruz is a coastal California city there may be additional environmental permitting and requirements that are not included in this cost estimate. These requirements would need to be evaluated as part of a detailed engineering design.

The design and cost estimates do not extend to service drops, electronics, network management systems, or fiber connectivity beyond City limits for Internet peering.

4.2.3 Fiber Maintenance Costs

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.

Typical fiber maintenance costs are 1 percent of the total construction cost per year—or roughly $425,000 annually. This is estimated based on a typical rate of occurrence in an urban environment, and the cost of individual repairs.

4.3 Network Electronics Costs

The costs for network electronics consists of the centralized network components that reside at the cores, hubs, and FDCs, and the CPE costs which represent the devices installed at subscriber premises. As shown in Table 9, the centralized network electronics costs for the network is $6.2 million, or $280 per passing.

Table 9: Estimated Central Network Electronics Costs

Network Segment	# of Sites	Cost Estimate	Subtotal	Passings	Cost per Passing
Core	2	$1,400,000	$2,800,000	22,100	$126
Hubs	2	$600,000	$1,200,000	22,100	$54
Distribution Cabinets	40	$56,000	$2,200,000	22,100	$100
		Central Electronics Total	**$6,200,000**	**22,100**	$280

The centralized network electronics was designed to support a 35 percent take rate, which is the percentage of total possible subscribers who purchase services. If the take rate were to be higher than 35 percent additional centralized electronics may be required to support the FTTP network. Conversely as the network is deployed and under construction, it may be possible to phase in the centralized network electronics as the take rate and demand increases.

Again, assuming a 35 percent take rate, we developed a cost to furnish and install the CPEs required to support the various users on the network. The total cost of CPEs for the network is $3.5 million, or an average of $455 per subscriber.

4.3.1 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 be have modular chassis to provide high availability in terms of redundant components and they ability to "hot swappable"[7] 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.

The cost estimate design envisions a redundant 40 Gbps ring 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 40 Gbps rings can be added as network bandwidth on the

[7] 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.

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 100 Gbps to Internet service providers that connect the FTTP network to the Internet.

The cost of the core routing equipment for the two core sites is $2.8 million. These costs do not include the service provider's Operational Support Systems (OSS) such as provisioning platforms, fault and performance management systems, remote access, and other operational support systems for FTTP operations. The services providers and/or their content providers may already have these systems in place.

4.3.2 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 two core sites is $1.2 million. These costs do not include any of the service provider's OSS or other management equipment.

4.3.3 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 Active Ethernet 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 40 FDCs is $2.2 million. These costs are based on a take rate of 35 percent and include optical splitters at the FDCs for that take rate.

4.3.4 Customer Premises Equipment

CPEs are the subscriber's interface to the FTTP network. CPEs for this cost estimate were selected that only provide Ethernet data services, however there are a wide variety of CPEs offering other voice, video, and data services.

As referenced in Section 3.3.3, for cost estimates we have developed CPE kits, which include the cost of installation and hardware. The costs of the kits vary with the products and services selected by the subscriber.

Using a take rate of 35 percent and a breakdown of take rates for each type of CPE kit, we developed a total CPE cost of $3.5 million and an average cost to furnish and install a CPE of $455. Drop installation from the optical tap is not included in this cost number.

Appendix A: Field Survey Notes

These brief survey notes match the service areas described in Section 2.

Service Area 1001: Residential along US 1, with few exceptions, is 100 percent aerial fed. The exceptions are new homes built behind the main road fed by buried drops to aerial terminals on the road. Grunewald Ct is buried from pole line on Branciforte Dr. North of this community, the rest of the area has widely scattered buildings, residential, business, golf course, sports complexes.

Service Area 1002: Opposite side of US 1 from Area 1001. Mostly residential with some commercial. I was not able to find anything buried, but will not rule out the possibility that is does exist. The commercial areas are almost all rear-fed aerial. Same type or rear fed in alley ways as in area 1001 throughout this area. The four sub-sections are similar in nature.

Service Area 1003 (northeast): Two sub-sections vastly differently in scope of plant. Mostly commercial developments, some residential. Aerial into the development and along front of roadways. Buried plant off the main roads throughout the area. Outside of the area to the north, very sparsely built region. A cemetery on the eastern edge of this service area, east of the "river." Identifying the underground/buried ingress to each building is difficult to see from Google Earth. This will need to be on-site inspected by the contractor feeding each building.

Service Area 1003 (southwest): Two sub-sections vastly differently in scope of plant. Mostly residential. Mix between front and rear-fed aerial plant. Same alleyway design and front fed as has been seen in the other areas of the City.

Service Area 1005: All three sub-sections contain basically the same makeup of houses and plant. Rather newer subdivisions and some multi-dwelling units so a lot more buried plant than what has been in other areas of the City.

Service Area 1006: Established housing area. Commercial area along Cabrillo Hwy and Mission St. Buried portions are along this area; rest of area is aerial.

Service Area 1007: Downtown area. Most of the commercial and business areas appear to be fed from the underground. There are no or very few poles visible in this area. On the surrounding area of the inner-city area, this is primarily aerial and front fed more than rear fed.

Service Area 1008 (north): Mostly commercial/business and MDU. There are some SFU areas as well, mostly through the center of the area. In the business section, there are underground fed buildings as well here.

Service Area 1008 (south): Mostly SFU areas with some business and MDU. Most businesses and MDUs appear to be fed from poles lines in front or the side of the buildings. Some areas have dual pole lines with the power poles needing less make-ready work then the telephone poles. Majority of pole lines appear to be front fed as well.

Service Area 1009: Varied mixed-use area of business, commercial, residential, and marina. Marinas will be all buried fed to the dock where new tap or pedestal MDU term should be placed. The buried sections are not contiguous, but scattered from what is visible, and the aerial sections are front fed for the vast majority of this area.

Service Area 1010: Varied mixed-use. Everything along Beach Street is rear-fed aerial. Amusement Park appears to be fed aerial from Park Place. “Mom and Pop” storefronts (and there are a lot) are aerial fed, mixed front and rear depending on density of the block, it appears. Motels and MDUs in area are mostly buried fed off pole lines (risers), some are drop fed from front poles.

Service Area 1011: Mostly a mix of SFU and MDU. MDUs are fed from pole lines to buried into buildings for the most part. Section of buried plant along Woodrow Ave. Poles are front fed mostly, inner-most part of the circle is mostly storefronts, front fed.

Service Area 1012 (east): Densely populated with SFUs, some MDUs. Entire western portion of this area is buried. Area around Western Colligate School around to the business area and the residential portion south of the business area is buried. Business is mixed front and rear, but residential is all front fed.

Service Area 1012 (west): About 40 percent open space consisting of a mobile home park in the southern region 100 percent buried, private community so cannot tell if front or rear. I would think with the closeness of the mobile homes, it would be rear fed so as not to plow the plant over when moving in a new home. Other sections of housing is in the eastern portion and is front-fed aerial. In between are large businesses and a great deal of open space.

Service Area 1207: “Santa Cruz Memorial, Mortuaries, Crematory, Cemeteries.” Single building in southern region. North area is City’s water treatment plant.

Service Area 1208: Two small residential areas. Southernmost area is mostly MDUs; SFUs are few and front buried. The second is a few homes on top of a knoll that are fed by a rear pole line through the middle of the homes.

Service area 1212: Newer developments, very hilly terrain. Little front footage in some areas where current plant was located. This area also has a great deal of open green space. With the terrain, may not be buildable but homes are built on the side of cliffs in some areas.

Service Area 1214: One building. Front fed. Buried.

Service Area 1214 (north): North area is 100 percent open green space. If utilities are present in this area they will be aerial plant. Cannot see evidence of any plant running into this region. Southern region is Woods Lagoon Marina. Marinas are normally fed with the terminal to the dock and then service drop wires laid under the dock to each slip to provide service.

Appendix B: Glossary

AE – Active Ethernet. AE provides a symmetrical (up/down) Ethernet service that does not share optical wavelengths with other users. For subscribers that receive Active Ethernet 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 FDCs.

Drop – The fiber connection from an optical tap in the right-of-way to the customer premises

FDC – Fiber distribution cabinet; houses the fiber connections between the distribution fiber and the feeder 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 – 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 rights-of-way.

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 EPB. GPON uses passive optical splitting, which is performed inside FDCs, to connect fiber from the OLTs to multiple customer premises over using a single GPON port.

MDU – Multi-dwelling unit (i.e., 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 Active Ethernet 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 operational support systems for FTTP operations. OSS is housed in a network's core locations.

Passing – A potential customer address (e.g., an individual home or business).

ROW – Right-of-way; land reserved for the public good such as utility construction (typically abutting public roadways).