Networking Technology Adoption: System Dynamics Modeling of Fiber-to-the-Home

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Abstract

A system dynamics model is developed and run to study the adoption of fiber-to-the-home as a residential broadband technology. Communities that currently do not have broadband in the United States are modeled. This case is of particular interest to U.S. policymakers, but also relevant to other regions concerned with economic development in rural areas. The model is used to explore the effects of government policy on fiber-to-the-home deployment and on the telecommunications supply chain. The research finds that government policy relating to broadband deployment has been based on a weak understanding of the dynamics involved, resulting in trial and error policy making that has unintended consequences.

The thesis shows that the current monitoring of broadband deployment by the Federal Communications Commission is inadequate to contribute to the formation of reasoned policy decisions. The model is used to explore the consequences that different regulatory scenarios have on fiber-to-the-home deployment. Among the policy choices considered are: resale of fiber-to-the-home lines to competitive providers; low cost government loans for commercial deployments; rapid deployment to all communities currently without service; and a ban on municipal deployments. The current Rural Utilities Service loan program is also included in the model and its effects are analyzed.

The model is used to examine the consequences for the optoelectronics industry of different deployment scenarios. It shows that the interests of consumers, regulators, and even service providers are in conflict with the interests of the optoelectronics industry which provides a critical component necessary for the service. Strategies to help mitigate that conflict and to promote the health of the components industry are explored.

Deployment of fiber-to-the-home is costly, and cost recovery is difficult for both incumbent and competitive service providers, especially in rural and suburban regions that do not currently have service. The interests of policy makers, service providers, and component suppliers need to be aligned to implement effective policy that encourages the deployment of broadband to unserved regions. The Federal Communications Commission needs to rearchitect its monitoring of service providers and their activities to better understand the status of deployment and how its policies can help or hinder.

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Chapter 1: Introduction

1.1 Background and Motivation

Networking technologies have network externalities – the value a consumer derives from the technology increases with the number of people that own the technology. Telephones are an excellent example. If only one person owned a telephone it would be uninteresting; what makes a telephone desirable is that it allows consumers to use it to communicate with others who have one. The more people that have telephones, the more useful having a telephone becomes.

Networking technologies are also enabling technologies. They allow consumers to interact in ways that were not possible before the existence of the technology. The telephone brought the ability to communicate instantly with people around the globe. Broadband connectivity and fiber-to-the-home extend that communication to include streaming media, video teleconferencing, telemedicine and many other applications yet to be developed.

Fiber-to-the-home (FTTH) was chosen as a case study for networking technology adoption because it is a technology that is still in the early stages of development and deployment. There is no dominant fiber-to-the-home technology and change is still possible. Fiber-to-the-home also brings with it many policy related issues associated with the Internet and with telecommunications in general. An understanding of how key factors interact and how different adoption rates can be brought about is crucial to deploying this technology in a way that will encourage user adoption.

The Internet as a communications network and commerce enabler has been experiencing exponential growth, both in terms of users and in terms of bandwidth consumed, for many years. The bandwidth used by applications on the Internet has grown from the early text-based days of email, Usenet, and gopher to the advent of the World Wide Web, peer-to-peer applications, and streaming media.

People are no longer limited to simple text-based applications, but can use broadband (high bandwidth) connections to view lectures or download music and movies over the Internet. The Internet has moved from use by academics at research universities to use by the public at large to use by businesses and ultimately to use in the home.

Providing broadband telecommunications to the home is not a new idea, though its definition varies widely. Trial fiber-to-the-home deployments in the United States, the U.K., and France began as early as the mid-to-late 1980s (Esty, 1987; Rowbotham, 1989; Shumate, 1989; Veyres & Mauro, 1988).

High-speed service, or today's broadband, is defined by the Federal Communications Commission (FCC) as being at least 200 kbps in either the customer-to-provider or provider-to-customer direction. While this definition distinguishes between 56 kbps dialup services and higher speed services, it neglects to distinguish across a wide range of data speeds. What is considered broadband today will likely not be so labeled in the future, just as the 300 bps modems of the early 1980s pale in comparison to today's 56 kbps modems.

The FCC chose 200 kbps as its delimiter in 1999 because of a belief that this speed was enough to support the most popular applications, such as web browsing at the same speed as turning the pages of a book (Federal Communications Commission, 2002). Recognizing that the capability to send and receive information at high speeds was important, the FCC also defined advanced telecommunications service as having speeds of 200 kbps in both directions. However, the FCC seemingly disregarded the fact that the data speeds needed for streaming music or video or for large data transfers far exceed those of reading a book.

The notion of advanced services lines, or connections that can deliver high-speed service in both directions, is similar to the definition of broadband developed by the Committee on Broadband Last Mile Technology of the National Research Council. The Committee provides two definitions of broadband:

1. Local access link performance should not be the limiting factor in a user's capability for running today's applications.
2. Broadband services should provide sufficient performance – and wide enough penetration of services reaching that performance level – to encourage the development of new applications (National Research Council Committee on Broadband Last Mile Technology, 2002).

The FCC's definition of broadband falls squarely under definition one above, assuming the use of the dominant applications from 1999. In order to ensure that the ability to run today's and future applications continues to be met, and under a mandate from the Telecommunications Act of 1996, the FCC has been collecting data on both high speed lines and advanced services lines twice a year since December of 1999. Any facilities-based company that provides 250 or more high-speed service lines in a given state is required to report information on its services and customers twice a year. These providers are also required to report the fraction of lines that are connected to residential and small business customers. The number of high-speed and advanced services lines as reported to the FCC is shown in Figure 1.1. The FCC tracks both total high-speed and advanced services lines and also the number of residential and small business lines.

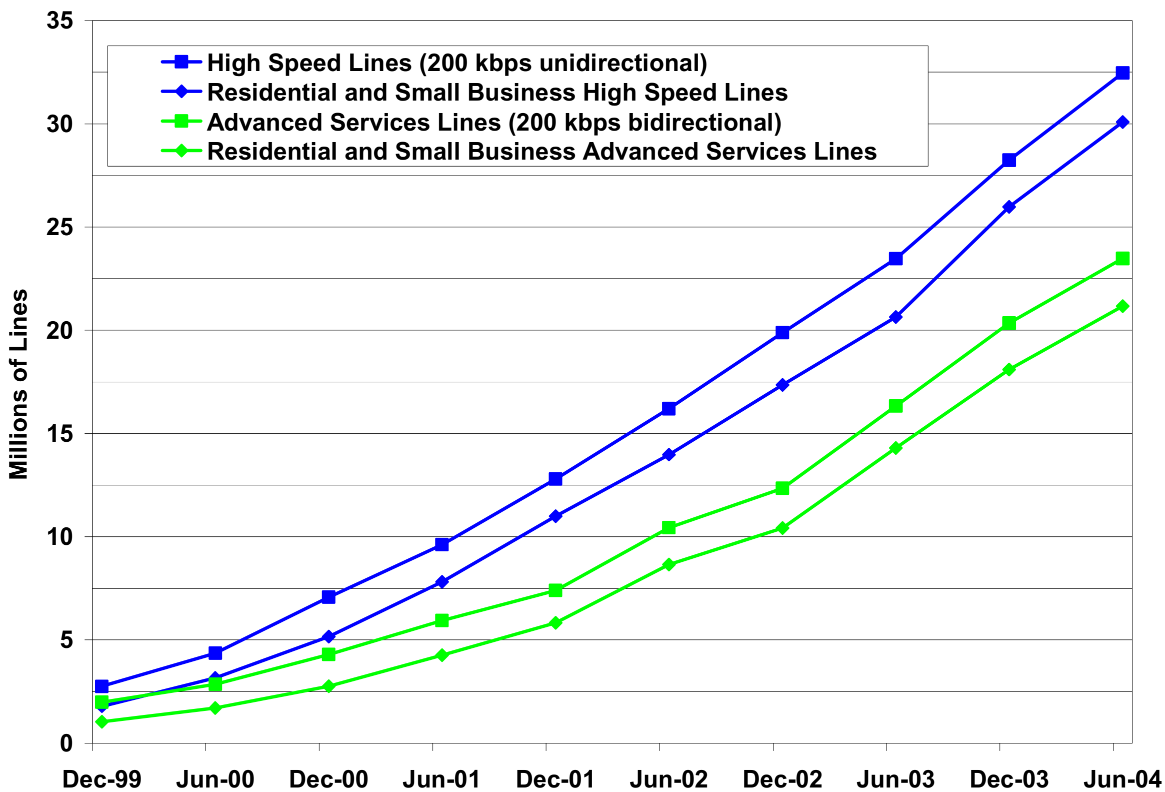


Figure 1.1: Deployment of High Speed and Advanced Services Lines

As shown in the figure, the deployment of both advanced services and high-speed lines is increasing. The deployment of advanced services lines lags that of high-speed lines in both categories of deployments. In the first half of 2004, total high-speed lines grew by 15% to nearly 32.5 million lines; total advanced services lines by 15% to 23.5 million lines; high speed residential and small business lines grew by 16% to 30 million lines; and advanced services residential and small business lines grew by 17% to 21 million lines. The number of lines deployed to customers continues to grow, although this represents lower growth rates than previous periods.

A study by the Department of Commerce's National Telecommunications and Information Administration based on the U.S. Census Bureau current population survey, estimated that approximately 55% of U.S. households had Internet connections in September 2003 (National Telecommunications and Information Administration, 2004). Figure 1.2 shows the breakdown of residential and small business advanced services lines by technology.

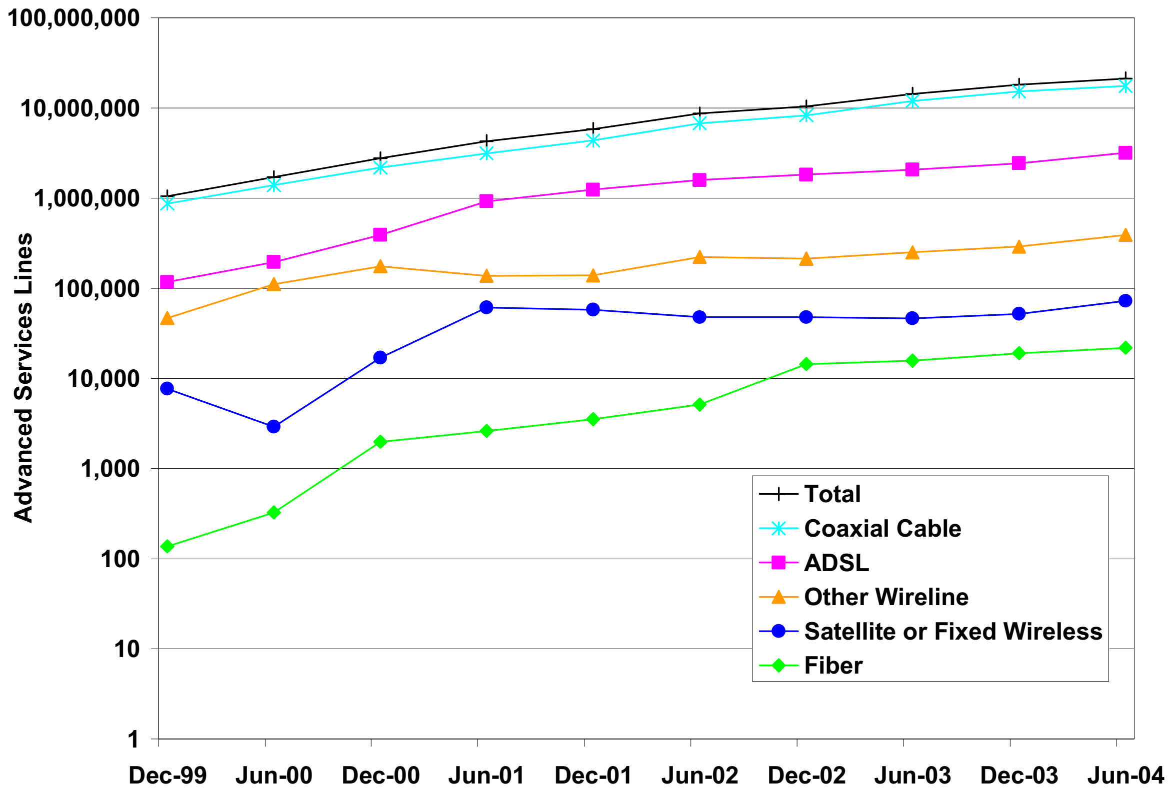


Figure 1.2: Breakdown of Residential and Small Business Advanced Services Lines by Technology (Log Scale)

An end user's use of the Internet is limited by the speed of the slowest link. For most end users this is in the last mile connection between the user and their service provider (also sometimes called the first mile or the access network). Many users today connect via dial-up connections at 56 kbps, and many businesses are connected at 1.5 Mbps.

Today's residential broadband services operate primarily over copper wire. Specifically, coaxial cable (cable modems) and ADSL (asymmetric digital subscriber line) make up approximately 96% of today's residential and small business advanced services lines, as shown in Figure 1.3. Coaxial cable is dominant in the market, with ADSL as a far second, and all other technologies making up one to two percent of the market. The percent of fiber lines is not visible in the figure, since fiber lines make up under 1% of the deployed lines in any given time period.

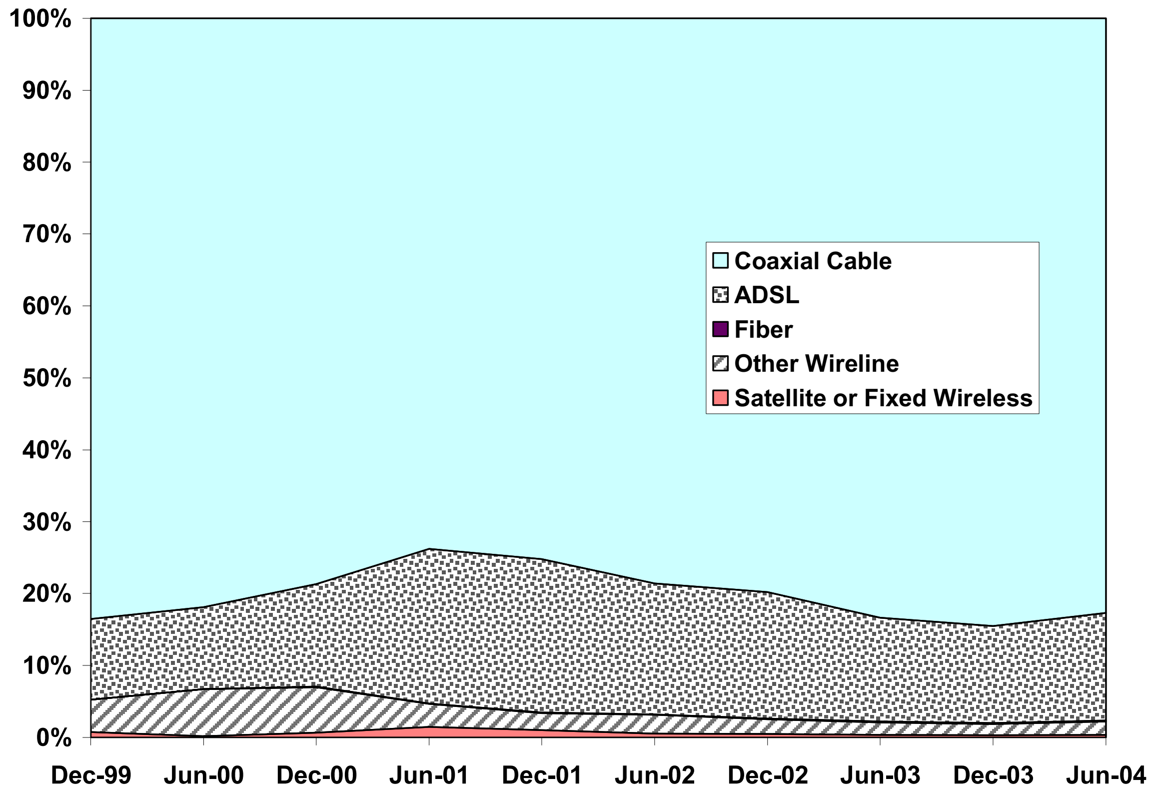


Figure 1.3: Percent of Residential and Small Business Advanced Services Lines

The peak data rate of copper in the last mile is in the tens of Mbps. Today's optical fiber has a limit of 10 Gbps. Fiber to the end user would provide the potential for greater bandwidth. Higher bandwidth opens the door to new applications that are not possible today, such as telemedicine, telepresence, and video teleconferencing. Fiber has the potential to be future proof; its electronics and optical components can be upgraded into the foreseeable future for greater bandwidth, instead of having to run new cable.

Initial attempts to deploy fiber to residential customers began in the United States in 1989. Currently deployment is still not widespread, though there are many more trials underway. Widespread fiber-to-the-home deployment has suffered in part due to competition from lower-speed, cheaper, easier-to-deploy technologies such as DSL (digital subscriber line) and cable modem service.

Broadband providers have discovered that the user market that they had envisioned for their service hasn't materialized to an extent to keep them all viable. Excite@home, the cable modem Internet provider with the largest subscriber base at the time (approximately 3.7 million customers in the United States and Canada) filed for bankruptcy in September 2001. Even incumbent telephone and cable operators are not immune to the financial troubles.

In addition to broadband service offered by traditional carriers such as cable and telephone companies, non-profit efforts to provide broadband also play an important role. Several communities have started initiatives to provide more bandwidth, including fiber-to-the-home, to their areas.

In the state of Washington, Grant County wanted more bandwidth than was available in their area. In 2000, the Grant County Public Utility District began a six year build plan for a fiber-to-the-home network (Grant County Public Utility District, 2004). Twenty-one Internet service providers currently offer service over the network. Because of state of Washington law, the Public Utility District cannot be a service provider and must serve as a wholesaler of the network.

The city of Palo Alto, California already had a broadband cable modem provider and access to DSL, yet wanted more bandwidth. Initial planning for the deployment of fiber-to-the-home began in 1998. The city has had a much more rocky experience with its fiber-to-the-home deployment attempts than Grant County. The first Request for Proposals in 1999 to construct a fiber-to-the-home network in Palo Alto went virtually unanswered, the sole ISP bidder subsequently went out of business. In December 2000, the plans were rearchitected and a trial network deployed by the local utility. In July 2004, the city council stalled plans to expand the network, citing financial viability (D'Agostino, 2004).

Many companies that provide broadband services have experienced financial trouble. The technologies involved are uncertain and changing rapidly. The deployment of DSL rapidly eclipsed ISDN deployment, and ISDN is falling out of use. Bi-directional broadband satellite systems were proposed in 1995 but none of the fourteen systems that filed applications with the FCC have materialized. Many service providers and analysts think that fiber will eventually dominate the last mile, such that DSL and cable modems are interim solutions. However, they recognize a “chicken and egg” phenomenon for fiber deployment and applications requiring fiber-enabled speeds.

There are many issues surrounding the supply and demand of broadband that interact on many different levels. The research explores the forces at work and the conditions needed for further deployment.

1.2 Key Questions

The key questions the research proposes to answer are:

- What are the key policy factors that influence fiber-to-the-home deployment? The research considers alternatives in both public and industrial policy.
- What changes to telecommunications policies might facilitate more rapid and successful fiber-to-the-home deployment? The research explores current policy and how it influences deployment of fiber-to-the-home. Alternate policies and their effects on deployment are explored in an effort to contribute to the FCC's discussions on high speed Internet service.
- What technologies and roll-out strategies are best for a given set of circumstances? The research examines how different technologies and deployment strategies can be used to effectively deploy fiber-to-the-home in a way that will encourage adoption by users.

1.3 Method

Fiber-to-the-home deployment occurs within the context of telecommunications policy governing the provision of Internet and video services, where technical, regulatory, economic, and social issues intertwine. The interactions between the many forces and players involved in fiber-to-the-home deployment are not currently well understood. The issues surrounding such a deployment are explored through a system dynamics model. The goal of the model is to assist with the assessment of deployment options by the various players such as communities, regulators, and components companies to help them understand the interactions involved in making deployment decisions.

The research draws from systems engineering, technology strategy, and policy analysis. To develop a reasonable model, technical knowledge of the characteristics and limitations of the technologies available has to be combined with business strategy knowledge and characteristics of user adoption. Policies that govern the deployment of broadband technologies are also taken into account, along with the notion of how policies could be modified or implemented to facilitate deployment.

The model includes consideration of the key players and interactions involved in the supply and demand of bandwidth. Key players include: the telecommunications industry, the user community, and regulators. These players interact to shape the market for broadband Internet services.

The telecommunications industry includes a wide range of component, system, and service suppliers. The cost of providing the service, including the cost of the necessary components and infrastructure, is included as part of the model. This portion of the model addresses cost of components and systems, cost of fiber deployment, the capability of the industry to provide the technology, the demand for the technology, and prices likely to arise in the respective markets.

Users are affected by both the price and the availability of service. To explore user demand, information on prices and Internet adoption rates is included. The growth rate of Internet users vs. the growth rate of broadband is explored, accounting for those geographical areas where broadband is not available.

Regulators are responsible for policies that affect everything from the cost to provide service to how competition will evolve. The portion of the model dealing with public policy assesses the effects of various policies on prices, deployment, and adoption rates.

System dynamics modeling was chosen as a methodology for the analysis because one of its key features is the ability to explore "what if" scenarios and complex interactions, such as analyzing the effects of new developments like "killer" applications, or large cost reductions. A system dynamics model is a simplified version of the real world. Through the use of graphical tools for implementing differential equations, system dynamics models attempt to capture key behaviors that are observed in real world systems. They allow the modeler to see what structures in the real world might cause an observed behavior: adoption rates are observed to increase, what is causing it? The model also allows the observation of what types of behaviors a structure in the real world can produce: how can adoption rates be made to increase or decrease? This information is useful in analyzing how public policy changes could influence user adoption.

Much of the information required to develop such a model is available in published reports. Annual demographic data for the United States are available that include the number of Internet users, the availability of broadband technologies, and the subscribership of phone service and dialup Internet service.

Effects of current telecommunications policies have been explored by the FCC. The FCC also collects comments from interested parties, some of which also explore potential effects of proposed policies on the market.

The telecommunications industry tracks component prices and volumes. These are documented in industry publications, which address technology issues and also attempt to address consumer demand. Many equipment vendors publish pricing information in print catalogs and on the Internet. The FCC also tracks the deployment of telecommunications infrastructure in various reports.

Despite all the data available, there have been no attempts to combine it all into a comprehensive model of fiber-to-the-home deployment.

1.4 Model Overview

As described earlier, the broadband customer base is growing. Along with this growth, many communities are beginning to deploy fiber-to-the-home in conjunction with public utilities. The majority of these communities do not currently have broadband and are afraid of being left behind by telecommunications companies that decide there is no business case for deployment in that community.

A high-level view of the dynamics driving this growth is in Figure 1.4. Plus signs on arrows connecting the factors in the diagram mean that an increase or decrease of the first factor results in a change in the same direction of the second factor. For example, as the broadband customer base increases, the available content and applications for broadband users also increases, or as the broadband customer base decreases, the available content and applications for broadband users also decreases.

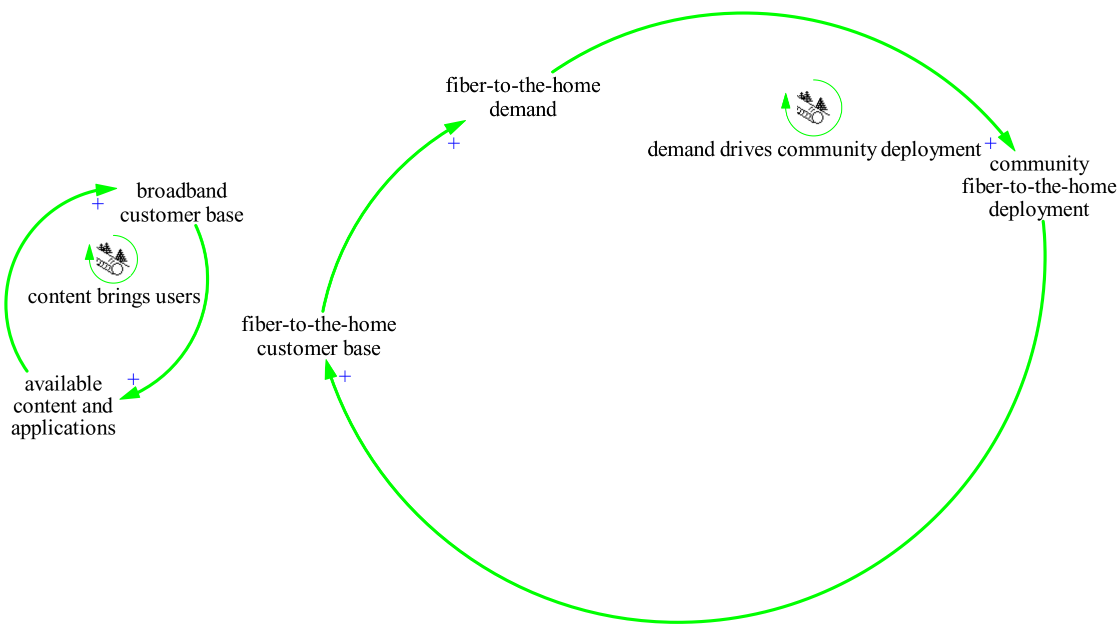


Figure 1.4: "Community Deployment" and "Individual User Demand"

The two loops shown in the diagram are called positive, or reinforcing, loops. Loops are labeled as balancing or reinforcing, depending on how a change in one variable changes that same variable after going around the loop. If a change in the variable results in the same change of that variable after going around the loop, the loop is a reinforcing loop. If a change in the variable results in the opposite change in that variable once going around the loop, that loop is a balancing loop. For example, the reinforcing loop "demand drives community deployment" shown in the diagram shows an increase in fiber-to-the-home demand results in an increase in community fiber-to-the-home deployment which increases the fiber-to-the-home customer base, which ultimately increases demand for fiber-to-the-home. A balancing loop would show an increase in fiber-to-the-home demand resulting in a decrease in fiber-to-the-home demand after going around the factors in the loop.

Figure 1.5 shows an additional loop, called the “cost drives community deployment” loop. Components and system companies are hoping that community deployments will result in sufficient volume to spur further fiber-to-the-home technology development. This development in turn would cause the costs of fiber-to-the-home deployment to go down. The minus sign on the connecting arrow between “fiber-to-the-home technology innovation and cost reduction” and “cost to provide fiber-to-the-home service” implies that change in one factor results in the opposite change in the other factor (i.e., increases in technology innovation result in decreases in cost).

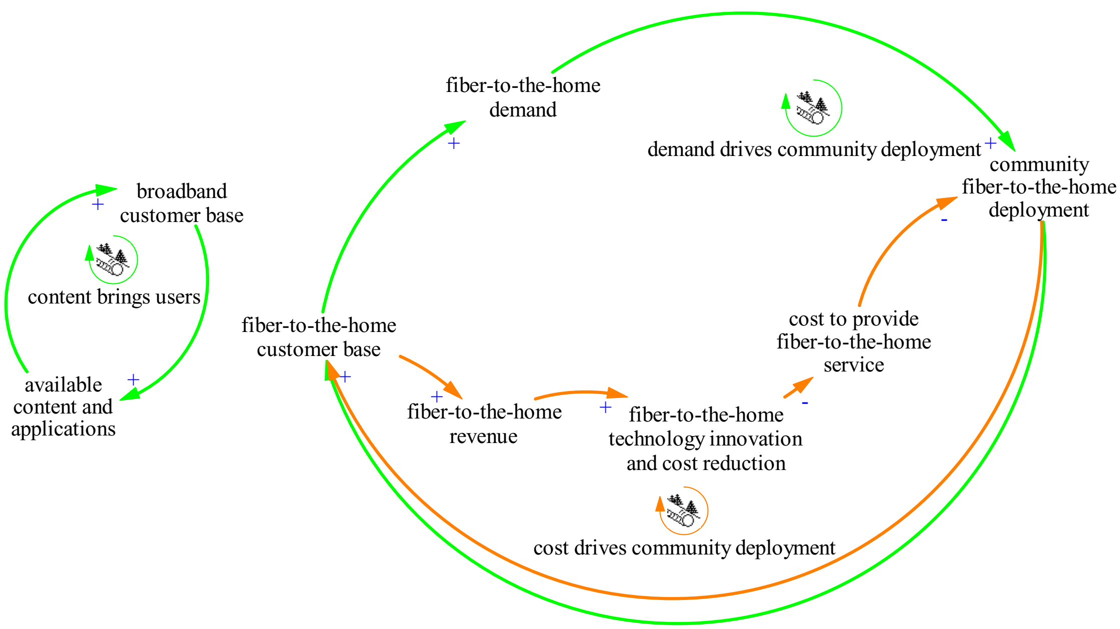


Figure 1.5: Emerging “Cost Reduction” Loop

Figure 1.6 adds the “community network externalities” loop to the diagram. This loop captures the idea of more individuals having broadband causing the demand for broadband in communities that do not have it to rise. Since many of these communities are choosing to deploy fiber rather than other forms of broadband, this demand translates into community demand for fiber-to-the-home. As more communities deploy fiber-to-the-home the broadband customer base increases, thereby increasing the network externality effect. This is a reinforcing loop.

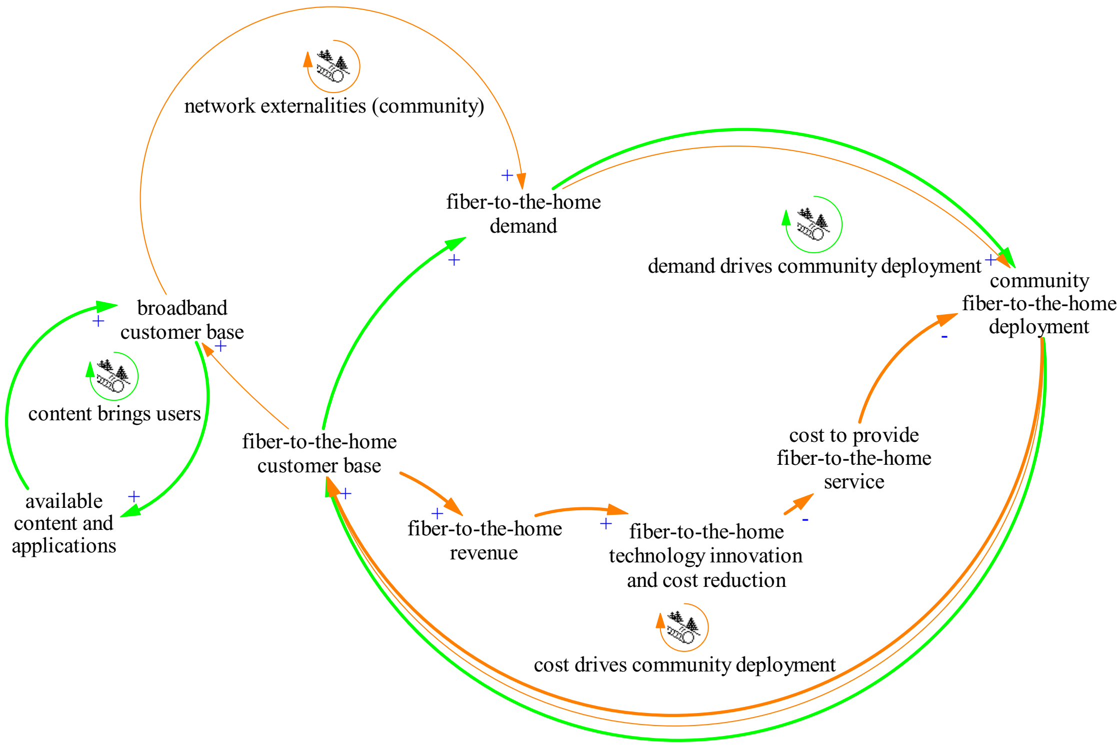


Figure 1.6: Emerging "Community Network Externalities" Loop

Proponents of fiber-to-the-home deployment hope that the cost reduction and demand generated by the "cost reduction" and "community network externalities" loops of Figure 1.5 and Figure 1.6 are sufficient to provide a business case for commercial deployment of fiber-to-the-home as shown in Figure 1.7. The sheer cost of deploying fiber-to-the-home is the reason most cited by telecommunications companies for not pursuing fiber-to-the-home deployment. Once commercial deployment begins, the system generates more revenue and further cost reduction, continuing the deployment trend.

Once cost reduction allows a viable business case for commercial fiber-to-the-home deployment, the "commercial network externalities" loop shown in Figure 1.8 will continue to drive the system. As seen in Figure 1.8, all loops at the high level of this system are reinforcing loops. Thus, once all of the loops become active the system will continue to grow and feed on itself until adoption saturates. The expected trend is similar to that seen in other telecommunications technologies (e.g. fax machines and telephones). To date, commercial deployments by telecommunications companies have not been a reality. The difficulty in this system is the transition from community deployments to wider-scale commercial deployments.

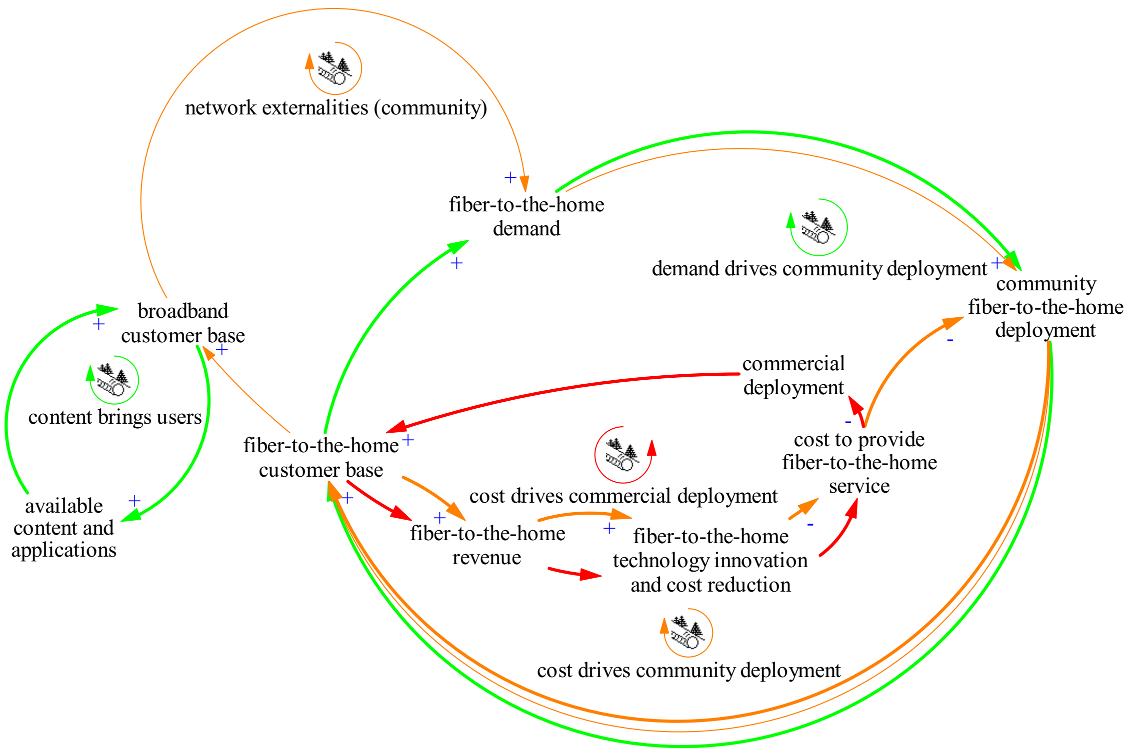


Figure 1.7: "Cost Reduction Drives Commercial Deployment" Inactive Loop

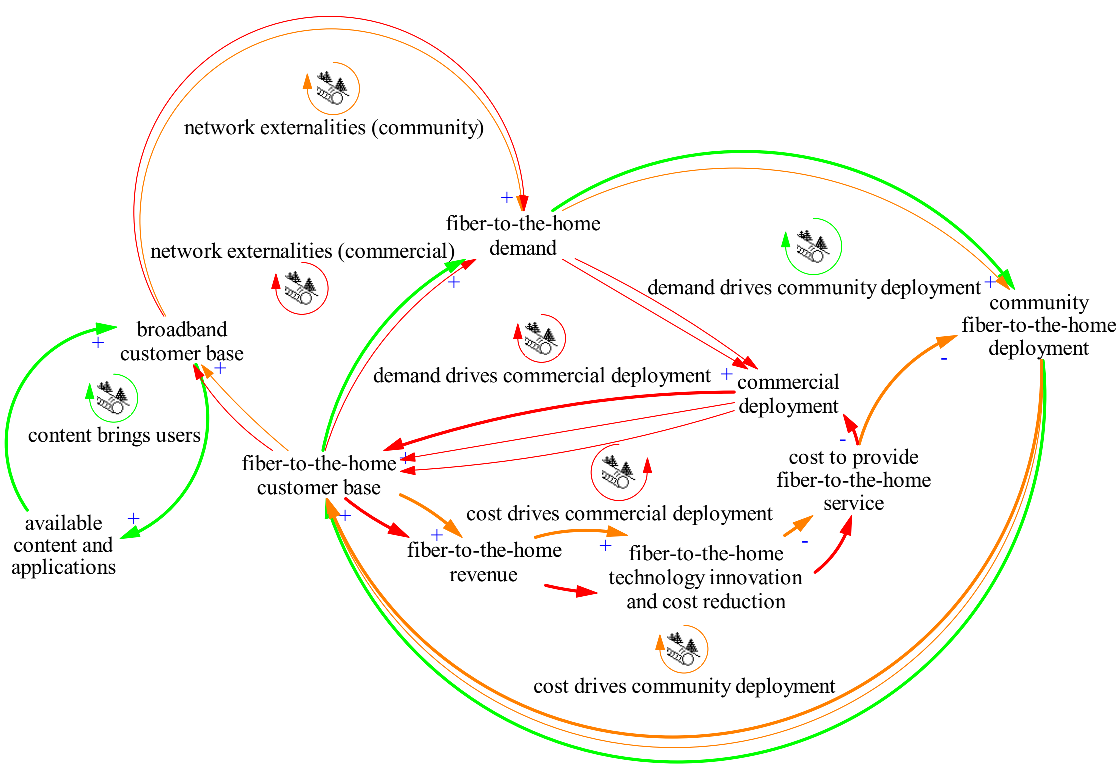


Figure 1.8: High-Level System Dynamics Fiber-to-the-Home Model

1.5 Regulation

Regulation is a key factor that could cause community deployments to happen more rapidly and commercial deployments to become viable. Regulation does not have its own variable at the high-level of Figure 1.8 because regulation may have an effect anywhere and everywhere in this system.

Regulation can have a profound effect on how the deployment of fiber-to-the-home progresses and on the number of competitors participating in any given region. The FCC has been monitoring the deployment of broadband and the investment in broadband infrastructure to determine if, when, and how regulation may be appropriate. Opponents of regulation believe that if regulations are put in place that require facilities providers to share infrastructure with competitors, the facilities providers will be less likely to invest in upgrading equipment. Proponents of regulation believe that forcing the sharing of infrastructure is the only way to ensure that the consumer will have a choice of providers and a choice of services.

Policy makers are interested in ensuring that broadband service becomes available to all consumers regardless of their geographical area. This is particularly an issue in rural areas where the low population density makes commercial deployment costly and uninteresting to traditional providers. The United States Department of Agriculture (USDA) through its Rural Utilities Service (RUS) provides low cost loans to assist with deployment of broadband services in rural areas.

State and local level regulations can also help or hinder deployment. Currently many states have implemented or are considering statutes that would limit the entry of municipalities into the broadband market. From the loops shown in the previous section this may directly affect commercial viability of fiber-to-the-home.

To incorporate these effects into the model, various regulatory scenarios are developed and included in the model runs.

1.6 Conclusions

The key areas that need to be addressed to help bring broadband service to unserved regions are: a better understanding of the current state of deployment so that regulation that encourages adoption is possible; recognition of the conflicts of interest that are present in the fiber-to-the-home supply chain and actions that can be taken to resolve those conflicts; and a better understanding of the effects that potential regulatory policies have on deployment.

The current monitoring of broadband deployment done by the Federal Communications Commission is inadequate for the formation of good policy decisions. The FCC's statistics on broadband availability drastically overstate the true state of broadband deployment, especially in rural regions.

Deployment of fiber-to-the-home is costly, and cost recovery for the deployment for both incumbent and competitive providers is difficult, especially in rural and suburban regions that do not currently have service. Policies such as required resale of facilities to competitors only make cost recovery more difficult and deployment less attractive. The Rural Utilities Service funding program assists in providing loans for service in rural areas. However, there does not appear to be enough funding for the demand being placed on the program, so deployments are being held back as they wait for funding.

The interests of consumers, regulators, and even service providers are in conflict with the interests of the optoelectronics industry which provides a critical component necessary for the service.

As long as the dynamics of fiber-to-the-home and broadband deployment are not well understood by regulators, deployment to unserved regions will be slow and policies are unlikely to move deployment forward. The optoelectronics industry also needs to move towards aligning its interests with those of consumers, regulators, and the rest of the telecommunications supply chain.

1.7 Document Overview

The remainder of this document is organized as follows:

Chapter 2: Building the Model – Technology

The various technology options for fiber-to-the-home are described in detail. The standards governing fiber-to-the-home, the vendors providing the technology, and the applicable patents are explored to determine their implication on the design of the model.

Chapter 3: Building the Model – Technology Adopters

In order for fiber-to-the-home to be successful, it requires adoption by three different groups. First, communities that currently do not have broadband are beginning to deploy fiber-to-the-home. Secondly, individuals that have fiber-to-the-home available to them need to want the service. They can also serve as a catalyst for community deployment. Finally, telecommunications companies need to begin adopting the technology to make it available to more consumers. This chapter explores the dynamics relating to these three groups.

Chapter 4: Building the Model – Regulatory Effects

Regulation is involved in many aspects of the model. This chapter describes some of the important effects that regulation can have on the players described in Chapter 3 and how they will be incorporated into the model.

Chapter 5: Model Overview

The model is described in detail, along with the initial conditions and assumptions. Transition from the loop diagrams to an actual coded model based on the information from previous chapters is described.

Chapter 6: Model Results and Sensitivities

The results of the model for different scenarios are discussed. Sensitivity of the model to variation in the parameters is analyzed.

Chapter 7: Conclusions

Implications of the model results and the sensitivities for industry, adoption, and regulation are discussed. The further implications of the results on networking technology adoption and areas of further research are examined.

Chapter 2: Technology

A model of fiber-to-the-home deployment cannot be developed without an understanding of the technologies that can be used to provide fiber-to-the-home service. Standards, vendors, and patents can all provide hints to how fiber-to-the-home technology will evolve and how to capture this process in a system dynamics model. This chapter explores the different ways that fiber-to-the-home can be deployed, the technologies involved, the standards that govern those technologies, and the patents that relate to fiber-to-the-home technologies. The current state of the vendor base for the technologies is also examined.

The questions to be answered for the purposes of building the model include:

- What is the current state of the technologies, standards, and patents?
- Are the technologies converging?
- Is there something that is driving convergence?
- How can economies of scale best be achieved?

2.1 Technology Overview

There are several different methods of deploying optical telecommunications fiber to end users today. They include fiber-to-the-curb (FTTC), fiber-to-the-business (FTTB), and fiber-to-the-home (FTTH). Fiber-to-the-curb is a fiber run from the central office of the provider to a nearby location outside the customer premises. Fiber-to-the-business and fiber-to-the-home imply the running of fiber optic cable all the way to the customer premises. Collectively these deployment methods are known as FTTx. The focus of this study is fiber-to-the-home.

2.1.1 Network Topologies

A network topology is a description of how the nodes in a network are connected to each other. The topology can be physical, describing the physical layout of the wiring, or logical, describing the communications path between the nodes. The network topologies described here refer to the physical layout of the fiber-to-the-home system.

Several different topologies can be used in a fiber-to-the-home system. Choice of topology depends on several different factors including choice of delivery technology and desired cost of the system. The primary network topologies for fiber-to-the-home are the home run and the star.

2.1.1.1 Home Run

A home run network topology is a point-to-point topology with a run of fiber from the provider's central office optical line terminal (OLT) out to each customer's optical network terminal (ONT) or optical network unit (ONU). The fiber run can be either one fiber, with different wavelengths for upstream and downstream transmission or two separate fibers, one for upstream and one for downstream transmission. A home run network topology is shown in Figure 2.1.

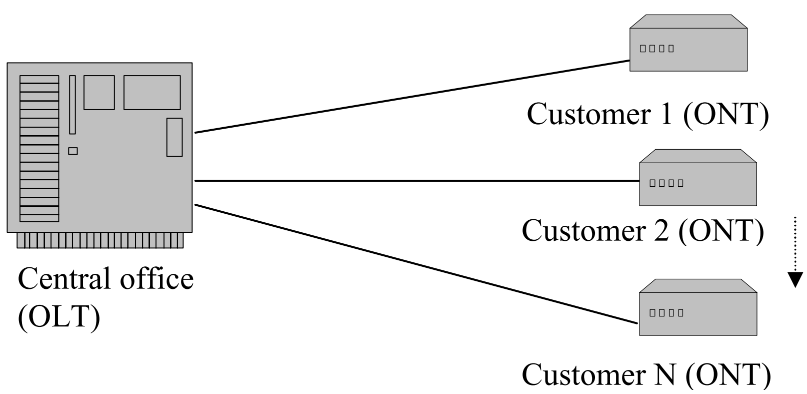


Figure 2.1: Home Run Topology

2.1.1.2 Star

In this topology, a remote node is deployed between the central office and the customer premises, as can be seen in Figure 2.2 and Figure 2.3. The link between the central office and remote node is called the feeder link and the links between the remote nodes and the customer premises are called distribution links. A star topology is considered more cost effective because more of the network resources are shared amongst the customers.

2.1.2 Delivery Technologies

The delivery technologies describe the actual devices that are deployed in a particular system. The various fiber-to-the-home delivery technologies fall into two categories: active and passive optical networks. Both categories of technology are capable of delivering voice, video, and data services.

2.1.2.1 Active Optical Networks

Active optical networks have an active component (such as a switch or a router) between the central office and the end-user. These are point-to-point networks with switched traffic, as shown in Figure 2.2. The topology can be configured as desired. For example, the active switch could be located within or near the central office with long runs of fiber out to each customer (home run), or as far away as within a floor of an apartment building of customers (star).

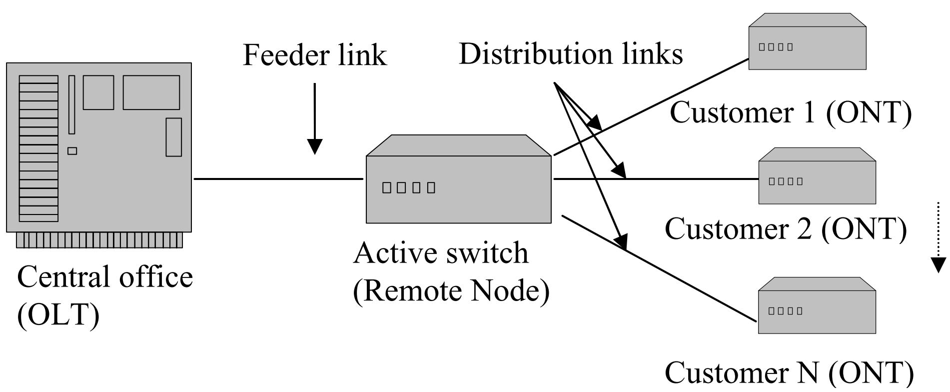


Figure 2.2: Active Optical Network

Active optical networks for fiber-to-the-home, known as EFM Fiber, are being developed and championed by the Ethernet in the First Mile (EFM) Alliance. The EFM Alliance is composed primarily of equipment manufacturers such as Analog Devices, Cisco, Ericsson, Infineon, Intel, and NTT.

2.1.2.2 Passive Optical Networks

Passive optical networks (PONs), or passive star topologies, as shown in Figure 2.3, have no active components between the provider's central office and the subscriber. PONs are point-to-multipoint systems with all downstream traffic broadcast to all ONTs. The majority of fiber-to-the-home technologies being developed and deployed today are passive.

The PONs under development are ATM-based PONs (APONs), Gigabit-capable PONs (GPONs), and Ethernet-based PONs (EPONs). APONs are the most commonly deployed fiber-to-the-home networks with several different deployments around the world. Aside from EPON, which falls under the EFM Alliance due to its use of Ethernet, PONs are being championed by the Full Services Access Network (FSAN). FSAN is an organization of service providers and equipment vendors including: British Telecomm, NTT, SBC, Alcatel, Fujitsu, Lucent, and NEC.

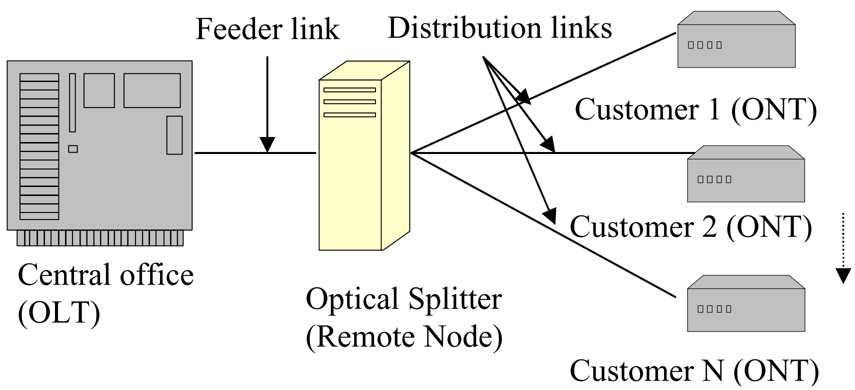


Figure 2.3: Passive Optical Network

2.2 The Standards

Standards work for fiber-to-the-home networks has been taking place in two different organizations: the Institute of Electrical and Electronics Engineers (IEEE) and the International Telecommunications Union (ITU). The IEEE standards work is focused on EFM and the ITU standards work focuses primarily on PONs.

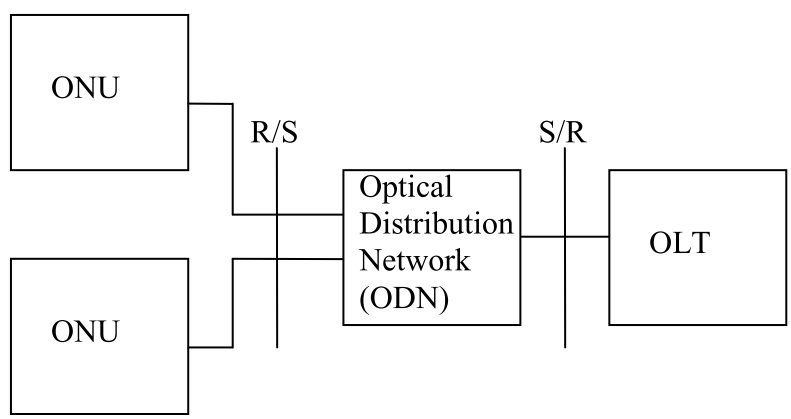
The EFM Alliance is working with the IEEE 802.3ah Task Force to implement standards for Ethernet in the first mile. The EFM work being conducted within the IEEE is an extension of the Ethernet protocol (IEEE 802.3). The standards work in the IEEE 802.3ah Task Force covers EFM copper[1], EFM fiber, and EPON.

IEEE 802.3ah was approved by the IEEE in June of 2004. Information in this document is based on a draft of the standard that was discussed and voted on by the working group in April, 2004. The IEEE 802.3ah draft consists of revisions and new additions to IEEE 802.3 that would incorporate Ethernet in the first mile.

[1] EFM copper includes a short reach and a long reach service. The standard specifies short reach service at up to 10 Mbps and a distance of 750 meters and long reach service at 2 Mbps and a distance of 2.7 km. Since EFM copper is not an FTTH delivery technology, it will not be further discussed in this document. For further information on FTTH copper see the IEEE 802.3ah Task Force web site at: http://www.ieee802.org/3/efm/

Recommendations for APONs and GPONs have been developed by the ITU as the G.983 and G.984 series of Recommendations through the work of FSAN. The standards fall under the Telecommunication Standardization Sector, ITU-T. The Sector is divided into sections; fiber-to-the-home is part of Section G: transmission systems and media, digital systems and networks. The ITU has also developed a Recommendation for point-to-point Ethernet in the first mile, G.985.

The Recommendations are non-binding, but are generally followed to allow for interoperability of networks. Figure 2.4 shows an adaptation of the optical access network reference configuration defined in Recommendation G.982 (Optical Access Networks to Support Services Up to the ISDN Primary Rate or Equivalent Bit Rates). Included are the parts of the reference configuration that will be referred to later in this chapter, the actual reference configuration is much more detailed.



S Point on the optical fibre just after the OLT[Downstream]/ONU[Upstream] optical connection point (i.e. optical connector or optical splice)

R Point on the optical fibre just after the ONU[Downstream]/OLT[Upstream] optical connection point (i.e. optical connector or optical splice)

Figure 2.4: Adaptation of ITU Reference Configuration (G.982)

2.2.1 EFM Fiber (IEEE 802.3ah)

EFM Fiber is similar in architecture to traditional hubs and switches that run local area networks today. The standards for EFM Fiber were developed in the IEEE 802.3ah Task Force with input from the EFM Alliance. The ITU has also developed a standard for point-to-point Ethernet over fiber, ITU-T G.985. The ITU standard came out of efforts by the Telecommunications Technology Committee (TTC) in Japan to achieve interoperability between vendors for deployed fiber-to-the-home systems. The efforts of the TTC also contributed to the compatibility of some physical layer specifications of IEEE 802.3ah that were approved in

January 2003. Communications between the ITU-T and IEEE standards groups is an ongoing effort to keep the standards from conflicting.

The technology consists of point-to-point single-mode fiber with a range of at least 10 km between the active switch and the ONT of Figure 2.2. EFM fiber employs Ethernet and active equipment at speeds of 100 Mbps and 1 Gbps. Operation can be over a single fiber or use one fiber for upstream transmission and a second fiber for downstream transmission.

For the two fiber configuration, transmission is in the 1260 to 1360 nm wavelength band. For operation over a single fiber, upstream transmission is in the 1260 to 1360 nm wavelength band and the downstream transmission wavelength varies depending on the transmission speed. 100 Mbps downstream operation uses the 1480 to 1580 nm wavelength band and 1 Gbps downstream operation uses the 1480 to 1500 nm wavelength band.

The Grant County Public Utility District in Grant County, Washington has deployed an active optical network with network equipment from Cisco Systems and termination equipment from World Wide Packets. The Taunton Massachusetts Municipal Lighting Plant is also proposing the deployment of an active optical network.

2.2.2 100 Mbit/s Point-To-Point Ethernet Based Optical Access System (ITU-T G.985)

G.985, currently in force, describes a single fiber 100 Mbps point-to-point Ethernet optical access system. The Recommendation includes specifications for the optical distribution network and the physical layer, and also the requirements for operation, administration, and maintenance.

Transmission is on a single fiber using wave division multiplexing (WDM), with downstream transmission in the 1480-1580 nm range and upstream transmission in the 1260-1360 nm range. These wavelengths are identical to those defined for EFM Fiber downstream and upstream transmission. The standard currently defines a transmission distance of 7.3 km with 20 and 30 km distances for further study.

2.2.3 Ethernet PON (EPON)

EPON is Ethernet over a passive optical network. Similar to the Ethernet active optical networks, standards are being developed with the assistance of the EFM Alliance in the IEEE 802.3ah Task Force. EPON was not originally within the scope of IEEE 802.3ah, but was added fairly early in the process. The protocol used in EPON is an extension of IEEE 802.3, and operates at 1 Gbps with a range of 10 or 20 km between the R/S and S/R points of Figure 2.4. The architecture is a single shared fiber with an optical splitter, as with other PON architectures. The supported split ratio is 16 users per PON. The system operates at 1480-1500 nm in the downstream and 1260-1360 nm in the upstream direction.

Since Ethernet does not utilize a point-to-multipoint topology, EPON required the development of a control protocol to make the point-to-multipoint topology appear as a point-to-point topology. This protocol is called the Multipoint Control Protocol (MPCP). MPCP uses a point-to-point emulation sublayer with two bytes of the Ethernet packet preamble for a Logical Link Identification (LLID) field. LLIDs are assigned to ONUs by the OLT as part of the automatic discovery of ONUs on the network. MPCP at the OLT is used to ensure that only one ONU transmits in the upstream direction at a time.

EPON operates differently in the downstream and upstream direction. In the downstream direction, EPON is a broadcast protocol. Every ONT receives all packets, looks at the LLID to extract the Ethernet frames intended for that customer and discards the rest. As with APON, transmission in the upstream direction is regulated by TDMA.

Periodically, the OLT transmits a “marker” frame downstream for synchronization. The marker frame defines the location of the “discovery window.” Stations wishing to transmit send discovery requests during the discovery window. When the OLT receives a discovery request from an ONT wishing to transmit, the OLT schedules the transmission and sends a GATE frame to the ONT letting it know to transmit. When an ONT receives a GATE frame from the OLT, it is then clear to transmit actual data.

2.2.4 ATM PON (APON)

APON systems are PONs that are based on ATM over SONET/SDH. APONs are also known by the preferred marketing name of BPON, or Broadband PON, to avoid confusing some users who believed that APONs could only provide ATM services to end users. The terms APON and BPON will be used interchangeably in this document. APONs are defined by the ITU-T G.983 series of Recommendations and FSAN.

SONET/SDH is a telecommunications industry standard for high speed fiber connections over long distances. Topologically, SONET supports a ring architecture, thought it can be deployed point-to-point (degenerate case). In addition to carrying voice and data, SONET supports a variety of alarm indication and performance monitoring features.

ATM is a protocol that runs on top of SONET. ATM uses 53-byte cells (5 bytes of header and 48 bytes of payload). Because of the fixed cell size, ATM implementations can enforce quality of service guarantees, e.g. bandwidth allocation, delay guarantees, etc. ATM was designed to support both voice and data payloads, so it is well-suited to fiber-to-the-home applications.

The OLT for an APON deployment can support multiple APONs with a split ratio of 32 or 64 subscribers each, depending on the vendor. APON can be deployed as two fibers to each customer (one upstream and one downstream), or, using WDM, as one fiber to each customer.

WDM divides the fiber by wavelength into two or more channels. APON implementations use one channel for upstream traffic, one for downstream traffic, and potentially one for broadcast technologies like video.

One possible future extension of the APON is the SuperPON. The target architecture of a SuperPON involves a cascade of passive optical splitters. Ideally the architecture will be able to support 2048 users and a range of 100 km, with a 2.5 Gbps downstream and a 311 Mbps upstream (Eilenberger, 1988).

2.2.4.1 Broadband Optical Access Systems Based on Passive Optical Networks (PON) (G.983.1)

G.983.1 was the original APON standard. Since its inception in October of 1998, there have been seven other standards published as part of the G.983 series further defining and extending the specifications of G.983.1. The information in this section covers G.983.1, corrections, and Amendment 1, all currently in force.

The standard defines the nominal bit rates for APON to be symmetric 155.52 Mbps or 622.08 Mbps, or asymmetric 622.08 Mbps in the downstream direction and 155.52 Mbps in the upstream direction. Transmission can be via a single fiber using WDM or via two fibers, one for transmission in each direction. The maximum differential logical reach[2] of the system is 20 km. The maximum distance between the S/R and R/S points in the diagram in Figure 2.4 is also 20 km. The standard also specifies a minimum supported split ratio of 16 or 32 users per PON.

The APON protocol operates differently in the downstream and upstream directions. In the downstream, APON operates at OC3 (155 Mbps) or OC12 (622 Mbps) speeds. On a single fiber using WDM, downstream transmission is at 1480-1580 nm. For two fibers, transmission is at 1260-1360 nm. At 155Mbps, the APON frame consists of 56 ATM cells (time slots); 54 for data, and 2 for physical layer operations and management (PLOAM). The PLOAM cells are inserted every 28 time slots. At 622 Mbps, an APON frame is 224 slots long with 216 ATM cells of data and 8 cells of PLOAM.

All downstream receivers receive all cells and discard those not intended for them, based on ATM addressing information. Due to the broadcast nature of the PON, downstream user data is churned, or scrambled, using a churn key generated by the ONU to provide a low level of protection for downstream user data.

In the upstream direction, the standard specifies OC3 and OC12 speeds, with both a WDM and two fiber wavelength of 1260-1360 nm. Upstream transmission is regulated with a TDMA system. Transmitters are told when to transmit by receipt of grant messages via received

[2] Logical reach is defined in the G.983 standards as the maximum length that can be achieved for a particular transmission system independent of optical budget.

PLOAM cells. Upstream APON modifies ATM and uses 56-byte ATM "cells," with the additional three bytes of header being used for guard time, preamble bits, and a delimiter before the start of the actual 53-byte ATM cell.

Protection mechanisms for the APON are discussed in the appendix of G.983.1 and are considered optional. Four possible duplex configurations are presented as examples.

1. Fiber duplex system: doubles the optical fibers between the OLT and the splitter.
2. OLT-only duplex system: doubles the fibers between the OLT and the splitter with two input/output ports on the OLT side of the splitter and two OLTs per PON at the central office.
3. Full duplex system: identical to the second configuration, but also doubles the ONU side facilities and splitters.
4. Partial duplex: allows for having only some ONUs duplexed with duplexing of the OLT-side facilities.

2.2.4.2 ONT Management And Control Interface Specification for B-PON (G.983.2)

G.983.2 and Amendment 1, both currently in force, specify the ONT management and control interface (OMCI) for the APON system described in G.983.1. The OMCI is designed to enable multi-vendor interoperability between the OLT and the ONT. In this Recommendation the term ONT is used to describe devices used for both fiber-to-the-home and FTTBusiness.

The OMCI protocol is used by the OLT to control the ONT. The protocol runs across an ATM connection between the OLT and the ONT, with a single OLT controller able to control multiple ONTs. The protocol allows the OLT to perform: configuration management; fault management; performance management; and security management on the ONT. The Recommendation goes on to specify the necessary management information base (MIB), control channels, and control protocol cell formats to provide the management.

2.2.4.3 A Broadband Optical Access System with Increased Service Capability by Wavelength Allocation (G.983.3)

G.983.3 and Amendment 1, both currently in force, define a more specific set of wavelengths for transmission than G.983.1. These changes apply primarily to single fiber systems, how the changes in allocation relate to two fiber systems is not addressed in the Recommendation. The spectrum allocation serves to enable video broadband distribution services or data services. Services can be either bidirectional or unidirectional.

The wavelength allocations leave the PON upstream wavelengths unchanged at 1260-1360 nm. The band from 1360-1480 nm includes guard bands and is reserved for future use. The band from 1480-1500 nm is referred to as the "Basic Band" and is for use in PON downstream transmission. "Enhancement Band (Option 1)", the 1539-1565 nm band, is for the use of additional digital services. For video distribution service, the Recommendation defines the 1550-1560 nm band as "Enhancement Band (Option 2)." A "Future L Band" in the 1480-1580 nm range is mentioned as for further study and for later allocation

Maximum differential logical reach, maximum fiber distance between S/R and R/S points, and bit rates remain the same as in G.983.1.

2.2.4.4 A Broadband Optical Access System with Increased Service Capability Using Dynamic Bandwidth Assignment (DBA) (G.983.4)

G.983.4, currently in force, extends G.983.1 to allow for dynamic bandwidth allocation to respond to bursty traffic requirements. Interoperability requirements are described between OLTs and ONUs where one or more of the OLTs or ONUs have dynamic bandwidth allocation functionality. In order to insure interoperability, the Recommendation describes methods for reporting ONU status, defines transmission container (T-CONT) types for support of variable rate services, and discusses performance benchmarks for request detection, request reporting, and grant recalculation and distribution. For details on T-CONTs please see Appendix 1.

Two different mechanisms for dynamic bandwidth assignment are discussed in the Recommendation. They are idle cell adjustment and buffer status reporting. In idle cell adjustment the OLT monitors bandwidth utilization of the ONUs. If the bandwidth usage exceeds a certain threshold, then the OLT assigns additional bandwidth to that ONU if it is available. This method can be used with ONUs that have no inherent dynamic bandwidth assignment capability, since it relies on the OLT to monitor traffic and infer utilization from current patterns. In buffer status reporting, the ONUs report the status of their buffers to the OLT which then reassigns bandwidth according to the reports.

2.2.4.5 A Broadband Optical Access System with Enhanced Survivability (G.983.5)

G.983.5, currently in force, describes the functions that extend G.983.1 to provide enhanced survivability. The protection mechanisms that are further defined are the second and third configurations discussed in Appendix IV of G.983.1. The second configuration doubles the fibers between the OLT and the splitter with two input/output ports on the OLT side of the splitter and two OLTs per PON at the central office. The third configuration is identical to the second, but also doubles the ONU side facilities and splitters. This Recommendation also allows for a mixture of protected and unprotected ONUs in the third configuration.

Protection switching is performed by the OLT in the event of a failure. Switching can be performed via either externally initiated commands from the OLT side or automatically initiated commands provided by the OLT and ONU. The expected switching triggers are "Signal Failure" or "Signal Degraded." The specified performance for Signal Failure detection is under 10 msec for transmission rates greater than 1.5 Mbps.

2.2.4.6 ONT Management and Control Interface Specifications for B-PON System with Protection Features (G.983.6)

G.983.6, currently in force, extends G.983.2 to provide OMCI support for voice, ATM adaptation layer type 2, media access control bridged local area networks, and WDM. The information from G.983.2 is expanded to include the necessary management information base (MIB), control channels, and control protocol cell formats to provide the management for these new services.

2.2.4.7 ONT Management and Control Interface Specification for Dynamic Bandwidth Assignment (DBA) B-PON System (G.983.7)

G.983.7, currently in force, extends the OMCI specifications in G.983.2 to operate with the dynamic bandwidth assignment function described in G.983.4. The additional managed entities necessary to specify T-CONT buffer and schedule functions are described. Some of the previously defined managed entities are assigned new attributes. The managed entities are described in detail in the Recommendation. Appendix 1 of the Recommendation describes the initial handshake, addition, and deletion procedures for a T-CONT.

2.2.4.8 B-PON OMCI Support for IP, ISDN, Video, VLAN Tagging, VC Cross-Connections and Other Select Functions (G.983.8)

G.983.8 is currently pre-published which means that it has been approved but is not yet in its final edited form. This Recommendation covers OMCI support for IP Router functionality on LAN cards, ISDN interfaces, additional Ethernet performance monitoring, video interfaces, virtual LAN tagging, extended MAC Bridge Filtering, local craft terminal interfaces, virtual channel cross-connections, and ONUs. The additional managed entities, along with modifications to existing managed entities to provide these services, are described in detail. This functionality was considered out of scope for G.983.2. This Recommendation does not cover management for ONUs with xDSL interfaces, which is for future study.

2.2.5 Gigabit PON (GPON)

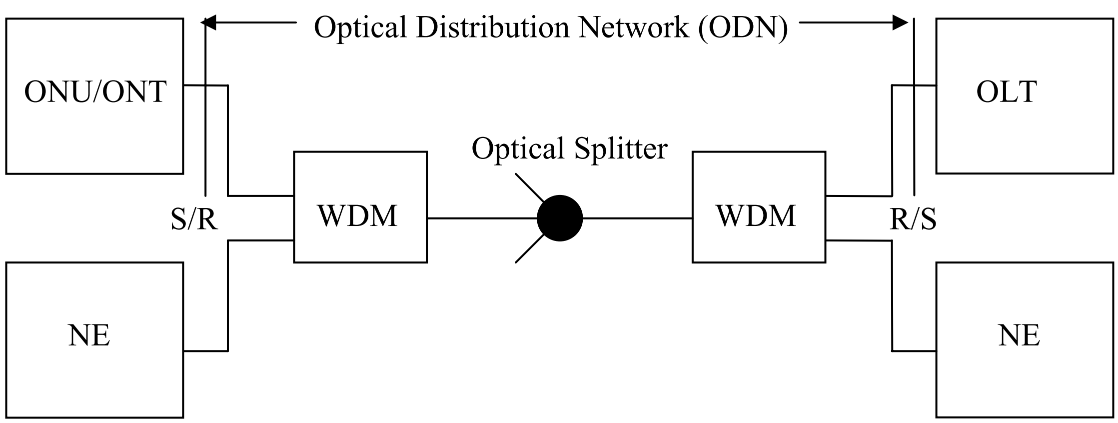
Efforts to standardize PON networks operating at above 1 Gbps were initiated in 2001 by FSAN in ITU-T G.984. GPON is a more generalized version of APON, not dependent on ATM. GPON supports line speeds of 1.2 Gbps and 2.4 Gbps in the downstream and 155 Mbps, 622 Mbps, 1.2 Gbps, and 2.4 Gbps in the upstream. The physical reach of the system is either 10 km or 20 km, depending on ONU speed. GPON realizes greater efficiency over APON by not requiring large IP packets to be broken up into 53-byte ATM cells.

The GPON OLT can support 64 ONUs per fiber with current technology, thought it is anticipated that future developments will allow the support of 128 users per fiber. The system has a reach of 10 or 20 km depending on speed.

GPON attempts to preserve as many characteristics of the G.983 series of Recommendations as possible, however due to technical issues relating to providing the higher line rates, the two systems are not interoperable.

2.2.5.1 Gigabit-Capable Passive Optical Networks (GPON): General Characteristics (G.984.1)

G.984.1, currently in force, describes the general characteristics of a GPON. The Recommendation keeps intact characteristics from the G.983 series of Recommendations whenever possible to promote backward compatibility with existing optical distribution networks that comply with those Recommendations. An adaptation of the GPON reference configuration is shown in Figure 2.5. This configuration differs from the APON reference configuration in Figure 2.4 by the addition of a network element at a different wavelength from the OLT and the ONU and a wavelength division multiplexer to multiplex that wavelength onto the optical distribution network.



S	Point on the optical fibre just after the OLT[Downstream]/ONU[Upstream] optical connection point (i.e. optical connector or optical splice)
R	Point on the optical fibre just after the ONU[Downstream]/OLT[Upstream] optical connection point (i.e. optical connector or optical splice)
NE	Network Element which uses a different wavelength from the OLT and the ONU

Figure 2.5: Adaptation of GPON Reference Configuration (G.984.1)

GPON has seven transmission speed combinations (line rates): symmetric 1.2 or 2.4 Gbps, or asymmetric 1.2 or 2.4 Gbps downstream with 155 Mbps, 622 Mbps, or 1.2 Gbps in the upstream. The physical reach of the GPON is 10 or 20 km depending on speed. The Recommendation assumes that 10 km is the furthest reach that can be achieved with a Fabry-Perot laser diode (FP-LD) in the ONU for speeds above 1.2 Gbps. Split ratios of up to 64 users per fiber are possible with current technology and the Recommendation anticipates ratios of up to 128 users per fiber and accounts for this in the transmission convergence layer.

Protection schemes for the GPON are considered optional; however, some possible duplex configurations are discussed. These duplex configurations are identical to the four configurations described in the Appendix of G.983.1: doubling of the optical fibers; doubling the OLT and the optical fibers between the OLT and the splitter, with two ports on the OLT side; doubling not only the OLT side facilities, but also the ONU side facilities; and duplexing of only some ONUs. Switching for the protection schemes can be either automatic or forced. Automatic switching is triggered by fault detection, while forced switching is activated by administrative events.

The Appendix of G.984.1 goes on to describe examples of services that the GPON is required to support and includes some additional information about those services.

2.2.5.2 Gigabit-Capable Passive Optical Networks (GPON): Physical Media Dependent (PMD) Layer Specification (G.984.2)

G.984.2, currently pre-published, describes the physical layer requirements and specifications for the physical media dependent (PMD) layer of the GPON. The parameters specified in the Recommendation are valid for cases without an Enhancement Band as specified in G.983.3. However, the wavelengths specified are compliant with G.983.3 and do allow for integration of an Enhancement Band in the future.

The system has a maximum fiber distance between the S/R and R/S points in Figure 2.5 of 20 km with 10 km as an option. The maximum differential logical reach is also 20 km. The minimum supported split ratios are 16, 32, or 64 users per PON. The nominal line rates for the system are as described in G.984.1. As with APON, the system may be either a one or two fiber system.

The nominal bit rate for the downstream direction is 1244.16 or 2488.32 Mbps with an operating wavelength on a single fiber system of 1480-1500 nm. For a two fiber system, the downstream operating wavelength is 1260-1360 nm. The nominal bit rate for the upstream direction is 155.52, 622.08, 1244.16, or 2488.32 Mbps with an operating wavelength of 1260-1360 nm on either a one or two fiber system.

2.2.5.3 Gigabit-Capable Passive Optical Networks (GPON): Transmission Convergence Layer Specification (G.984.3)

This Recommendation, currently pre-published, describes the transmission convergence layer for GPONs. It specifically covers the specifications for frame format, media access control, ranging, OAM functionality, and security for GPON networks.

GPON uses the GTC (GPON Transmission Convergence) framing sub-layer for framing. As in APON, GTC frames can encapsulate ATM cells. Unlike APON, GTC frames can also directly encapsulate packet data, through GEM (GPON Encapsulation Method). GTC frames sit within 8 kilobit SONET frames. GTC operates over any octet-synchronous path, such as SONET/SDH, but is designed to function over non-SONET transport as well. The payload portion of the GTC frame contains both an ATM segment and a GEM segment. However, each PON can be configured to be ATM, GEM, or both. Despite the ability to configure a GPON as ATM only with upstream data rates similar to G.983, the systems are incompatible.

In the downstream, the frame sizes are fixed at 125 μs. The downstream frame contains a header with frame synchronization, PLOAM, a payload length indicator, and an upstream bandwidth map telling ONUs what the start and end for their upstream transmission window is. The OLT has an effective control granularity of 64 kbps in assigning bandwidth to the ONUs. Traffic management is done via T-CONTs as described in G.983.4. The payload portion of the downstream frame contains both an ATM and GEM segment.

The GEM frame may contain either Ethernet or TDM packets. The frame contains a header which specifies the payload length, 12 bits for a port-ID, two bits for a fragmentation indicator, and one byte for error checking. This header is followed by the actual encapsulated payload. The ATM segment operates with T-CONTs as described in G.983.4.

In the upstream the GPON frame is the same length as in the downstream. Each frame contains transmissions from one or more ONUs and can have up to four overheads:

1. A physical layer overhead that contains guard bands, preamble bits, and a delimiter for frame synchronization;
2. PLOAM;
3. A physical control block overhead that contains dynamic bandwidth allocation reporting and traffic status information from the ONU; and
4. A power leveling sequence overhead.

GPON uses the Advanced Encryption Standard (AES) to encrypt the payload of GEM and ATM segments. The encryption system used assumes that privileged information, like the security keys to decode the payloads, can be passed upstream in the clear due to the directionality of the PON (i.e., that any ONU in the PON cannot observe the upstream traffic from any other ONU in the PON).

2.2.6 Summary

The standards define five different types of systems for fiber-to-the-home. A summary of those systems for single-fiber implementations can be found in Table 2.1. Two fiber implementations use the 1260 to 1360 nm band in both the upstream and downstream transmission direction. G.983.3 and G.985 are not defined for two fiber operation. Systems operating over a single fiber can also support a video overlay of 1 Ghz of bandwidth at 1550 nm, provided that 1550 nm is not being used for downstream transmission.

The homes per feeder fiber for the active systems, EFM Fiber and G.985, are listed as not applicable because these systems can support as many homes per feeder fiber as the number of ports on the switch that is put at the remote node. In some current implementations that number is as high as 48, however the limitations are in the switching technology itself and are not inherently fiber-to-the-home limitations.

Table 2.1: Fiber-to-the-Home Single-Fiber System Summary

Technology	Type	Wavelength (down/up)	Speed	Homes per Feeder Fiber	Reach	Standard
EFM Fiber	Active	1550/1310	100 Mbps	N/A	>10km	802.3ah
		1490/1310	1Gbps			
G.985	Active	1550/1310	100 Mbps	N/A	<7.3km	G.985
EPON	Passive	1490/1310	1Gbps	16	10 or 20km	802.3ah
APON	Passive	1550/1310	155 Mbps, 622 Mbps	16, 32	20km	G.983.1
		1490/1310				G.983.3
GPON	Passive	1490/1310	Down: 1.2/2.4 Gbps Up: 155/622Mbps, 1.2/2.4 Gbps	64,128	20km	G.984

The IEEE and ITU have attempted to work together to define standards that do not conflict. The standards are all moving towards the ability to provide 1 Ghz of bandwidth for video at 1550 nm and towards higher speed data transmission and the ability to support more users.

2.3 Analysis

Electronically, all of the systems are very different, employing different protocols and framing mechanisms to provide service. However, the standards are moving towards use of the same optical wavelengths for transmission. Newer standards specify the 1490 nm range for downstream transmission, 1310 nm range for upstream transmission, and 1550 nm for video service.

To explore the extent at which the standards for the optics have converged, several parameters of interest are excerpted from the standards. A transceiver is the optical component that provides both the transmit and receive functions in a single package. It contains a transmitter for sending optical signals along the fiber and a receiver to receive signals from the fiber. Aside from the purchasing of rights-of-way and the laying of fiber, the optics are considered the most costly parts of these systems, thus there is interest in exploring methods of lowering that cost. A comparison of the transceivers allows the assessment of the potential for using the same transceiver for multiple systems, thereby lowering cost by achieving economies of scale.

The parameters that are examined are those that most strongly affect the cost of the transceiver: operating wavelength, mean launch power, extinction ratio, and receiver sensitivity. Operating wavelength is the frequency of light emitted by the laser in the transceiver or the frequency that can be received by the optical receiver. Mean launch power is the power that the transmitter injects onto the fiber. Extinction ratio is defined as the ratio of the laser output power for the transmission of a 1 bit to the output power for the transmission of a 0 bit. The receiver sensitivity is the minimum average optical power needed to achieve a desired bit error rate. These parameters are all important in system design and transceiver cost.

A brief summary of the parameters as they relate to the development of the model are presented in this chapter, for more detail please see Appendix 1.

The standards contain a large proliferation of transceiver specifications for the key parameters. If transceivers are considered to be a unique combination of the parameters in the tables found in Appendix 1, including wavelength, over 100 transceivers are specified by the standards. Thirty-six of these are the transceiver possibilities for GPON alone. Parameters for 2488 Mbps GPON are not yet defined and will likely cause the number of possible combinations to increase. If the parameters are looked at more aggressively such that bit rate and operating wavelength are unique, but any overlap in launch power, extinction ratio, and receiver sensitivity would allow the transceiver to be usable in both applications, then there are still about 30 combinations. In order to achieve economies of scale for the optical components in fiber-to-the-home systems, either one specific set of parameters needs to dominate the deployments, or optical components that can meet the specifications for multiple systems are required.

G.984.2 explicitly mentions the use of Fabry-Perot Laser Diodes (FPLDs) for the customer premise equipment. The remaining standards all specify parameters that fall into line with those specified for GPON systems, so the use of FPLDs in the transceiver is assumed for the following analysis.

The three parameters that are explored more closely for the possibility of making a few transceivers that meet all or as many of the specified transceivers as possible are data rate, maximum launch power, and receiver sensitivity. At least two different transceivers are necessary, one operating at 1490 nm and one at 1310 nm to support bidirectional operation over a single fiber and the possibility of video overlay for the system. Since the majority of the standards require that the transmitters have an extinction ratio of 10 dB, that is the assumed target extinction ratio. Aside from G.985, the standards also seem to have a transmission distance break point of 1 Gbps for reach. Systems that are 1 Gbps or less are specified at a transmission distance of 20 km, while those at data rates greater than 1 Gbps are specified with a reach of 10 km.

Graphs of transmitted data rate and maximum launch power can be found in Figure 2.6 and Figure 2.7 for 1310 nm and 1490 nm respectively. At both 1310 nm and 1490 nm, the maximum launch power that is required to meet the specifications is 9 dBm. Note that there are no single fiber specifications for 1310 nm at 2488 Mbps because upstream 2488 Mbps parameters have not yet been defined by the ITU. The single fiber parameters are expected to be similar to the two fiber parameters as they are for 1244 Mbps operation.

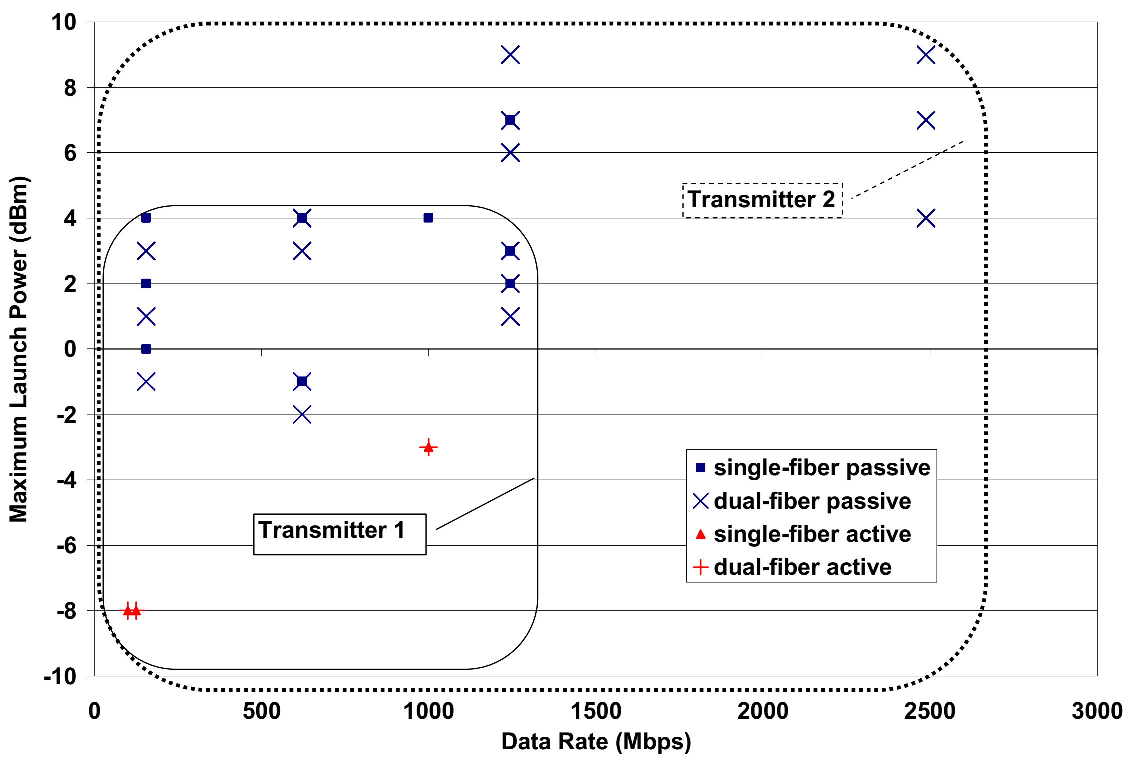


Figure 2.6: 1310 nm Transmitter: Data Rate vs. Maximum Launch Power

Examining the graphs more closely for the possibility of a natural break point for launch power and data rate does not provide an obvious second transmitter option. A launch power of 4 dBm at 1310 nm would meet the standards up to 1 Gbps and some of the 1244 Mbps standards. At 1490 nm, 4 dBm only meets standards up to 622 Mbps and some 1 Gbps standards. To achieve full 1 Gbps standards compliance, a launch power of 7 dBm would be required. This leaves the possibility of developing a 9 dBm 1310 nm and 1490 nm transmitter to meet all specifications, or both a 4 dBm and a 9 dBm transmitter. The 9 dBm transmitter to meet all specifications would have to operate at up to 2488 Mbps.

In a two transmitter situation, for 1310 nm, the 9 dBm transmitter would be for operation at 1244 Mbps and higher, and the 4 dBm transmitter would operate at speeds up to 1 Gbps. For 1490 nm, the 4 dBm transmitter could operate at up to 622 Mbps and the 9 dBm transmitter would be for operation from 1 Gbps up to 2488 Mbps. Note that in both cases the 4 dBm transmitter would also be able to meet a few of the higher speed specifications if it were designed to operate at a higher speed. Essentially this means that at 1310 nm an APON, EPON, G.985, and EFM Fiber transmitter could be developed to operate at 4 dBm along with a 9 dBm GPON transmitter. At 1490 nm the 4 dBm transmitter would be for APON, 100 Mbps EFM Fiber, and G.985. The 9dBm transmitter would be required for EPON, 1 Gbps EFM Fiber, and GPON.

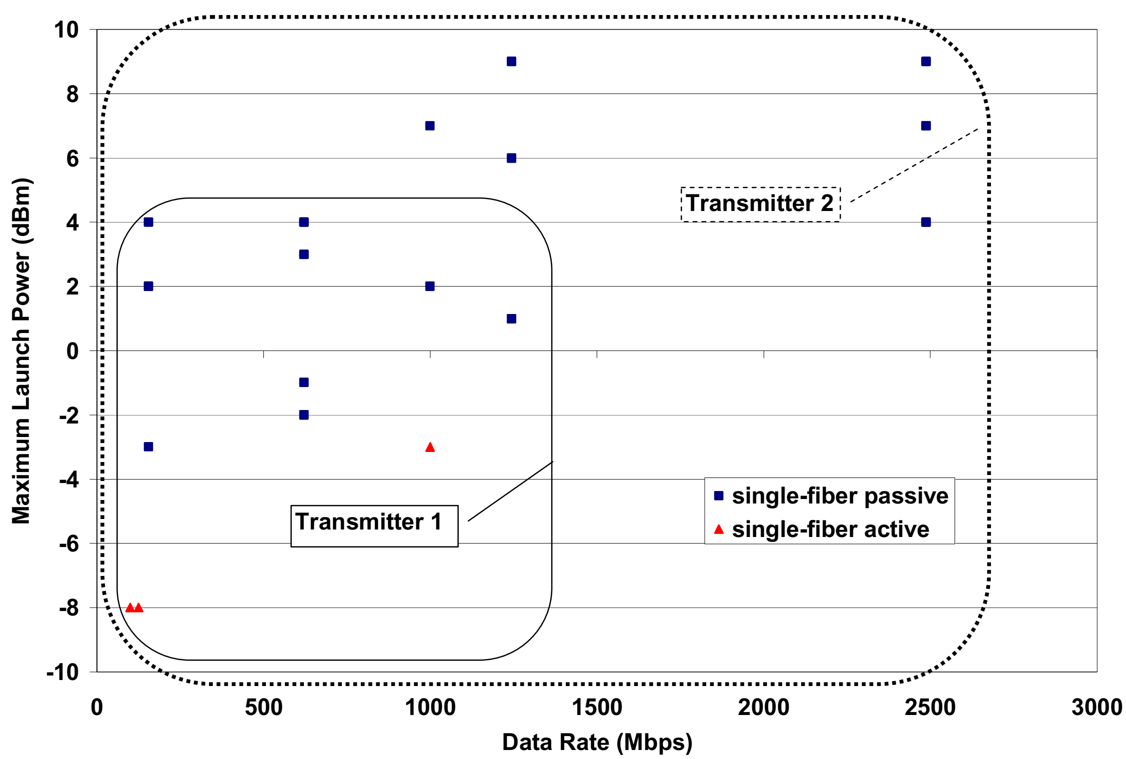


Figure 2.7: 1490 nm Transmitter: Data Rate vs. Maximum Launch Power

The other important component in the transceiver is the receiver. Graphs of received data rate and receiver sensitivity for 1310 nm and 1490 nm are found in Figure 2.8 and Figure 2.9 respectively. For the 1310 nm receivers, -34.5 dBm is the most sensitive receiver. Its received data rate is 155 Mbps. For speeds of 2488 Mbps, a receiver sensitivity of -28 dBm is required. At 1490 nm, -33 dBm is the most sensitive receiver, also with a data rate of 155 Mbps. For operation at 2488 Mbps, a sensitivity of -28 dBm is required. For receivers there doesn't seem to be any clear point at which it would make sense to make a second less sensitive receiver. The sensitivities are fairly well distributed amongst data rates and types of systems. A single receiver at -34.5 dBm for 1310 nm operation and one at -33 dBm for 1490 nm operation should be paired with the transmitters mentioned above.

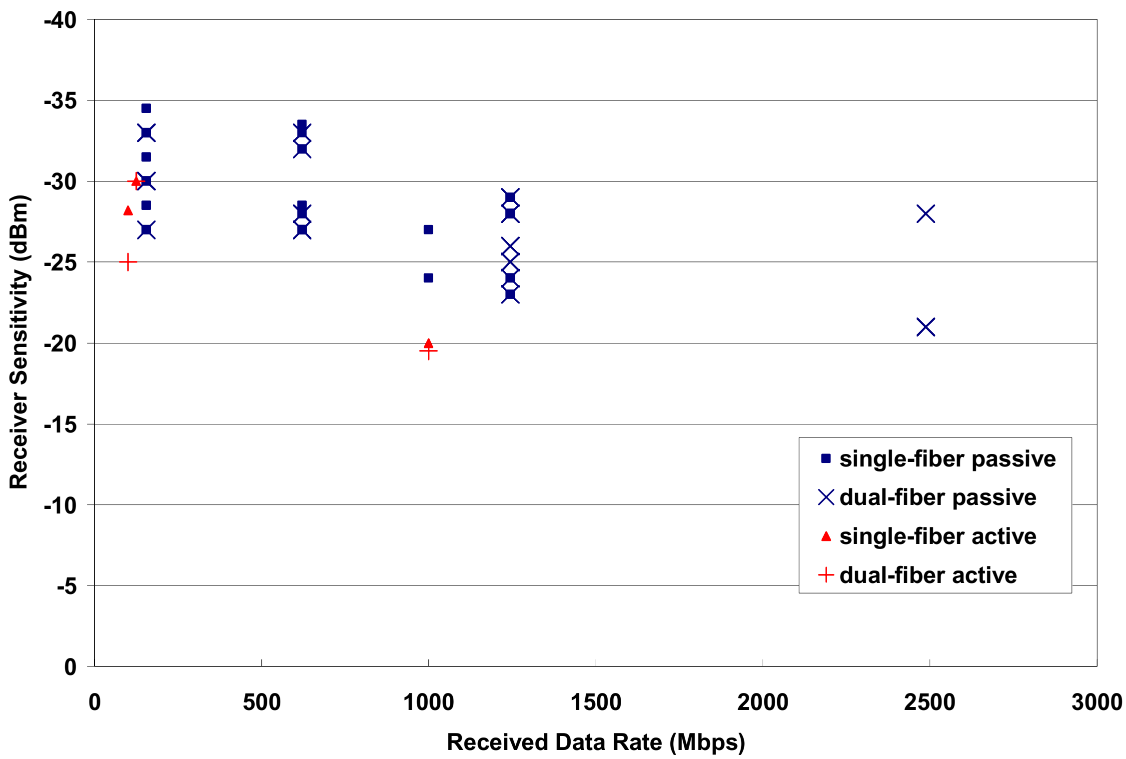


Figure 2.8: 1310 nm Receiver: Received Data Rate vs. Receiver Sensitivity

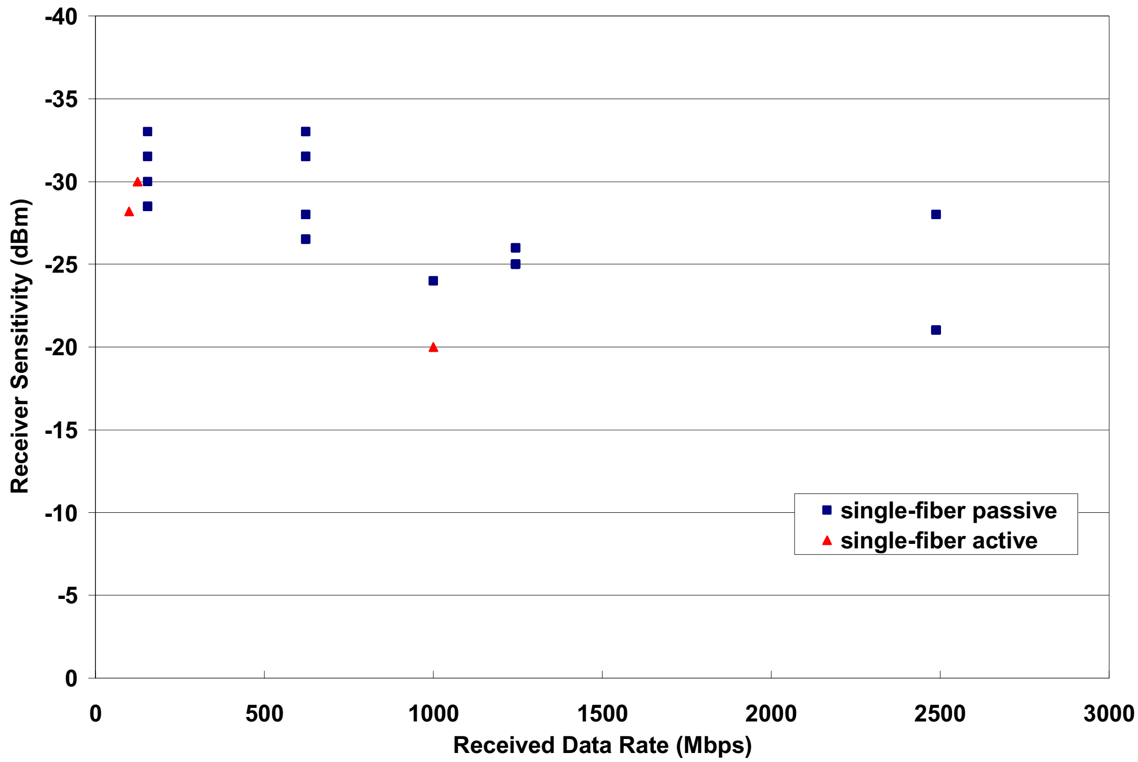


Figure 2.9: 1490 nm Receiver: Received Data Rate vs. Receiver Sensitivity

2.4 Vendors and Products

An analysis of the standards wouldn't be complete without some information about what kinds of systems are actually being developed. Information on fiber-to-the-home equipment companies and their products was gathered in July and August, 2003. Detailed information on the vendors and equipment can be found in Appendix 3.

The equipment vendors have not converged to a single type of system, nor do they appear to be doing so. All systems appear to be on equal footing from a vendor standpoint. The vendors in all categories range from startup companies to businesses with many years of experience in the network equipment market.

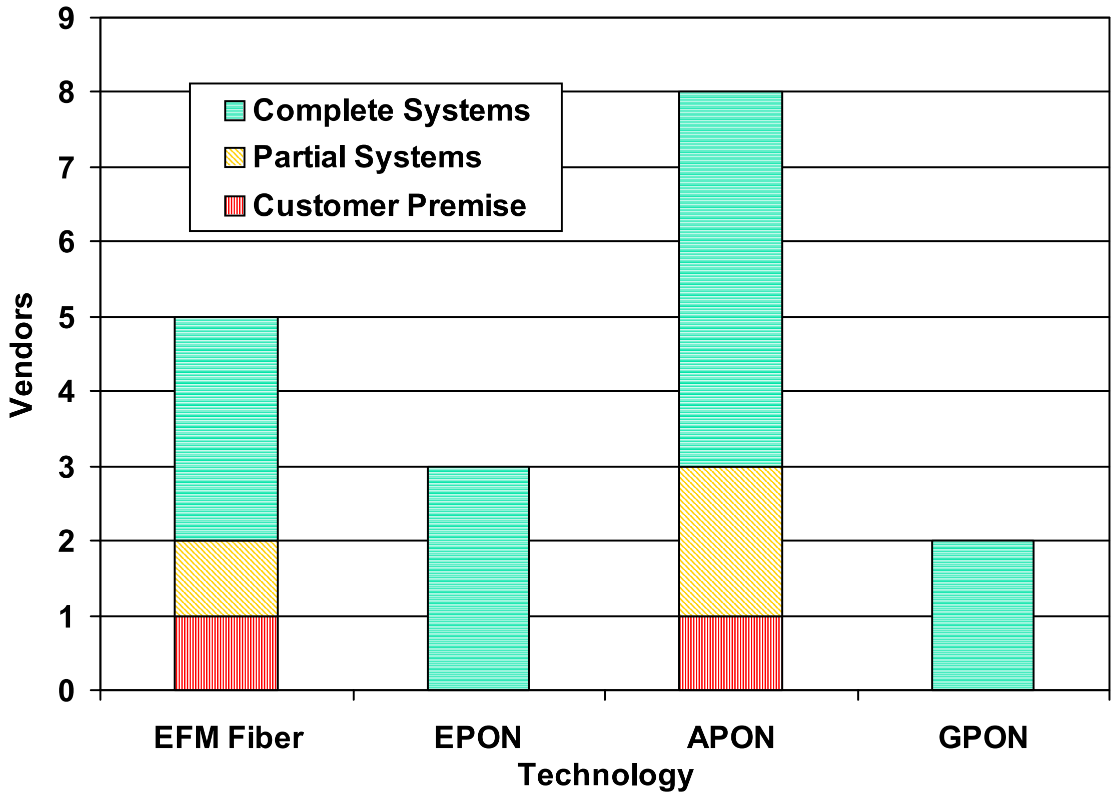


Figure 2.10: Vendor Breakdown

As shown in Figure 2.10, EFM has three complete system vendors. EPON also has three, however one places the OLT of its PON system at the remote node rather than in the central office. APON, with the most complete system vendors, has five. Most of these comply with the newer G.983.3 Recommendation for their transmission characteristics. GPON, the newest of the ITU PON standards, has two complete system vendors.

There are also five vendors that do not provide complete systems. APON and EFM both have a vendor that only provides customer premise equipment. The APON ONT vendor is developing its product line such that it should be compatible with any PON standard, however. EFM also has a vendor that provides remote node and customer premise equipment, but does not provide central office equipment. APON has a vendor that is currently only FTTBusiness, and one that runs a PON to the curb with some form of DSL to the home.

Vendors seem to be migrating to the newer standards over time. Only one of the currently marketed systems complies with the original APON standard (G.983.1) from 1998. Newly announced systems and next generation systems have moved on to G.983.3 or to GPON. The EFM vendors are moving away from ad-hoc use of current IEEE 802.3-compliant products to products specifically designed to meet IEEE 802.3ah. This process is causing the number of different transceiver possibilities to decrease slightly. For example, with equipment vendors moving away from G.983.1, transceivers that incorporate 1550 nm transmit and 1310 nm receive at the OLT are falling out of use. However, under G.983.3, 1550 nm is being used for broadcast video, as a result the ONT 1310 nm transmit and 1550 nm receive transceiver is still in use, though it now incorporates an additional 1490 nm receiver.

2.5 Patents

Patents can play an important role in the technology that dominates a particular market. A search was performed for fiber-to-the-home-related patents and for FPLD patents in the United States patent database at http://www.uspto.gov. The search yielded 656 fiber-to-the-home-related patents and 58 FPLD patents. A small number of patents are duplicated in the two lists, however, currently many of the FPLD patents do not specifically cite fiber-to-the-home as an application. Since it is unclear which, if any, of the current FPLD patents that do not reference fiber-to-the-home may be important in FPLD development for fiber-to-the-home applications, all found FPLD patents are included in this analysis. A complete list of the patents and details of the search terms used can be found in Appendix 4.

As shown in Table 2.2, the large patent holders in this area are the telecommunications companies that are currently active in the market for Internet infrastructure. The specific areas the fiber-to-the-home-related patents fall under most commonly are shown in Table 2.3. The patents most commonly are in the areas of optical communications, optical waveguides, and multiplex communications. Given that the patent holders seem to be the infrastructure component providers that coexist in today's market, there is no reason to expect that they will be a driving force for a dominant technology.

Table 2.2: Patent Holders with 10 or More Fiber-to-the-Home-Related Patents

Assignee	Patents
Lucent Technologies, Inc.	90
British Telecommunications	67
Alcatel	39
Fujitsu Limited	33
Nortel Networks Corporation	26
AT&T Bell Laboratories	24
NEC Corporation	22
AT&T Corp.	21
Siemens Aktiengesellschaft	15
Borden Chemicals, Inc.	13
Bell Atlantic Network Services, Inc.	12
Corning Incorporated	12
Sony Corporation	10
Telefonaktiebolaget LM Ericsson	10

Table 2.3: Most Common Patent Classes for Fiber-to-the-Home-Related Patents

Patents	Class Name and Number
253	398 Optical Communications
182	385 Optical Waveguides
147	370 Multiplex Communications
48	359 Optical: Systems And Elements
45	725 Interactive Video Distribution Systems
44	372 Coherent Light Generators
44	375 Pulse Or Digital Communications
27	379 Telephonic Communications

Unlike the fiber-to-the-home-related patents, there is no large difference in the number of FPLD patents held by any given company, as shown in Table 2.4. Seagate, at the top of the list, holds its patents for FPLDs in storage area networks. The FPLD patents fall primarily in the areas of Coherent Light Generators, Optical Waveguides, and Optical: Systems and Elements, as shown in Table 2.5.

The patent holders of FPLD patents are companies that currently participate in the component and telecommunications market. As with the fiber-to-the-home-related patent holders, there is no reason to believe that these companies and patents will be a driving force for technology convergence.

Table 2.4: Patent Holders with More Than One Fabry-Perot Laser Diode Patent

Assignee	Patents
Seagate Technology LLC	5
Accuwave Corporation	3
AT&T Bell Laboratories	3
British Telecommunications public limited company	3
International Business Machines Corporation	3
Iolon, Inc.	3
Lucent Technologies Inc.	3
New Focus, Inc.	3
E-Tek Dynamics, Inc.	2
Eastman Kodak Company	2
Intel Corporation	2
Kwangju Institute of Science & Technology	2
Telefonaktiebolaget LM Ericsson	2
The Furukawa Electric Co., Ltd.	2

Table 2.5: Patent Classes Cited More Than Once in Fabry-Perot Laser Diode Patents

Patents	Class Name and Number
24	372 Coherent Light Generators
16	385 Optical Waveguides
14	359 Optical: Systems And Elements
6	369 Dynamic Information Storage Or Retrieval
5	356 Optics: Measuring And Testing
5	398 Optical Communications
4	250 Radiant Energy
2	257 Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)

2.6 Conclusions

Both the ITU and the IEEE are working to develop standards that don't conflict with one another. These standards are modifications of current standards, and the standards bodies are attempting to keep as much of the current standards intact as possible. The ITU standards seem to be geared towards the use of Fabry-Perot Laser Diodes (FPLD), at least at the customer premise. The IEEE seems to be considering transceivers with similar transmit characteristics. The extent of convergence in the standards is towards higher speed, more users, and the optical wavelengths used for downstream, upstream, and video transmission.

The standards contain a large variety of transceiver specifications. Equipment manufacturers appear to be keeping pace with the newer standards by developing equipment that complies. However the standards and equipment do not appear to be converging on any one type of system. Active equipment manufacturers are moving to support the higher speed active equipment standards. Passive equipment manufacturers are moving towards faster passive standards. Multiple vendors exist for EFM, APON, EPON, and GPON systems.

With the large number of transceivers specified by the various standards and the spread of vendor systems across those standards, the number of different standards specified transceivers for fiber-to-the-home is unlikely to decrease significantly over time. Concentrating effort on being able to manufacture a single transceiver for each wavelength at a reasonable price will help in achieving volume and economies of scale in an uncertain environment.

All transceivers require an extinction ratio of 10 dB and an operating distance of 20 km at speeds of 1 Gbps or less and a distance of 10 km at speeds greater than 1 Gbps. A single transceiver at 1310 nm would need a launch power of 9 dBm and a receiver sensitivity of -34.5 dBm. The single transceiver at 1410 nm would also require a launch power of 9 dBm with a receiver sensitivity of -33 dBm. These two transceivers would both require operating speeds of up to 2488 Mbps.

Manufacturing two transmitters at each of the data wavelengths is a more conservative approach, given that vendor migration to newer standards takes some time, and the standards for GPON operation at 2488 Mbps are not yet finalized. The analysis suggests that a 1310 nm transceiver at 4dBm operating at up to 1 Gbps could be used for APON, EPON, G.985, and EFM Fiber. The 9 dBm 1310 nm transmitter at up to 2488 Mbps would be for GPON systems. Since the GPON standards are still in flux, this would allow for more time to develop the higher powered transmitter. At 1490 nm, a 4 dBm transmitter could operate at up to 622 Mbps and the 9 dBm transmitter would be for operation from 1 Gbps up to 2488 Mbps. A 4 dBm 1490 nm transmitter operating at 1 Gbps could also meet the 1 Gbps EFM Fiber requirements and some of the 1 Gbps EPON requirements. Again, this would give more time to develop the higher power transmitter for GPON and make it easier to evolve the GPON device to meet the changing standards. The receiver sensitivities are the same as in the single transceiver approach.

For transceiver production volume, the best case scenario is the deployment of only EFM systems which require one transceiver at the OLT and one at the ONT for each user. For 64 users, 130 transceivers are required (128 for user service and two additional for the uplink between the remote node and the central office). However, even in this best case, the 64 transceivers at the ONT would have the opposite transmit and receive wavelengths from the 64 at the remote node. The worst-case scenario is a 1:64 split of the APON or GPON systems where one transceiver is required at the OLT for every 64 ONTs, thus resulting in 65 transceivers per PON. EPON falls very close to APON/GPON with a 1:16 split ratio, thus requiring 68 transceivers to support 64 users.

There appears to be no clear dominant technology from the standpoint of standards, vendor convergence, or patents. None of the fiber-to-the-home technologies specified by the standards have any natural advantage over any of the other fiber-to-the-home technologies. To account for this, the system dynamics model needs to allow for the ability to analyze any combination of types of technologies being deployed. For example, the ability to support a scenario where the RBOCs decided to all deploy GPON systems, or a scenario where a sudden change in public opinion makes everyone want to deploy an EFM system, or any combination in between.

Chapter 3: Technology Adopters

3.1 Introduction

The most common image of a technology adopter is the consumer that makes the decision to purchase one technology over another. However, in the case of a broadband technology such as fiber-to-the-home, infrastructure is required for the consumer device to be useful. A telephone is useless without a phone jack and the corresponding network to plug it into. A cellular telephone is useless without the cellular network to carry calls. For fiber-to-the-home to be a viable technology, the technology needs to be adopted by the microphotonics industry that makes the transceivers, the device manufacturers that build the hardware, the telecommunications company that builds the network, and then finally by the consumer that decides to subscribe to fiber-to-the-home rather than a competing service.

The microphotonics industry and device manufacturers were discussed in Chapter 2. This chapter covers the remaining pieces of the puzzle: the telecommunications company and the user. The factors influencing adoption are explored in the light of their implications on the system dynamics model.

3.2 Users

A user for the purposes of the model is defined as a household: a residential customer or a small office/home office. Dwellings with multiple households, such as apartment buildings or condos, are counted by the number of households in the dwelling. This method of counting corresponds to the definition of household used by the U.S. Census. Users react differently to incentives and have different motivations governing their desire for bandwidth. New applications may appear that require still more bandwidth. The World Wide Web was virtually unheard of and still primarily text-based in 1992. In 1993, the first multi-platform graphical browser was introduced. Only a year after that, Web traffic surpassed email traffic traversing the Internet (Merit Network Inc., 1995). Today, peer-to-peer applications for the transfer of music and movies seem to be the new bandwidth-demanding application.

Household computer ownership and Internet access are part of the data gathered by the U.S Census Bureau's Current Population Survey. Computer ownership data collection began in the 1984 survey, and Internet access was added in 1997 (National Telecommunications and Information Administration, 2004; Newburger, 2001). Results from the 1984 through 2003 surveys are summarized in Figure 3.1. Computer ownership is used as an upper bound for home Internet access, since few households have Internet access in the home but do not have a computer.

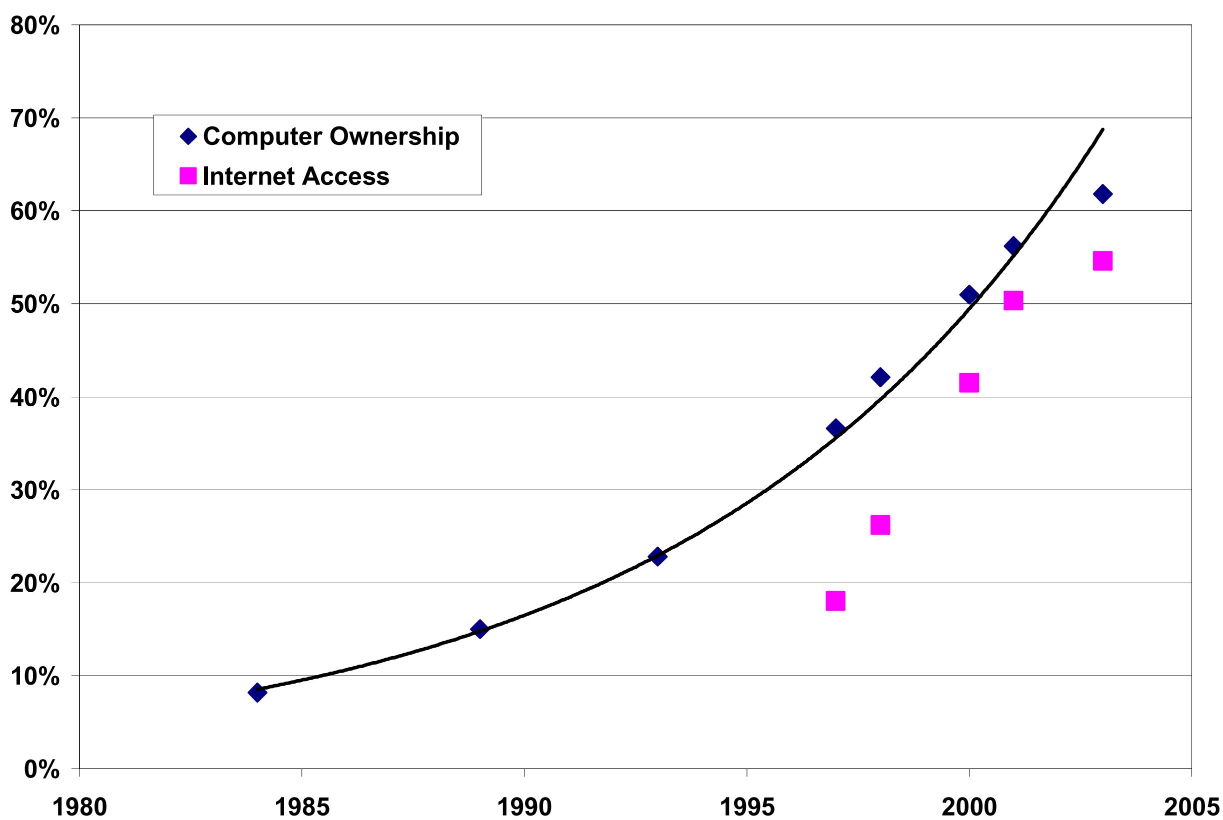


Figure 3.1: Percent of Household Computer Ownership and Internet Access

The growth rate of residential computer ownership is beginning to slow as the market saturates. The computer ownership data can be fit with an exponential growth curve with an R^2 of .9948. The 2003 data point lies off the trend line at a slower growth rate. It is expected that Internet access will follow a similar S-shaped growth trend, bounded by computer ownership.

S-shaped growth curves represent markets that have physical limits to their growth and cannot grow without bound. For example, in population growth studies, the limit to growth is typically the carrying capacity of the land. In the case of the Internet market, the model assumes that households will typically only have one Internet connection and a household will not have an Internet connection if it does not have a computer. The Census population survey tracks whether a household has at least one computer, so the percentage of household computer ownership from the survey provides a good approximation for Internet carrying capacity in the population of U.S. households.

The U.S. Census data includes any form of Internet access, and up until 2000, did not differentiate between broadband and dialup access. The most recent data from the 2003 survey show 20% of Internet connected households as having broadband access. Internet connected households represent 55% of the 2003 survey total households (National Telecommunications and Information Administration, 2004). Detailed broadband growth data comes from the FCC's monitoring of the adoption of advanced telecommunications capabilities by households. The FCC uses telecommunication carrier information on the number of deployed advanced services lines. As illustrated in Figure 3.2 (logarithmic scale), the number of users is currently growing exponentially, with fiber service trailing behind other forms of residential broadband.

The FCC considers small office and home office users sufficiently similar to residential subscribers in their usage and adoption patterns that they are tracked together as the growth of residential and small business advanced services lines and are not further broken down. Thus, the model considers both residential and small office/home office subscribers together and does not explore drivers that are specific to small business subscribers.

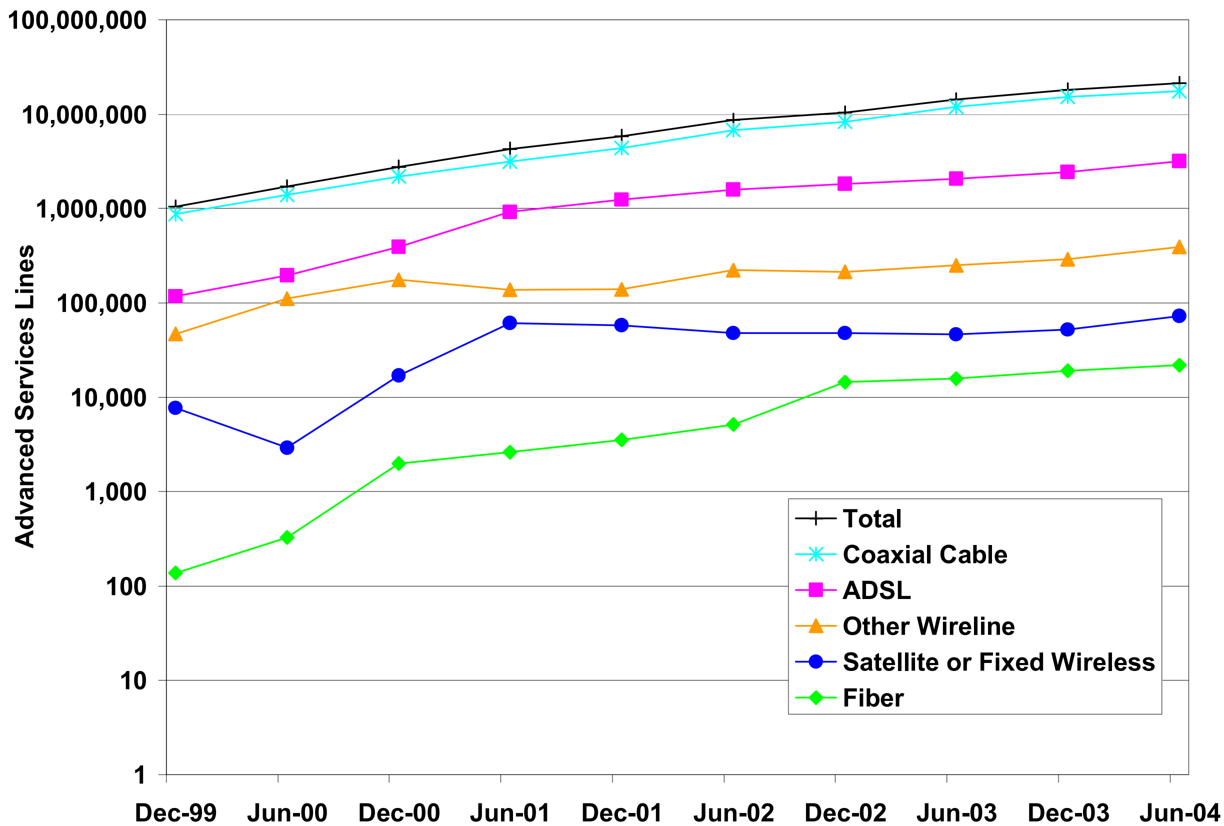


Figure 3.2: User Adoption of Advanced Services Technologies

3.2.1 User Drivers

Two conditions have to be met before a user can adopt any service. First, the service has to exist in the user's particular geographical area. Second, the user has to know about the service and have some reason to want it. If service is not available in a particular area, the user cannot adopt it. While it can be argued that satellite service is available in the majority of locations, it is not a true substitute for users that want to use interactive services, such as online gaming, or host their own web sites due to the latency (Borin, 2004). Users can hear about broadband Internet service through advertising from the local service provider, and also through word of mouth from users that already have the service, both in their area (neighbors) and those outside of their area (coworkers, friends and relatives that live in other communities). Advertising can be used to make people aware that the service is now available in their region, and start the adoption process which can then be carried through word of mouth.

Once the conditions are met, user adoption is primarily driven by price, with 63% of dial-up households in a 2002 Yankee Group survey indicating they had not subscribed to broadband services yet because it was too expensive (Ainscough, 2003). Interestingly, the survey data, shown in Table 3.1 indicates that price sensitivity declines for users that have a desired content that is better accessed via broadband services – in this case, the downloading of music.

Table 3.1: Price for Dial-up Households to Switch to Broadband (Ainscough, 2003)

Monthly Fee	Dial-up Households	Music Downloaders	Households with Children
$50	16%	16%	16%
$40	25%	33%	38%
$35	30%	43%	38%
$30	35%	56%	38%

3.3 Service Providers

The Telecommunications Act of 1996 mandated the FCC to monitor deployment of advanced telecommunications services. As part of its effort, the FCC collects data every six months on the number of high speed providers per zip code across the country, including Washington, D.C., and Puerto Rico. As defined by the FCC, a high-speed service provider provides access at speeds of at least 200 kbps in one direction to its customers. Figure 3.3 shows the spread of high-speed service providers over time across the United States. As shown in the figure, the number of zip code regions with at least one service provider has been growing fairly rapidly. The graph suggests that currently fewer than 10% of zip code regions across the United States do not have broadband service. Since this research is interested in the provision of advanced services, defined by the FCC as providing at least 200kbps in both the upstream and downstream to a customer, the FCC data is a poor estimate for residential service availability. The FCC data overestimates the availability of high-speed service because a provider can list itself as providing high-speed service to an entire zip code as long as it has at least one customer receiving high-speed service in the zip code.

The FCC data on service providers can be used to illustrate the link between the growth of availability of the service and the growth of subscribers. Figure 3.4 shows the growth rate of residential advanced services lines and providers over the six month sample intervals from December 1999 through June 2004. To help account for the overestimation in the zip code data, the figure includes the growth rates for both one or more and two or more service providers in a zip code. Again, the service provider does not have to be providing residential service to claim that it is offering high-speed service to customers, so this data is also an approximation.

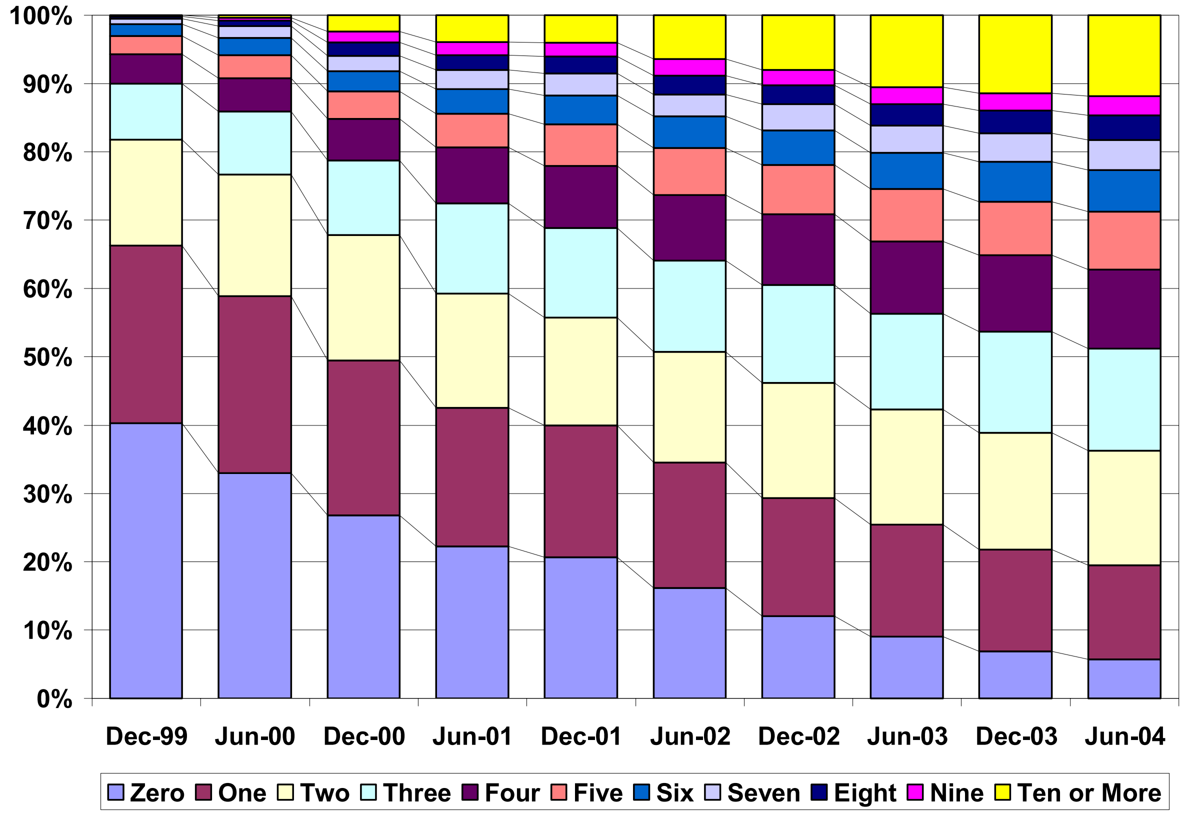


Figure 3.3: Percent of Zip Codes with Number of Service Providers

Figure 3.4 shows that growth rates of residential advanced services subscribers seem to track the growth rate of provider deployment of service, and both are slowing. When service was first deployed, the growth rate of subscribers was high, since there was latent demand due to lack of service availability. While latent demand still exists, the rate of service deployment has slowed and so has the growth rate in subscriber adoption.

To obtain a more accurate representation of the availability of residential advanced services, a different data set was constructed and is described in the remainder of this chapter. The data set addresses the most common type of advanced service provision as shown in the breakdown of types of residential advanced services lines of Figure 3.2: DSL and cable modem service. The following sections will first address the construction of the DSL portion of the data set and then the cable modem service portion of the data set.

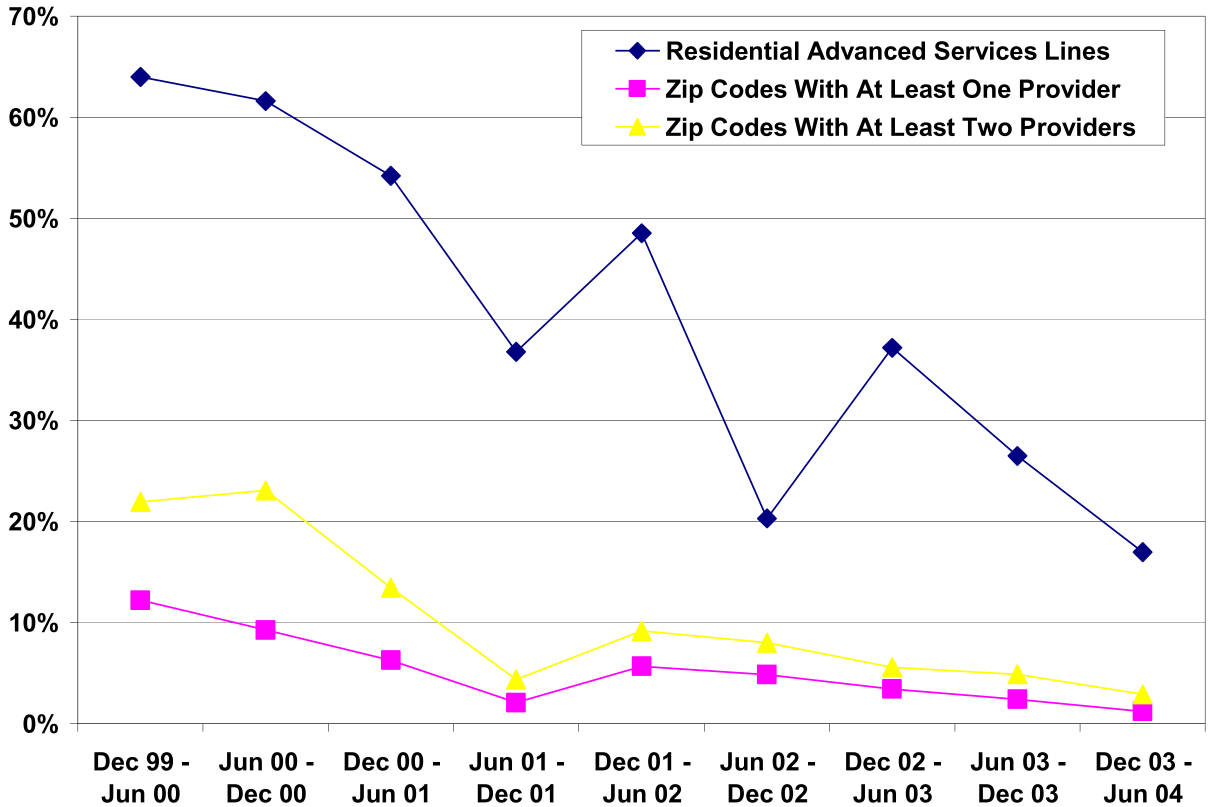


Figure 3.4: Growth Rate of Residential Lines and Service Providers

3.3.1 DSL Adoption

DSL is a technology that operates over the telephone company's existing copper plant. The providers of primary interest in this study are those that own their own physical wiring infrastructure, which includes the local loop wiring from the central office to the subscriber. For the purposes of DSL current deployment statistics, all providers that provide DSL service, whether they own all of the local infrastructure or lease lines and provide only the electronics, are considered.

An entire alphabet soup of companies are currently in the business of providing DSL service, these include: the former Bell companies, known as RBOCs (Regional Bell Operating Companies); competitive providers known as CLECs (Competitive Local Exchange Carriers) or CAPs (Competitive Access Providers); and other local exchange carriers, known as ICOs (Independent telephone COmpanies) if they are the primary carrier in a region without an RBOC. To add to the confusion, both ICOs and RBOCs are also referred to as ILECs (Incumbent Local Exchange Carriers). In this document, the term ILEC is used when referring to both RBOCs and ICOs.

The most commonly deployed form of the technology to residential subscribers is ADSL (Asymmetric Digital Subscriber Line). ADSL provides service at a downstream rate of 1.544 Mbps at distances up to 18,000 feet from the aggregation point called a DSLAM (Digital Subscriber Line Access Multiplexer). The upstream data rates vary from 16 kbps to 768 kbps.

The reach of the service is dependent on the age and condition of the existing copper wires. Providers sometimes replace failing copper in the access network with fiber. The installation of this fiber in the subscriber loop prevents DSL service from being provided beyond the fiber splice point. In order to provide DSL service beyond this point, the service provider would need to install a DSLAM at the end of the fiber. These splice locations may not always be at points where it is convenient to place electronic equipment that needs to have power and be climate controlled. The presence of loading coils in the local loop can also make the provision of DSL service to customers on the other side of the loading coil impossible. Loading coils are used to boost voice quality on phone lines by filtering out high frequency signals. They are frequently found in rural areas where the loop from the subscriber to the central office is long enough to cause the signal to deteriorate. Unfortunately the high frequency signals are necessary for DSL service. Even though DSL subscribership is growing, many households may find themselves in locations that are either too far from the central office or in locations where the condition of the local loop plant makes DSL service unavailable.

The newest DSL technology is VDSL (Very High Speed Digital Subscriber Line), which promises to deliver asymmetric speeds of up to 52 Mbps downstream and 6 Mbps upstream, or symmetric speeds of 26 Mbps (International Engineering Consortium). Unfortunately the technology is distance limited and the maximum speeds can only be achieved up to a distance of 1000 feet. Longer distances result in a reduction in speed. At these data rates, VDSL enables services such as digital broadcast video or video on demand. For comparison, a single HDTV channel requires 19.4 Mbps (Advanced Television Systems Committee, 2004). Being able to provide video over their networks would allow ILECs to better compete with cable companies for the provision of multimedia services.

A data set of DSL service availability by community and type of provider was developed for this research. A list of communities along with select demographic data (land area, housing units, and population) was obtained from the 2000 U.S. Census Gazetteer (U.S. Bureau of the Census, 2000) and a list of states, area codes, exchanges and their associated providers, rate centers, and switch identifiers[3] was obtained from the North American Numbering Plan Association in August 2004 (North American Numbering Plan Association, 2004).

[3] Switch identifier codes are known as CLLIs (Common Language Location Identification) and specify an individual switch in a central office. The identifier is eleven characters long. The shortened version of a CLLI is a

Census Place data include all areas that have a concentrated population with a clear center of population. This includes all incorporated places, consolidated cities, independent cities, and census designated places. Incorporated places in the listing are those that existed under state law as of January 1, 2000. Consolidated cities are places in which the city and county or county equivalent government functions have merged. Independent cities are incorporated places that are not part of a county. Census designated places (CDP) are non-incorporated places that have a clear concentration of population, housing, and businesses. CDPs are delineated in cooperation with state and local government.

Rate centers are the geographic areas used by exchange carriers to assign phone numbers and set boundaries for billing rates. DSL information for rate centers is linked to the Census list of communities to provide information on whether a given community has DSL service in the entire community, partial service, or no service at all.

The NANPA data for the United States consist of 139,065 area code/exchange entries. The data include all categories of providers of some form of exchange service, including interexchange carriers and wireless providers. Using data from telcodata.us (Timmins, personal communication, August 2004), the entries for wireless, PCS, wireless resellers, and interexchange carriers were removed. Also removed were any entries for which rate center or provider information was blank. This left 83,328 entries. The switch identifiers were shortened from eleven characters to eight to obtain the central office identifier codes, since DSL data is only available on the central office level, and the area code and exchange information was removed. After elimination of duplicate entries due to the aggregation, 49,741 unique entries and 23,293 unique central office codes remained.

The central office codes were then searched for on dslreports.com (broadbandreports.com, 2004), a site that tracks DSL availability by telephone exchange. Of the 23,293 entries, 1680 were not found and lines associated with those central offices were removed. The central offices were then aggregated by rate center and a count of the central offices with and without DSL service was produced for each rate center. The result was a listing of 18,403 rate centers, the number of central offices associated with those rate centers that do and do not have DSL service, the state the rate center is in, and the providers associated with that rate center.

In order to obtain an accurate representation of DSL service availability, competitive providers that did not provide any DSL service in a rate center were not counted against that rate center. The overriding assumption was that if the incumbent carrier was providing DSL service in all the central offices associated with a rate center, a household in the rate center could obtain

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CLLI8 (the first eight characters of a CLLI) which is the identification code for a central office location and will be the same for all switches in a particular central office.

DSL service and the competitive provider was simply a competitive telephony provider. The data revealed 1,131 rate centers where only a competitive carrier, and not the incumbent, was providing DSL service. These 1,131 rate centers were coded as not having service, since the research is focusing on the likelihood of fiber builds by incumbent carriers. For modeling purposes, this suggests that the model should track the cost of deploying fiber-to-the-home by a competitive carrier. The end result of the coding of the rate centers is shown in Table 3.2. Rate centers were coded as either having service, having partial service, or having no service. Having service means all central offices in the rate center could provide DSL service; having partial service means that only some central offices in the rate center were DSL capable; and having no service means that none of the central offices in the rate center could providing DSL service.

Table 3.2: DSL Service Breakdown

Total Rate Centers	DSL Service	Partial Service	No Service
18,403	4,815	1,659	11,929

For large incumbent carriers such as the RBOCs, rate centers are geographic areas with more than 20,000 people. Smaller communities that are served by RBOCs are not individually listed, so the DSL data will provide a more accurate representation of service for larger communities than it does for smaller ones.

First, all rate centers having service and having partial service were matched to the Census Places data. Unfortunately, since NANPA rate centers are 10 character abbreviations for geographic areas, directly matching the rate centers to Census Places yielded many rate centers that did not match. The matching results can be found in Table 3.3. As can be seen in the table, about 60% of the rate centers matched Census Place names directly.

Table 3.3: Rate Center to Census Places Matching

	Total Rate Centers	DSL Service	Partial Service
Direct Match	3,895	2,864	1,031
Coded Match	1,366*	1,081	306
Original Breakdown	18,403	4,815	1,659

*The coding method resulted in 21 overlaps

The remaining rate centers that did not match directly were matched with the Soundex algorithm (Knuth, 1998), as implemented in perl's Text::Soundex (Stok, 2003), and then checked by hand. The results are the "coded matches" in Table 3.3. There were 1,192 rate centers for which no matching Census Place names could be found. As mentioned in the table, there were

21 rate centers that overlapped and were coded as both having DSL service and having partial DSL service. These overlaps come from the expansion of large urban center exchange data into community names. Many communities that are served by central offices in urban centers seem to be served by multiple central offices. In many cases, exchanges serve customers in more than one community, thus there is some ambiguity in which communities are served by a given central office, especially in urban centers. To account for this ambiguity and not arbitrarily assign any particular community to a yes or partial category, two data files were developed. One that coded these 21 as yes entries, called the 'generous' file, and the other coded these entries as having partial service, called the 'stingy' file. These two files represent upper and lower bounds for the adoption of DSL service by telecommunications carriers.

3.3.2 Cable Companies

Cable modem service, as shown in the FCC data of Figure 3.2, is the most prevalent form of residential broadband connection. Currently the maximum raw data rate of the downstream connection is 40 Mbps and 10 Mbps for the upstream connection (Cable Television Laboratories Inc., 2003). Unlike DSL, which runs over dedicated pairs to the subscriber, cable modem service runs over an RF channel on coaxial cable that is shared amongst neighborhoods of subscribers. This means that residential customers are typically allocated downstream speeds of 3 Mbps and 384 kbps in the upstream. Cable modem services' newest standard, DOCSIS 2.0 (Cable Television Laboratories Inc., 2004) is capable of a raw data rate of 40 Mbps in the downstream and 30 Mbps in the upstream. The 2.0 specification essentially creates a network with symmetric downstream and upstream transmission speeds. Again, due to the broadcast nature of the system, this bandwidth will typically be shared.

Since cable providers already have the ability to provide multimedia services, such as a form of video on demand, via their cable networks, they are unlikely candidates for building a complete fiber network any time in the near term. Also, with the deployment of equipment meeting the DOCSIS 2.0 standard, cable companies will be able to better compete with any potential symmetric bandwidth offerings of other telecommunications providers. The model tracks the deployment of cable modem service, and continued growth in that service, but does not consider cable companies as potential implementers of fiber-to-the-home.

In order to incorporate the cable data into the DSL datasets, a column was added to both the generous and stingy files. The data for cable service came from the Television & Cable Factbook Online in August 2004 (Warren Communications News Inc., 2004). The Factbook contains information on which communities are served by any particular cable system, whether that system provides Internet service or has plans to provide Internet service, and in some cases the monthly cost of service, one-time connection fee, and modem rental fees.

Similar to the NANPA data, the Factbook data is somewhat difficult to match to the Census Places data and has overlapping entries. The listings for a given community typically contain entries for other communities that a particular cable system "also serves." Internet service data is by cable system, and it is not entirely clear if all communities that are listed in the also serves section also have Internet service. Some communities have multiple providers, and some of those providers provide Internet service and other do not. The listings also do not clearly show if a community is fully covered by a particular provider, or only partially. Many listings also contain parts of counties that are served, not including incorporated areas, thus there are more service areas listed than there are Census Places. To overcome the limitations of the data, a similar practice to that used for the DSL data was employed. For the generous dataset all of the yes entries were matched first, followed by the planned entries. For the stingy dataset, all of the plan entries were matched first followed by the yes entries.

Table 3.4: Cable Modem Service Breakdown

	Total Cable Areas	Service	Planned
Matches	12,397*	11,433	1,021
Original Breakdown	21,526	19,893	1,633

*57 matches overlapped

The Factbook returned 3,116 entries for systems providing Internet service and 846 entries for systems planning Internet service. Pulling out all of the geographic areas associated with the entries yielded 19,893 areas with Internet service, and 1,633 planning service. The resulting yes and planned lists had an overlap of 162 geographical areas. The totals yield an average of six areas for a provider that has Internet service available, and an average of two areas for providers that are planning service. It is unsurprising that the larger providers are those that are already providing Internet service in regions, since the provision of service requires a substantial infrastructure investment. The FCC entered into 'social contracts' with larger providers from 1995 through 1997 to establish specific requirements for network upgrades. The contracts required providers to upgrade their system capacity to at least 550 MHz on the majority of their systems and ensure that at least 50% of their subscribers were served by systems with at least 750 MHz transmission capacity (Federal Communications Commission, 2000). These higher transmission capacities allow the providers to better provide two-way services without sacrificing capacity for existing video services.

3.3.3 Cable and DSL Provider Adoption Comparisons

As can be seen in Table 3.5, cable modem service has penetrated to nearly 50% of the 25,150 geographic areas in the Census Places file while complete DSL service only exists in 21% of places. This is a far cry from the Federal Communications Commissions estimate of greater than 90% of U.S. zip codes having some form of advanced services (Federal Communications Commission, 2004a). Interestingly, the cable availability estimate obtained from the data is similar to the FCC's estimate for areas which have four or more providers offering advanced services. Zip codes are not a direct analog for cities, and more populous areas tend to have more zip codes, however the census data is also biased towards larger populations. Areas for which there are both a Census designated place and an incorporated place of the same name are both counted as having service if the place name is found to have service. This assumption is reasonable because the census designated place with an identical name to an incorporated place is typically an unincorporated surrounding area. The drastic difference between the penetration numbers found here and those cited by the FCC call into question the use of zip codes and the user of a single provider providing service to a single customer to track broadband penetration.

Table 3.5: DSL and Cable Modem Service in Places

	DSL	Cable Modem
Service	3,945	11,433
Partial/Planned	1,337	1,021
Totals*	5,261	12,397
Percent of Places	21%	49%

*neglecting overlapping entries

If the Census Places that have cable and DSL are different places, then the penetration of broadband services approaches 71%. Table 3.6 explores this possibility using the generous data file, where any overlaps between areas with complete DSL coverage and partial coverage are coded as having complete coverage and any areas with cable service and planned service are coded as having service. Nearly 75% of the areas that have DSL service also have cable service. The remaining places with DSL service and without cable service make up a tiny fraction of the total census places, i.e. 4%. This suggests that the source of the discrepancy between the census estimate and the data calculated here is not due to cable and DSL service being deployed to different places with little overlap.

Table 3.6: Cable and DSL Service Overlap (Generous)

	With DSL	Partial DSL	With Cable	Cable Plan
DSL Places	100%	0	74%	3%
Partial DSL	0	100%	63%	4%
Cable Places	25%	7%	100%	0
Cable Plan	14%	6%	0	100%

Table 3.6 also shows that cable service is expanding into areas that do not already have DSL service, as show by the cable planned service data. If the partial DSL data can be considered expanding of service, then DSL is expanding primarily into regions already served by cable.

3.4 Municipalities and Rural Local Exchange Carriers

Municipalities and Rural Local Exchange Carriers (RLECs or Rural LECs) are considered together because they have a common characteristic: they have an interest in the economic prosperity of the area they serve and can be swayed by local interests (American Public Power Association, 2004a).

Municipalities for the purposes of the research are those areas that have a publicly-owned utility. In many cases these areas have been left behind by commercial deployments and are exploring their own broadband deployment via their municipal electric utility. A listing of 1,815 municipalities with municipal electric utilities and their associated demographic characteristics was obtained from a research project at the Massachusetts Institute of Technology (Osorio Urzua, 2004).

When the list of municipalities is merged with the Census Places data, an additional five places are added to the listing. These five places are census designated places with the same name as the municipality in the immediately surrounding regions. As shown in Table 3.7, municipalities are well ahead of the general population, with 66% of the communities either with cable service or planning service, compare to the general population's 49%. Municipalities are also well ahead in DSL deployment, with 39% having either complete or partial DSL service, compared to 21% in the general population.

Table 3.7: Percent Cable and DSL Service in Municipalities

	Cable	DSL	Cable Plan	Partial DSL
Generous	61%	29%	5.5%	10%
Stingy	61%	29%	6.0%	10%

Comparing cable and DSL availability to determine how many communities have both forms of broadband service results in Table 3.8. Examining the table shows that 128 of the places that have DSL service do not have cable modem service. Unlike in the general population case where the areas that have DSL but do not have cable represent only 4% of the total population, the 128 municipalities represent 7% of the total number of municipalities. This results in 1,129 municipalities with either cable or DSL broadband service, or 68% of the total communities.

Table 3.8 also shows that the expansion of cable and DSL in municipalities is following a trend nearly identical to that of the general population. Cable service is expanding primarily into regions that do not have DSL service, and 23% of the expansion is into areas that already have DSL service. From the partial DSL data, DSL is expanding primarily into regions already served by cable similar to the trend seen in Table 3.6.

Table 3.8: Municipal Cable and DSL Service Overlap (Generous)

	With DSL	Partial DSL	With Cable	Cable Plan
DSL Places	100%	0	76%	4.4%
Partial DSL	0	100%	71%	4.4%
Cable Places	36%	12%	100%	0
Cable Plan	23%	7.9%	0	100%

Since a listing of rural local exchange carriers was unavailable, the research assumes that any area that meets a combination of the United States Department of Agriculture (USDA) Rural Utilities Service (RUS) eligibility requirements and the FCC's small town definition is served by a rural local exchange carrier. Under the USDA RUS funding requirements, a rural community may have no more than 20,000 inhabitants. Since this would also include the census designated places that are immediately adjacent to urban centers, the FCC designation that a small town is in the 25th to 75th population density percentile is also used. For the purposes of this research, a community that is served by a rural local exchange carrier has no more than 20,000 inhabitants and is below the 75th percentile in population density. This works out to a housing density of at most 735 households per square mile.

3.5 The Demographics of Service

A look at service provision that neglects the demographics of the areas masks any disparity in service that might exist between urban, suburban, and rural communities. This section explores service availability by demographic region for several possible definitions of urban, suburban, and rural.

Since cost information for fiber-to-the-home infrastructure comes from the CMU model, the first look at service availability by region is done using those definitions. In the CMU model, urban regions have housing densities greater than 2000 households per square mile, suburban regions have at least 500 and no more than 2000 households per square mile, and rural regions have fewer than 500 households per square mile. The service breakdown obtained from these density classifications are shown in Table 3.9. The table shows that service availability is dependent on the type of community. Urban and suburban communities have service availability that is higher than the 51% shown in Table 3.5, while rural regions are less likely to have service available to them than the nationwide average. The table also shows that there is no significant difference between service availability resulting from the different coding method used for the generous and stingy data file.

Table 3.9: Breakdown of Places and Percent Service Based on Housing Density

			Percent Service	
	Places	**Average Households**	**Generous**	**Stingy**
Urban	1121	17868	75%	75%
Suburban	9223	5407	65%	65%
Rural	14806	995	38%	38%

The CMU breakdown differs slightly from the rural classification given by RUS and the FCC which defines a rural community, or small town, as one having a population of no more than 20,000 and a population density below the 75th percentile. Since this work deals primarily with households and housing density, the model assumes that RUS would be willing to fund communities that have a housing density that is below the 75th percentile, or no more than 735 households per square mile. The classification scheme adjusted to match this definition results in the service breakdown shown in Table 3.10. The new classification scheme moves 3,763 communities from a classification of suburban to rural, and additionally moves 251 rural communities into the suburban category, for having a population of greater than 20,000 people. Again, there is no significant difference between the generous and stingy coding schemes.

Table 3.10: Service Breakdown (FCC and RUS Rural Definition)

			Percent Service	
	Places	**Average Households**	**Generous**	**Stingy**
Urban	1121	17868	75%	75%
Suburban	5711	8590	73%	73%
Rural	18318	848	41%	41%

Table 3.11 shows a breakdown of municipalities into urban, suburban, and rural communities using the FCC and RUS definition for rural. As can be seen in the table, municipalities have greater service availability in all categories, and not just in the general population. Again there is no significant difference in availability due to the generous and stingy coding schemes.

Table 3.11: Service Breakdown for Municipalities (FCC and RUS Rural Definition)

		Percent Service	
	Places	**Generous**	**Stingy**
Urban	31	97%	97%
Suburban	529	85%	84%
Rural	1260	60%	60%

Since municipalities have far greater service availability, and will in some cases be treated separately in the model, Table 3.12 looks at service availability for the population with municipalities removed. There is a slight decrease in suburban availability from 73% to 72% and a slightly larger decrease in rural availability from 41% to 39%. Since the model assumes that RUS is willing to fund all deployments that meet its classification of rural, municipal rural communities are tracked with the general population so this availability difference can be neglected. The change in availability in suburban communities with and without municipalities is sufficiently small that it will be neglected for runs of the model where municipal deployments are merged with the general population. The model bases its initial values on the generous coding scheme, since no significant difference in availability was found due to the generous and stingy coding schemes. More mode implementation details can be found in Chapter 5.

Table 3.12: Non-Municipal Service Breakdown (FCC and RUS Rural Definition)

		Percent Service	
	Places	**Generous**	**Stingy**
Urban	1090	75%	75%
Suburban	5182	72%	72%
Rural	17058	39%	39%

3.6 Summary

This chapter has focused on the remaining two adopters of broadband technology: residential customers and service providers. Residential customers are adopting broadband technology, but their adoption rate is slowing, limited by both the availability of the technology and also by computer ownership. There is latent demand in regions that do not yet have broadband where people are already familiar with the technology and the available content. Residential customers are primarily price sensitive, but that sensitivity is tempered somewhat if the customer has found an application or content that is better served via broadband than dialup, e.g. music downloading.

The FCC's data on broadband availability seems to drastically overestimate the availability of broadband service. A data set was developed to map cable and DSL service availability as of August 2004 to Places defined by the Census Bureau in the 2000 U.S. Census. This data set, along with the FCC data on broadband subscribership, is used as a starting point for broadband availability in the fiber-to-the-home system dynamics model.

Table 3.13 and Table 3.14 show the results of the service availability analysis along with the details of the demographics of the various regions. As shown in the tables, rural communities are less likely to have service available than their urban and suburban counterparts. Also, communities with municipally owned public utilities are far more likely to have service than their urban, suburban, and rural counterparts in the general population. The census data and the availability analysis likely underestimate the availability of service in urban regions. In many areas there are densely populated non-incorporated communities surrounding city centers that are considered separate places by the census. These places are not found separately listed in the DSL or cable data, but are considered part of the urban region.

Table 3.13: Demographic Breakdown and Service Percentages

	Number	Average Households	Percent Service
Urban	1,121	17868	75%
Suburban	5,711	8590	73%
Rural	18,318	848	41%

Table 3.14: Municipal Demographic Breakdown and Service Percentage

	Number	Percent Service
Urban	31	97%
Suburban	529	85%
Rural	1260	60%

Many different service providers for broadband exist, including traditional telecommunications carriers, from large regional Bell companies to small rural independents, competitive carriers, cable operators, and municipalities. All of these potential providers are currently deploying broadband, though on different scales. Cable modem service has the largest penetration in terms of both number of customers and regions in which service is available. DSL service provided by various telecommunications companies is a distant second. DSL service is distance limited and even in its newest form of VDSL has difficulty competing with cable companies in the distribution of multimedia content. Thus traditional telecommunications companies are good candidates for the deployment of fiber-to-the-home while cable companies are not.

Municipalities and rural local exchange carriers are also deploying broadband. These two types of providers share the characteristic of being closely tied to the economic prosperity of the community that they serve. They are influenced by the needs of the community and have an incentive to provide broadband service in areas that have been left behind by traditional deployments. These types of providers are also good candidates for fiber-to-the-home deployment.

Chapter 4: Regulatory Effects

The telecommunications industry has a long history of consolidation and divestiture cycles. These cycles are coupled with regulatory interactions that have led to the tangled mess of dynamics within the industry that we have today. The provision of broadband service is not free from this tangle.

Broadband service provided by traditional telecommunications providers, such as the Regional Bell Operating Companies, is federally regulated in order to help promote competition. Cable companies that provide broadband are not federally regulated, and in many cases, have monopolies for providing cable service, and also cable broadband service, to particular communities or regions.

Government can be involved in the deployment of broadband at many different levels. This chapter explores the history of telecommunications regulation, regulatory policies that have been tried, current policies, and emerging policies. Some discussion of potential policies that can be applied in the system dynamics model is also included.

4.1 A Brief History

AT&T provides an excellent example of the ups and downs of the industry. In its early days, from 1876 to 1894, AT&T was protected by the Bell patents. After those patents expired in the mid 1890s, AT&T aggressively bought out patents and competitors, until it had acquired nearly 80% of the national telephone system. In less than a decade, that market share dropped below 50%. In 1913, AT&T made a deal with the Justice Department to refrain from further territorial expansion through mergers and acquisitions and move to a goal of universal penetration in the territory it held. In 1919, AT&T's long distance wires were nationalized and turned over to the federal post office. The large rate hikes that followed resulted in the denationalization of AT&T less than a year later. AT&T became a protected common carrier in the 1930s, with regulations that protected it from both interstate and intrastate competition. In 1956, an anti-trust suit ended with AT&T agreeing to keep out of all businesses not directly related to telecommunications. In 1982, AT&T was under fire again and forced to divest itself of its regional operating companies. The restriction on AT&T's ability to participate in businesses not directly related to telecommunications was also lifted at this time (Neuman *et al.*, 1997).

After January 1, 1984, pursuant to the Modification of Final Judgment, the seven divested operating companies were: Ameritech, Bell Atlantic, BellSouth Telecommunications, NYNEX, Pacific Telesis, Southwestern Bell Telephone, and US West. Three larger independent companies also existed: GTE, Cincinnati Bell, and Southern New England Telephone (SNET). Since the 1984 divestiture there has been a great deal of merger and acquisition activity among these companies. In 1997 NYNEX was acquired by Bell Atlantic. In 1998 Southwestern Bell acquired Pacific Telesis and Ameritech and changed its name to SBC Communications. In 2000, Bell Atlantic merged with GTE forming Verizon. Also in 2000 SBC acquired SNET and US West merged into Qwest.

Today, of the ten larger local exchange carriers existing in 1984, the original seven divested RBOCs and three independent companies, only five remain: BellSouth, Cincinnati Bell, Qwest, SBC, and Verizon. BellSouth and Cincinnati Bell are the only two companies that have remained outside of the many mergers and acquisitions. In February, 2005, SBC announced acquisition plans for the long distance carrier, and its former parent company, AT&T. Qwest and Verizon are currently both bidding on the long distance carrier MCI.

The original plan to split long distance companies from local exchange companies in the hopes of promoting competition has resulted in four large regional companies providing both local and long distance service. AT&T went from a telecommunications giant that required government intervention to a company that is being acquired. However, the divestiture of AT&T was not the only interaction of government with the telecommunications industry. In 1996, Congress passed new legislation modifying the Telecommunications Act of 1934.

4.2 The Telecommunications Act of 1996 to the Present Day

Congress passed the Telecommunications Act of 1996 to promote competition and encourage rapid growth of new telecommunications technologies. One of the ways in which the

Act intended to promote competition was by requiring that incumbent carriers unbundle parts of their networks and provide access to these network elements to competitive carriers. The details of which network elements needed to be unbundled to promote competition were left with the FCC. Initially the FCC mandated that seven network elements needed to be unbundled for access to competitive carriers. These seven elements were: loops, including those for advanced telecommunications services; network interface devices; local circuit switching (except for large customers in urban centers); dedicated and shared transport; signaling and call-related databases; and, operations and support systems (Federal Communications Commission, 1999). The FCC also required incumbents to provide competitors access to combinations of loop, multiplexing/concentrating equipment, and dedicated transport. This combination is known as UNE-P (unbundled network element-platform).

In 1999, the FCC modified this list and removed operator services and directory assistance, and packet switching. The FCC deemed it unnecessary to unbundle packet switching, because incumbent carriers were already required to allow competitive carriers a limited form of access to their facilities. That access is to allow competitive carriers to install DSLAMs, which are terminating equipment for DSL lines, in their facilities (Federal Communications Commission, 1999). UNE-P unbundling requirements were left intact.

Unfortunately, this set of rules did not result in rapid growth in broadband deployment and equipment upgrade by incumbents. Incumbents were required to share the benefits of new installations and upgrades with their competitors, but were unable to share the associated risks of the investment. If the investment succeeded, both the incumbent and the competitor enjoyed the benefits, but if the investment failed, the incumbent was left to absorb the loss. Faced with this environment, incumbents chose not to invest (Federal Communications Commission, 2003a). Recognizing this problem, the FCC released its Triennial Review Order (Federal Communications Commission, 2003a), which removed the unbundling requirements for fiber-to-the-home loops. Under the Order, an incumbent is only required to unbundle fiber-to-the-home loops for narrowband service in areas where the copper loops have been retired. The effects of this Order on fiber-to-the-home deployment remain to be seen.

The Triennial Review Order also continued UNE-P, pending state review of whether or not the lack of unbundled circuit switching constituted impairment to new entry. In March of 2004, the D.C. Circuit Court of Appeals vacated the Order with respect to circuit switching. In response the FCC drafted a new set of rules eliminating the unbundled element of local circuit switching (Federal Communications Commission, 2004c). Since UNE-P requires the use of unbundled switching with the loop, port, and transport element, the new rules effectively eliminate UNE-P as well. The new rules establish a twelve month period for providers that serve customers via UNE-P to transition to a combination of unbundled loops and their own switching facilities or to resale.

4.3 UNE Pricing and Status

The price for unbundled network elements is set by state commissions through a pricing scheme called TELRIC (Total Element Long Run Incremental Cost) that was developed by the FCC. TELRIC pricing sets prices for unbundled network elements based on the cost today of building and operating an efficient facility (Federal Communications Commission, 2003c). This pricing method was chosen to send economic signals to competitive carriers and to help encourage their investment in competitive facilities. The FCC also felt that by using forward-looking costs they would not be discouraging incumbents from investing in upgrading of their facilities.

The rules for setting TELRIC pricing are so general that states have a lot of leeway in applying the efficiency standard when they calculate forward-looking costs. This has resulted in a nationwide number of elements weighted average UNE-P rate of $16.71 per month and a loop rate of $13.49 per month (Gregg, 2005). The range of UNE-P prices vary by state from $13.04 to $27.13. Loop prices vary from $8.49 to $23.98. Since UNE-P rates include switching, the switching costs for the estimate assume 1000 minutes of use per month. The loop rates are independent of minutes of use.

Over half of the lines served by competitive carriers are served via UNE-P. However, UNE-P type provisioning of service for competitive broadband is a very unlikely future scenario. The FCC is moving away from UNE-P as described in the previous section, and switching has never been an unbundled element for competitive broadband provision. Thus a hypothetical regulatory scenario worth exploring is unbundled loop and port costs for fiber-to-the-home.

Weighted average unbundled loop plus port costs for all states excluding Alaska and Hawaii and including the District of Columbia as of February 2005 were $15.68. Since fiber-to-the-home is a residential broadband solution, UNE loop and port costs are compared to customer weighted average residential rates. The weighted average residential rate for the same geographic region was $24.18 (Gregg, 2005). Thus unbundled network element loop and port costs represent about 65% of the monthly revenue that an incumbent would earn by selling the service to a residential customer.

4.4 Open Access

Open access is a frequently discussed method of providing competitive carriers an entry point into providing broadband service. Open access carries with it similar risks to those seen from the FCC's unbundling requirements but also presents difficulties associated with specific implementations of fiber-to-the-home.

Network topology plays a large role in the ease of implementing open access, or service based competition with companies providing competing services over the same infrastructure. The home run topology of Figure 4.1 is the easiest topology to implement open access over. The customer's fiber runs can simply be connected to their provider's equipment at the central office. Thus central office facilities are shared, but each provider can deploy the equipment of its choice. However, given that this topology is more expensive to deploy, it is not a primary candidate for fiber-to-the-home deployments that are underway today or expected in the near future.

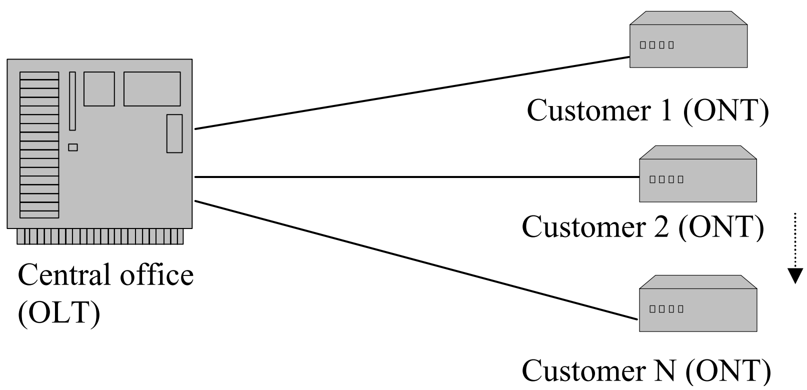

Figure 4.1: Home Run Topology

Instead many of the current and proposed future deployments are either active or passive star topologies. In an active star topology, such as that show in Figure 4.2, the feeder link is shared, but the distribution links are not since the active component at the remote node directs the signal to the appropriate customer. Open access with an active star topology would have to implement measures for dealing with contention for bandwidth over the feeder link.

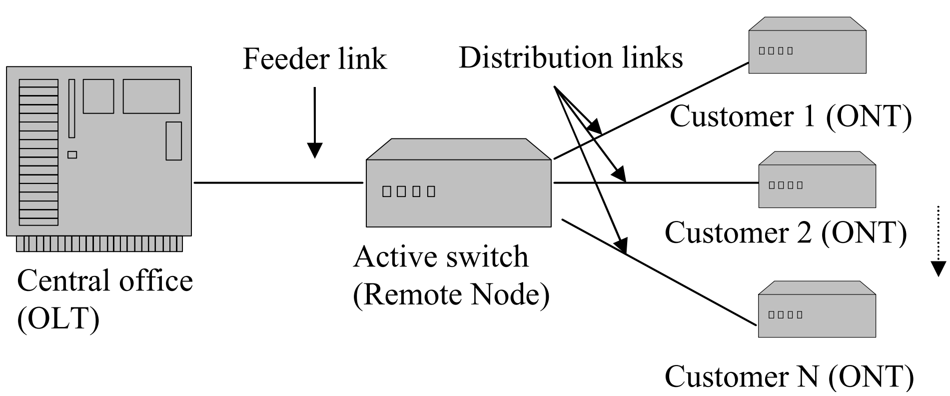

Figure 4.2: Active Optical Network

The passive star topology, such as that shown in Figure 4.3, is the most common proposed topology for current and near future fiber-to-the-home networks. In this topology, the feeder and distribution links are shared. Each customer link carries the downstream traffic of all the customers and customers must also contend for upstream bandwidth. Since the entire system is shared, implementing open access under this topology would require policies for traffic management to ensure that resources were managed efficiently between subscribers.

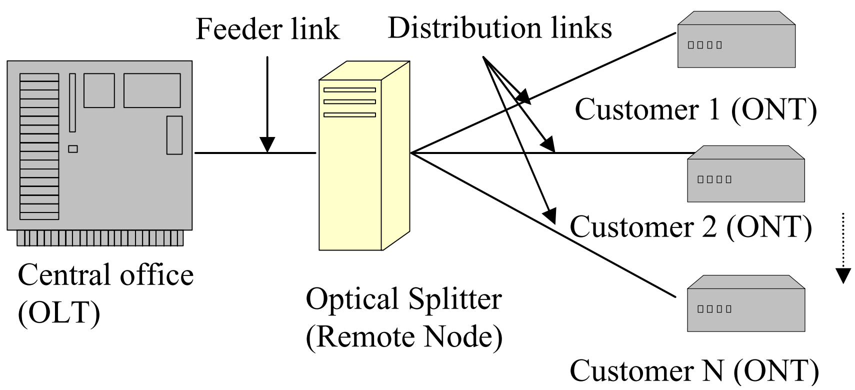

Figure 4.3: Passive Optical Network

4.4.1 Infrastructure Based Competition

Arguably, the FCC's elimination of circuit switching and UNE-P is a move towards encouraging CLECs to move towards infrastructure based competition. At the minimum level, CLECs would have to provide their own switching equipment collocated at facilities owned by incumbents. This brings the provision of local exchange service into line with the regulations that govern DSL service. In 1999, the FCC eliminated the unbundling of packet switching for DSL due to the existing provision that gave competitive carriers the ability to collocate their equipment in incumbents' facilities.

The hope of both the elimination of UNE-P and the requirement of facilities collocation was that competitive providers would use UNE-P and collocation as a stepping stone towards greater facilities-based provision. Facilities-based competition is considered the most desirable form of competition, since competitors do not have to rely on any of the incumbent's infrastructure to provide their service. The down side of facilities-based competition is that building a second parallel infrastructure is costly. For fiber-to-the-home facilities-based competition the competitor would have to lay all the fiber lines and build any remote facilities that would be required for service before it could begin offering service. It is not practical to wait until there is a customer order to start running fiber and putting a remote terminal in place. A full network build of this form is costly, and with two providers offering very similar services, the number of customers that each provider would be able to acquire would be smaller than in a situation with only one provider. The price that the provider would be required to charge the consumer to recover costs under a smaller market share may be prohibitive.

4.5 The Digital Divide

Several parts of the federal government recognize that there is a disparity between broadband availability in urban and rural areas. Building telecommunications networks in rural areas is costly and in many cases there is not a good commercial business case for rural deployments. Both the Rural Utilities Service (RUS) of the U.S. Department of Agriculture (USDA) and the National Telecommunications and Information Administration (NTIA) of the Department of Commerce have published reports on the difficulty of bringing broadband service to rural America and on the service disparity.

The 2004 NTIA report is based on the U.S. Census Bureau's Current Population Survey of 57,000 households from October 2003. According to the report, 24.7 percent of households in rural areas have broadband connections, compared to 40.4 percent in urban areas. Also 22.1 percent of dialup connected rural households site lack of availability as the reason they don't have broadband, as opposed to 4.7 percent of urban dialup subscribers (National Telecommunications and Information Administration, 2004).

In response to the lack of widespread rural deployment, the USDA RUS in 2003 began providing a low cost loan program to help finance rural broadband. The USDA provides these loans under the authority of the Farm Security and Rural Investment Act of 2002 which amended the Rural Electrification Act of 1936. For 2005, no less than $2.157 billion in loans is available (Marchiori, 2005).

RUS requires that a service provide 200 kbps in both directions, what the FCC calls advanced services lines, in order to be eligible for the loan program. The loans are available to communities that have fewer than 20,000 inhabitants. First priority is given to communities with no broadband service in the proposed service area. The loans can be used to fund the construction, improvement, and acquisition of facilities; finance the lease of broadband facilities; finance acquisition of another system, lines, or facilities; or refinance an outstanding obligation on a telecommunications loan provided under the Rural Electrification Act. The loan will not cover operating expenses or customer premise equipment.

The majority of loan funding available from RUS is a direct cost-of-money loan. The interest rate for this particular loan is equal to published Department of Treasury interest rates for obligations of comparable maturity.

The RUS loans are available to any entity that is not an individual or partnership of individuals and not a telecommunications carrier serving more than two percent of the lines in the United States. Municipalities that meet the population requirements are eligible for RUS loans. However, state legislation may pose an obstacle to many municipalities.

4.6 State Legislation and Municipal Deployments

There has been a great deal of debate about whether the Telecommunications Act of 1996 intended to include municipalities in its list of entities that states and local governments cannot prohibit from providing telecommunications services. The specific passage is 47 USC 253 and reads as follows:

> "IN GENERAL- No State or local statute or regulation, or other State or local legal requirement, may prohibit or have the effect of prohibiting the ability of any entity to provide any interstate or intrastate telecommunications service."

This debate made it all the way to the Supreme Court in 2004, and the Court held that, "The class of entities contemplated by §253 does not include the State's own subdivisions, so as to affect the power of States and localities to restrict their own (or their political inferiors') delivery of telecommunications services." ("Nixon v. Missouri Municipal League, 541 US 125", 2004)

As of March 2005, twelve states have some form of restriction on municipal provision of telecommunications services. These restrictions range from additional steps beyond those a commercial carrier would have to complete in order to be able to provide service, to outright bans. A list of states, statutes, and a brief description can be found in Table 4.1. Other states are following suit and attempting to restrict the provision of telecommunications services by their localities as shown in Table 4.2. As shown in the table, nine additional states are currently considering legislation that would restrict municipal provision of telecommunications services.

Table 4.1: Existing Municipal Barriers to Entry

State	Law	Type
Arkansas	Ark. Code § 23-17-409	Local exchange service prohibited
Missouri	Revised Statutes of Missouri § 392.410(7)	Prohibited aside from resale to carriers
Minnesota	Minn. Stat. Ann. § 237.19	Requires 65% approval of voters
Nevada	Nevada Statutes § 268.086, § 710.147	Prohibited in areas with population of 25,000 or more or counties with population of 50,000 or more
Pennsylvania	Passed 12/1/2004	Prohibited unless no commercial service and no compliance to request for service
South Carolina	S.C. Code § 58-8-2600	Restrictions, procedural and cost requirements
Tennessee	Tennessee Code Ann. § 7-52-601 et seq.	Requirements beyond that of private entity, paging and security services prohibited
Texas	Texas Utilities Code § 54.201 et seq.	Prohibited
Utah	Utah Code Title 10 Ch 18 Sec. 101, et seq.	Limited
Virginia	VA Code §§ 15.2-2108, 56-265.5:4, 56-484.7:1	Requirements beyond that of private entity
Washington	Revised Code of Washington § 54.16.330	Wholesale service only
Wisconsin	2003 Wisconsin Act 278, effective July 1, 2004	Requirements beyond those of private entity, including minimum pricing

Adapted from APPA Barriers List (American Public Power Association, 2004b)

Table 4.2: Proposed State Legislation Restricting Municipal Broadband

State	Bill Number	Status	Type
Colorado	SB 05-152	Passed out of Senate committee	Commercial entity requirements, grandfathered
Florida	SB 1714 HB 1325	Referred to committee Introduced	Private sector preferred, restricted grandfathering
Illinois	SB 499	Consideration delayed	Prohibited
Indiana	HB 1148	Died in committee	Private sector preferred, Restricted grandfathering
Iowa	SSB 1136 HSB 182	Study bill in committee	Restricted
Nebraska	LB 157 LB 645 LB 136 LB 722/AM 442	In committee In committee In committee In committee	Prohibited Prohibited BPL by public power BPL by public power study
Ohio	HB 591	Lapsed	Municipal cable requirements
Oregon	HB 2445	In committee	Three year time frame cost/benefit analysis
Tennessee	HB 1403 SB 1760	In committee In committee	Prohibited until comptroller audit and authorization
Texas	HB 789	Proposed	Prohibited, grandfathering
Virginia`	HB 2395	Died in committee	Wireless in areas with less than three private sector

Adapted from Proposed State Barriers list (The Baller Herbst Law Group, 2005)

4.7 Summary

Government at the federal, state, and local levels is involved in many different aspects of telecommunications deployment. The task of attempting to capture all possible ways that government may play a role in fiber-to-the-home deployment is beyond the scope of this research. For the purposes of modeling, some key government policies both current and potential are incorporated into the model and tested.

Despite the move away from unbundling for fiber-to-the-home, and even removing unbundled network elements and UNE-P in traditional networks, the notion of open access is a recurring topic in discussions on fiber-to-the-home. Open access can either be implemented with the owner of the network not providing any services over the network at all, but only serving as a transporter of Internet service providers' services to customers or with the owner of the network both providing services and being required to lease parts of the network to competitive providers. The first scenario goes beyond providing a broadband 'dial tone,' in that the network owner provides the 'dial tone' but does not actually sell services over the infrastructure. This particular scenario exists in a few municipal builds where state laws only allowed the municipality to only serve as a wholesaler to service providers however, it is a drastic change to the prevalent market structure of broadband, so is not covered in the model. Instead, the model treats open access like the FCC's unbundling requirements and assumes that in this regulatory scenario providers will be required to resell parts of their network (the local fiber loop and a port for fiber lines) to competitors at rates that are the same percentage of potential revenue as current nationwide average TELRIC rates.

The idea of facilities-based competition is an important component to telecommunications policy. The model combines the idea of CLEC deployments as discussed in Chapter 3 with the notion of facilities-based competition by calculating a WACC for CLECs and determining what the necessary price would need to be to recover costs under a more limited market scenario.

Federal funding in the form of the RUS loans is an important enabler of broadband services in rural areas. The model incorporates federal funding into the decision process for acquiring broadband services in rural areas. Low cost loans for non-rural area broadband projects are also explored as a potential government policy.

Municipal deployments are also an important vector for providing service to areas that have been skipped over by commercial deployments. In many cases, these deployments are by public utilities, as discussed in Chapter 3. If states continue to implement regulations blocking these deployments, it may have a negative impact on the deployment of fiber-to-the-home. The model allows for freezing the deployment of broadband by municipalities at their current level to account for the spread of restrictive state regulations.

Chapter 5: Model Overview

5.1 Introduction

Chapters 2 through 4 examined trends in fiber-to-the-home hardware, adoption, and government policy that needed to be accounted for in the development of the system dynamics model. This chapter delves into detailed formulations for the model and looks at the initial values used in the simulations.

A high-level view of the model is shown in Figure 5.1. Plus signs on arrows connecting the factors in the figure mean that an increase or decrease of the first factor results in a change in the same direction of the second factor. For example, as the broadband customer base increases, the available content and applications for broadband users also increases, or as the broadband customer base decreases, the available content and applications for broadband users also decreases. The loops shown in the figure are called positive, or reinforcing, loops. Loops are labeled as balancing or reinforcing depending on whether a change (increase or decrease) in one variable results in the same or opposite change of that variable after going around the loop. An increase in fiber-to-the-home demand results in an increase in community fiber-to-the-home deployment which increases the fiber-to-the-home customer base, which ultimately increases demand for fiber-to-the-home.

All of the loops shown in the figure are reinforcing loops. At a high level this means that once the loops are active and the various effects in the diagram are seen, the system will run without additional outside influence. However, the loops require something to get them started. Chapter 1 gave an overview of the high-level loops. This chapter explores the detailed lower level loops that ultimately become the system dynamics model used in this study.

The loop diagrams presented in this chapter focus primarily on variables relating directly to fiber-to-the-home. Other types of broadband installations are tracked in the model through extensions of the present day data on broadband deployment discussed in Chapter 3, but are external to the model so are not shown in the loop diagrams presented here except where they are necessary for clarity of model formulation.

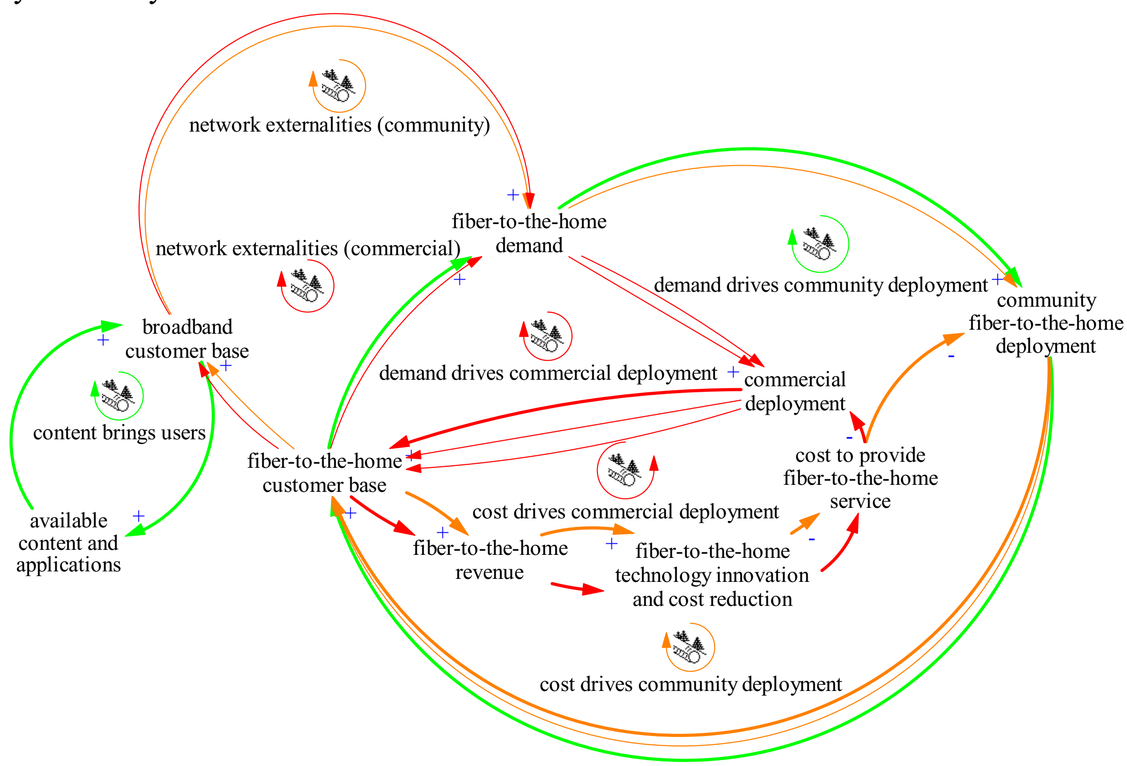

Figure 5.1: High-Level Fiber-to-the-Home Loops

5.2 Cost of Fiber-to-the-Home Deployment

Discussion of fiber-to-the-home deployment and even trial deployments are not new. Early trials have been taking place in the United States and Europe since the mid-to-late 1980s. These trials in the U.S., England, and France to provide telephone and broadcast video service to residential customers occurred did not lead to widespread deployments (Esty, 1987; Rowbotham, 1989; Shumate, 1989; Veyres & Mauro, 1988). Studies conducted at the time suggested that consumer demand for video and telephone service was not sufficient to warrant the funds necessary for wide scale deployment of the systems (Bergen, 1986; Sirbu & Reed, 1988).

The reports were published before the Internet and the World Wide Web became popular. Now, along with demand for video and telephone service, there is additional demand for broadband Internet service. This new demand, along with the popularity of cable modem service, has caused the Regional Bell Operating Companies and others to re-explore fiber-to-the-home with an eye toward real deployments. Cost of fiber and components has come down in recent years, however, the capital expenditure required to deploy the infrastructure is still a concern.

Figure 5.2 shows the variables relating to cost that are included in the model. The figure is an example of a loop diagram, which is used in system dynamics to represent the major variables and how they relate to one another in the model. The actual coding of the model typically requires the inclusion of other lower level variables to relate the major variables together and to perform calculations.

The loop diagrams shown in this chapter were originally developed through brainstorming sessions with Elizabeth Bruce of MIT's Microphotonics Center, and Gillian McColgan and Brian Vezza of Nortel Networks. The brainstorming session resulted in well over 100 variables relating to fiber-to-the-home deployment being identified. The loop diagrams presented here are a refinement of those original variables and diagrams in an effort to make the model simple, while still capturing the important effects.

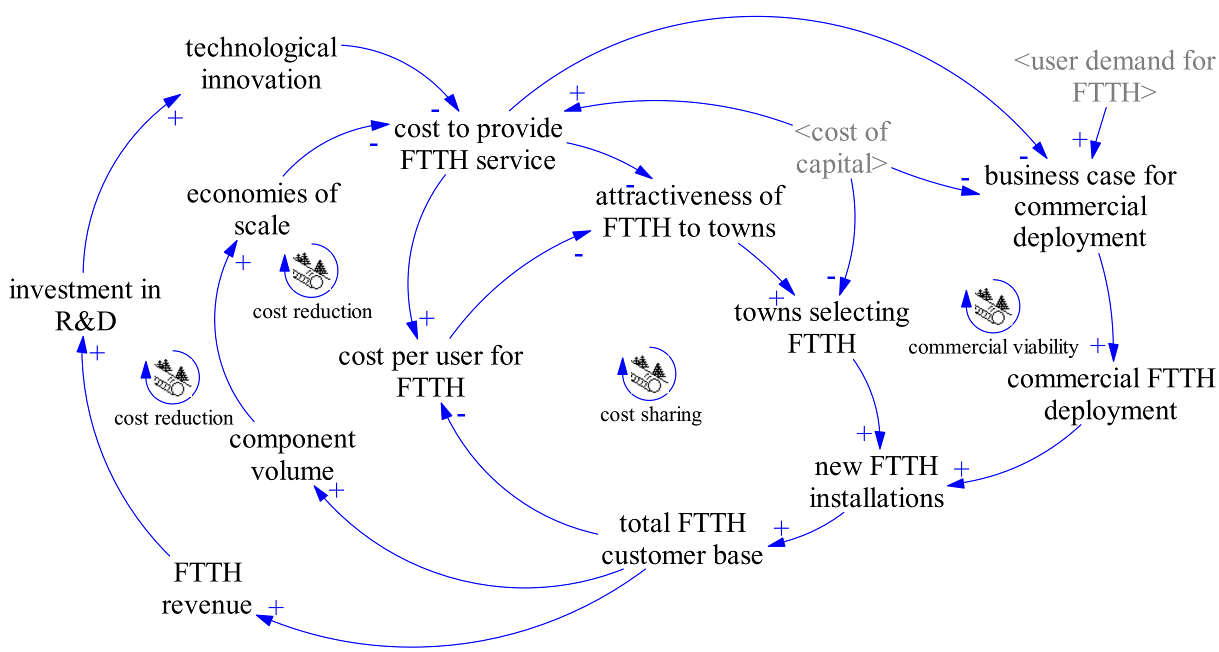

Figure 5.2: Fiber-to-the-Home Cost Related Loops

The loops in Figure 5.2 center on the cost to provide fiber-to-the-home service variable. This variable includes both the cost of infrastructure and the operating cost. As shown in the figure, there are two mechanisms for reduction in the cost to provide service. One is through revenue being directed towards research and development work, and that work resulting in new innovations that bring down cost. Cost reduction due to revenue and innovation can occur in the construction industry that lays the infrastructure, in the components industry the makes the fiber optic components, in the equipment industry that makes the customer premise and central office equipment, or within the service provider. The other path for cost reduction is through economies of scale and learning which come with increased production volume.

The cost reductions make fiber-to-the-home service more attractive, both to municipalities that are interested in deploying broadband, and to commercial providers, such as the RBOCs. The additional deployments that happen due to the increase in attractiveness in turn bring more component volume and more revenue, completing the loops by reducing cost to provide service.

The other loops pictured in Figure 5.2 relate to cost reduction to users due to infrastructure cost sharing. Parts of the infrastructure and associated costs are shared among users, so the more users that subscribe to fiber-to-the-home service, the cheaper the cost per user. A cheaper per-user cost means a more economical investment for communities, and thus makes the service more attractive. It also means that the provider can charge less for the service and attract more users.

5.2.1 Cost of Capital

A key factor that feeds into several of the decision processes captured in Figure 5.2 is the cost of capital. The cost of capital is the expected return that is not realized by investing in a project rather than leaving the funds in a portfolio of the company's securities. This cost of capital is used as a discount rate on cash flows for projects that have similar risk to the company as a whole (Brealey & Myers, 2003). In order to determine whether the project is worthwhile and the amount that a company would need to charge its customers to recover the cost of the investment, an appropriate discount rate, known as the weighted average cost of capital (WACC), must be calculated. The WACC is slightly different from the cost of capital in that it also accounts for the corporate tax rate as shown in Equation 5.1. The values and results of the calculations used to determine the WACC are found in Table 5.1 for the RBOCs and Table 5.2 for CLECs.

Table 5.1: Calculation of WACC for RBOC Fiber-to-the-Home Build

Company	Cox	Charter	Adelphia	Comcast	Time Warner	RCN	SBC	Verizon	Qwest	BellSouth	Cincinnati Bell	
Beta	0.648	2.619	1.538	0.782	2.217	1.919	0.759	0.922	2.677	1.052	2.673	
CAPM (cost of equity)	7.9248	22.9044	14.6888	8.9432	19.8492	17.5844	8.7684	10.0072	23.3452	10.9952	23.3148	
Debt (millions)	7015.8	18900	14850	26996	25745	2460.864	18240	40520	9873	14980	2287.8	
Long-term debt	6963.456	18647		23835	23458		16060	39413	6874	11489	2274.5	
Interest (millions)	467.763	1557		2018	1844	238.952	1241	2941	726	1048	234.2	
Cost of debt	6.6673	8.2381	0.0000	7.4752	7.1626	9.7101	6.8037	7.2581	7.3534	6.9960	10.2369	
Equity (millions)	21780	865.36	58.29	64010	74710	13.75	81680	107830	6030	47600	838.74	
Value (D+E)	28795.8	19765.36	14908.29	91006	100455	2474.614	99920	148350	15903	62580	3126.54	
D/V	0.2436	0.9562	0.9961	0.2966	0.2563	0.9944	0.1825	0.2731	0.6208	0.2394	0.7317	
E/V	0.7564	0.0438	0.0039	0.7034	0.7437	0.0056	0.8175	0.7269	0.3792	0.7606	0.2683	
D/E	0.3221	21.8406	254.7607	0.4217	0.3446	178.9719	0.2233	0.3758	1.6373	0.3147	2.7277	**Total Capex**
Capex 2003 (billions)	1.6	0.108		4.097	1.637		5.219	6.8	1.663	3.2	0.1264	24.4504
Capex 2002 (billions)	1.9	0.141		1.814	1.813		6.808	8	1.823	3.785	0.1759	26.2599
Capex 2001 (billions)	2.2			1.855	1.813		11.189	12.7	4.505	5.997	0.6485	40.9075
											Average	30.5393
risk free rate (intermediate term)	3											
equity market risk premium (intermediate term)	7.6											
Corporate tax rate	0.35											
WACC	7.0499	6.1231	0.0574	7.7316	15.9553	6.3742	7.9751	8.5625	11.8193	9.4518	11.1235	
Opportunity cost of capital	7.6184	8.8802	0.0574	8.5077	16.5978	9.7538	8.4098	9.2563	13.4171	10.0379	13.7452	
Desired D/E	0.3628											
New RBOC cost of equity (assume cost of debt stays the same)							8.9925	9.9813	15.6171	11.1416	15.0181	
New D/V	0.2655											
New E/V	0.7345											**Average**
New WACC							7.7790	8.5837	12.7395	9.3907	12.7973	8.5845
											Market cap weighted average:	8.5890

$$WACC = r_D (1 - T_C)\frac{D}{V} + r_E \frac{E}{V}$$

Equation 5.1: Weighted Average Cost of Capital

where:

r_D = cost of debt

T_C = corporate tax rate

D = market value of debt

E = market value of equity

V = $D + E$ = total value of the firm

r_E = cost of equity

The first step in determining the WACC is to calculate the cost of equity. The formula used is the Capital Asset Pricing Model (CAPM) shown in Equation 5.2. Beta (β) measures how sensitive a particular stock is to fluctuations in the market. Stocks with betas of less than 1 move with the market, but not as far. Stocks with a beta greater than 1 tend to amplify the movement of the market. The values for β for the companies of interest (RBOCs, CLECs, and cable modem providers) were taken from Yahoo! Finance on October 26, 2004.

The market risk premium is calculated by taking the difference between the market return and the risk free interest rate. The risk free rate for an intermediate term (five year) U.S Treasury Note at the end of 2003 was three percent. The associated market risk premium over the same time horizon was 7.6 percent (Ibbotson Associates, 2004). The intermediate term rates were used in the calculation since that is the expected return timeline for a fiber-to-the-home network build.

$$r - r_f = \beta(r_m - r_f)$$

Equation 5.2: Capital Asset Pricing Model

where:

$r = r_E$ = investor required return on equity, cost of equity

β = market risk of an individual security

r_m = market return

r_f = risk-free interest rate

$r_m - r_f$ = market risk premium

The cost of debt and the amount of debt for each firm were taken from the year-end 2003 annual reports for the firms shown in Table 5.1 and Table 5.2. The amount of debt used in the calculation is total debt, which includes both long-term and short-term debt. The cost of debt was calculated by dividing the total debt from the amount of interest paid in the annual reports.

Then a WACC for each company was calculated. This WACC represents a discount rate for a project that has similar risk associated with it as the company as a whole.

For the RBOCs, construction of a new fiber-to-the-home network is more expensive and more risky than a simple upgrade of a central office to provide DSL service. It requires far greater capital expenditure, since in order for the network to be usable to the consumer the RBOC needs to build sufficient infrastructure to connect the home user via fiber to the central office. In the DSL case, adding DSL service may be as simple as adding a DSL capable switch in the central office, or perhaps as complex as adding a remote DSLAM. Both of these options leave the copper cable to the customer premises intact and use that cable to provide services. Neither of these are as capital intensive as a fiber buildout to the user which requires both new equipment in the central office and new cabling between the user and the central office. The extent of modification to the network is similar to the large investment that cable companies made to convert their networks to be Internet capable. Thus the calculated weighted average cost of capital is adjusted to reflect the debt ratio of the cable companies (Hausman, personal communication, August 2004). The first step in this adjustment is to unlever the WACC. This involves calculating the WACC and the cost of equity at zero debt as shown in Equation 5.3.

$$\text{opportunity cost of capital} = r_D \frac{D}{V} + r_E \frac{E}{V}$$

Equation 5.3: Opportunity Cost of Capital

Then the new cost of equity is calculated from Equation 5.4 using the desired debt ratio and an estimated cost of debt. In this case, it is assumed that the cost of debt stays the same and is the RBOC cost of debt, and the new debt ratio is an average of Time Warner's, Comcast's, and Cox's debt ratio. The values for Charter, Adelphia, and RCN were also gathered and calculated, however they are not used in the final calculations due to the extremely high debt carried by these companies who were in various stages of declaring bankruptcy and recovering. The RBOCs that are used in the calculation are the final remaining RBOCs after several years of consolidation: BellSouth, Cincinnati Bell, SBC, Qwest, and Verizon.

$$r_E = r + (r - r_D)\frac{D}{E}$$

Equation 5.4: New Cost of Equity

where:

r_D = cost of debt

r = opportunity cost of capital

D = market value of debt

E = market value of equity

r_E = cost of equity

The WACC for each RBOC is then recalculated using Equation 5.1 and a market capitalization weighted average WACC of 8.59 is obtained for use in the model, as can be seen in Table 5.1. Market capitalization is used as a weight to average the calculated WACCs to account for the vastly different sizes of some of the remaining RBOCs.

Table 5.2 shows WACC calculations for the two remaining nationwide Internet service CLECs that are publicly traded. RCN built its own infrastructure as a competitive cable modem provider, and Covad provides its own equipment, but uses RBOC local loops to provide DSL service. The cost of equity for both of these providers is much higher than for the RBOCs, suggesting that the market expects better rates of return from these particular CLECs than from traditional cable modem service providers and the RBOCs. This results in a much higher WACC for a company that is not overburdened by debt. A simple average was taken between the average WACCs of RCN and the WACC of Covad to obtain a CLEC WACC of 11.8.

Table 5.2: CLEC WACC Calculation

Company	RCN (2001)	RCN (2002)	RCN	Covad
Beta	1.92	1.92	1.919	2.343
CAPM (cost of equity)	18.924	18.924	18.9168	21.9696
Debt (millions)	1896.148	1744.414	2428.785	114.317
Long-term debt	2460.864	1684.413	1654.585	58.646
Interest (millions)	196.733	167.644	180.206	5.526
Cost of debt	10.375	9.610	7.420	4.834
Preferred stock (millions)	2142.276	2304.426	1772.31	
Equity (millions)	13.75	13.75	13.75	383.05
Value (D+E)	1909.898	1758.164	2442.535	497.367
D/V	0.993	0.992	0.994	0.230
E/V	0.007	0.008	0.006	0.770
D/E	137.902	126.866	176.639	0.298
Capex 2003 (billions)				0.059
Capex 2002 (billions)				0.023
Capex 2001 (billions)				0.016
Capex 2000 (billions)	1.243			0.319
risk free rate	5.1			
equity market risk premium	7.2			
Corporate tax rate	0.35			
WACC	6.832	6.346	4.902	17.642
RCN Average	6.027			
Average CLEC	11.834			

5.2.2 Infrastructure Cost of Fiber-to-the-Home

The infrastructure cost used in the model comes from a combination of calculations and data obtained from outside sources. Cost of construction, fiber, and central office equipment for active deployments and any construction necessary for remote terminals come from a model developed by Anupam Banerjee at Carnegie-Mellon University (Banerjee, personal communication, May 2004).

The deployment cost calculations assume that all construction work required to provide service to all homes passed takes place during the deployment phase, but that only enough electronics are deployed in the central office and remote terminal to accommodate the initial assumption for the take rate (in the model base case, 30%). The construction work includes all of the equipment necessary for fiber management, building of aggregation points and enclosures, and the running of fiber to all homes.

The CMU model assumes that urban and suburban communities have an average of 18,000 households and rural communities have an average of 9,000 households. This is drastically different than found in the Census places data as shown in Chapter 3 and replicated in rounded form in Table 5.3. CMU model pricing data is adjusted for use in the model to better correspond to Census household data by dividing by the appropriate factor: two for suburban communities and nine for rural communities. Initial values for the percent of communities that have service are also shown in the table. Municipal suburban communities shown in the table are communities that have publicly owned utilities.

Small carriers, typically called rural local exchange carriers, or RLECs, are defined by the Rural Utilities Service as carriers that do not serve more than two percent of the local exchange lines in the United States. RLECs and other small carriers are eligible for Rural Utilities Service funding provided they serve an eligible community as defined in Chapter 4. Since no good data were available on how many rural communities are served by large and small carriers, the model assumes that all rural communities can get funding from the Rural Utilities Service. The model tracks the cost for a large carrier, an RBOC, to deploy to a rural area, but does not model rural deployment by RBOCs.

Table 5.3: Model Initial Values for Households and Service

	Number	Average Households	Percent Service	Number FTTH
Urban	1,100	18,000	100%	0
Suburban	5,500	9,000	72%	27
Rural	18,000	1,000	41%	111
Municipal (suburban)	529	9,000	85%	12

Cost of active and passive electronics at the customer premise, passive electronics at the central office, and active electronics at the remote terminal are constructed from published data on the cost of fiber-to-the-home deployment (Weldon & Zane, 2003) coupled with current GBIC and SFP transceiver pricing information and manufacturing costs (Fuchs & Kirchain, personal communication, Dec. 2004). This information is used to fit learning and economies of scale curves that relate price to production volume. The curve used for the fit is shown in Equation 5.5.

$$NP * \left(\frac{CV}{NV}\right)^{\frac{\ln(1-SF)}{\ln(2)}} + FP$$

Equation 5.5: Transceiver Learning and Scale Economies Curve

where

NP = nominal price = variable price before application of learning curve;

CV = current production volume in units per year;

NV = nominal production volume = initial production volume in units per year;

SF = scale fraction = the amount that price drops whenever production volume doubles;

FP = fixed price = part of the price not subject to learning effects

As discussed in Chapter 2, currently different transceivers are used for active and passive deployments. However, the potential for developing a standardized transceiver also exists, thus a curve for a hypothetical standardized transceiver was also developed. The starting values for the curves are shown in Table 5.4. In the table, standard is the hypothetical standardized transceiver curve, passive refers to customer premise transceivers in a PON installation, and active is for transceivers used at both the customer premise and remote terminal in an active fiber-to-the-home installation. Scale fraction is the percent that price drops when production volume doubles. Fixed price is the part of the price that is fixed and not affected by either learning or economies of scale. As can be seen in the table the standardized and passive transceivers share the same variable prices, however the fixed price and scale fraction for the standardized transceiver is slightly higher. This means that the standardized transceiver will start out more expensive than either the passive or active transceivers, but the price will fall more rapidly than the passive transceiver. The active transceiver is cheaper overall with a higher scale fraction because the transceiver is largely based on lower priced technologies that are similar to those used in current local and wide area network fiber installations, such as university or corporate campuses.

Table 5.4: Transceiver Learning and Scale Economies Curve Starting Values

	standard	**active**	**passive**
nominal price	150	80	150
nominal volume (units/year)	25000	25000	25000
scale fraction	.25	.30	.20
fixed price	40	20	30

Electronic equipment at the customer premise, the remote terminal, and the central office passive electronics have their own learning and scale economies curve. The model assumes that the electronics and casing that house the transceiver in the customer premise equipment for both passive and active installations have an identical cost structure and price. The price of the CPE not including the transceiver has a scale fraction of .05, dropping by five percent every time production doubles (Weldon & Zane, 2003). Price of central office equipment for active installations is obtained from the Carnegie Mellon model for active installations, and not calculated separately. A five percent annual reduction of all deployment costs represents cost reduction due to technological innovation.

Table 5.5: Other Electronics Learning and Scale Economies Curves

	CPE (no transceiver)	RT	CO Port
nominal price	300	7550	12100
nominal volume (units/year)	25000	25000	25000
scale fraction	.05	.05	.05

5.2.3 Greenfield Versus Brownfield

The data from both Carnegie Mellon and Weldon and Zane assume a greenfield build situation. This means that the provider will need to build all the infrastructure required for a deployment and does not account for pre-existing facilities, such as fiber in the network. In this configuration, the system dynamics model tended to calculate a price per user for fiber-to-the-home buildout that was too high to result in deployment.

The system dynamics model assumes that any deployment of fiber-to-the-home will be done by a service provider, or in conjunction with a service provider, that already has a central office facilities, so the cost of construction of a central office is neglected. To account for the fact that providers of telephone services have been replacing failed copper with fiber both between central offices and in the customer segment of their outside plant, data from the FCC's ARMIS database was obtained. The ARMIS database contains financial, operational, service quality, and network infrastructure information filed by the largest ILECs (Federal Communications Commission, 2003b). ARMIS data on the amount of fiber in the outside plant of large ILECs are found in Table 5.6. Sheath kilometers are the kilometers of bundles of cabling in the network. Each bundle, or sheath, typically contains multiple strands of cable. The average growth rate of fiber in the network over the shown time period is 5.4% and fiber is 12.3% of the sheath miles that make up the wiring infrastructure.

Table 5.6: Fiber Infrastructure

	2003	2002	2001	2000
Total Sheath Kilometers	5,851,790	5,791,105	5,848,516	5,761,869
Copper	5,118,314	5,086,669	5,166,537	5,132,364
Fiber	720,877	692,031	665,805	613,646
Other	12,600	12,406	16,174	15,860
% fiber	12.32%	11.95%	11.38%	10.65%
Growth Rate	4.17%	3.94%	8.50%	4.96%

5.2.4 Operating Cost of Fiber-to-the-Home

The other piece of the cost picture is the operating costs for both adding a customer and for providing service to that customer. Monthly recurring costs and customer acquisition costs are shown in Table 5.7 and Table 5.8 respectively. The monthly recurring costs are taken directly from the recurring cost for a DSL subscriber. Since actual bandwidth used by users is not tracked in the system dynamics model, transport costs are not adjusted with time, it is assumed that the monetary figures are in constant 2005 dollars, and that the cost of transport will drop at a rate comparable to the rate that new capacity will be required.

Table 5.7: Monthly Recurring Costs per Subscriber

Tech Support	$9.50
Backbone/Transport	$6.00
Customer Care/Billing	$5.00
Network Operations	$3.63
Maintenance Marketing	$0.50
Content	$2.00
Bad Debt	$1.24
Other	$5.00
Total	$32.87

Source: (Credit Suisse First Boston Equity Research, 2003)

The cost of acquisition is adjusted from values for DSL customers. Fiber subscribers bear the full burden of the cost of a truck roll to their house and neighborhood, since it is assumed that installation will need to be done by a skilled technician, unlike the self-install DSL method. Marketing and help desk call costs are decreased to be similar to the cost for cable modem subscribers, since the majority of calls made to helpdesk after the first month of DSL installation are directly related to difficulties with the installation. Many of these difficulties can be removed with a trained technician performing the installation and initial configuration, as is typical with cable modem installations. Estimates for DSL marketing and help desk customer acquisition costs were $250 at year-end 2002, while cable marketing and sales and first month customer care costs were $30. The DSL rate has been adjusted to $50 to reflect the use of technicians for installation. The number chose is somewhat higher than cable to recognize some of the additional complexity associated with fiber-to-the-home installations and any associated difficulties with the new user service.

The cost of a CPE starts at $500 and is then adjusted in the model by economies of scale and technological innovation during the model run. The model also assumes that the installation fee collected from the customer will be $300 regardless of the actual cost of the CPE.

Table 5.8: Acquisition Costs

Marketing/Help Desk	$50.00
CPE*	$500.00
House Truckroll	$125.00
Neighborhood Truckroll	$42.00
CPE Revenue	$(300.00)
Net Acquisition Cost	$417.00

Source: Adjusted from (Credit Suisse First Boston Equity Research, 2003)

The churn rate, or what percentage of customers leave the service every year, is an important driver for the monthly fee that customers need to be charged to recover the cost of service. As of the end of 2002, the churn rate for DSL service was very high averaging 55% using a market capitalization average of BellSouth, SBC, Qwest, and Verizon (Credit Suisse First Boston Equity Research, 2003). Cable modem churn on the other hand has stayed constant at around 30%. Since it is hoped that the installation of fiber-to-the-home will reduce churn rate to closer to the rate for cable modem service, the system dynamics model assumes an initial churn rate of 35%.

5.3 Government Funding

In Chapter 4 ways in which government could influence the deployment of fiber-to-the-home and broadband in general were explored. One of the major methods of government influence is through funding, both at the federal and local levels. At the federal level, the government funds rural deployments through loans and grants and also may make low cost loans available for non-rural deployments. In the case of municipal deployments, the link with the local government allows the initiative to be funded via a long term and low interest municipal bond.

The loop diagrams shown in Figure 5.3 illustrate the influence of government funding on rural and municipal deployments. The U.S. Department of Agriculture (USDA) through the Rural Utilities Service (RUS) provides loans to eligible entities for broadband deployment. Eligible entities must provide service to communities that have no more than 20,000 inhabitants. The other restriction is that the entities providing service cannot be individuals, partnerships, or serve more than 2% of the telephone subscriber lines installed in the United States. Since NANPA rate centers are communities or geographic areas with 20,000 or more people it is difficult to determine which smaller regions are served by large or small carriers. The system dynamics model errors on the side of assuming that the USDA RUS program would be willing to provide loans to large carriers as well as small carriers for provision of services specifically to rural areas. The model also calculates the cost for a large carrier to provide service in a rural region to determine commercial viability.

The popularity of broadband services is a dual edged sword. On one side as more urban and suburban areas get service, the discrepancy between rural and non-rural areas increases, increasing the so-called "digital divide." This provides the government with additional incentive to allocate more funding towards broadband for rural areas, which in turn causes more rural communities to want broadband. As time passes and more and more rural communities have service, the government begins allocating less and less funding towards rural broadband service, making it less desirable to the remaining rural areas.

Communities are also aware of similar communities that have broadband. Associations such as the American Public Power Association publish newsletters and conduct and publish surveys about municipal broadband offerings. The USDA publishes information on both municipal and rural groups that have received funding from RUS to deploy broadband. The media is also a source of information on communities that have broadband. Increasing numbers of similar communities with broadband causes communities to feel as if they are being left behind and increases their desire to deploy broadband service.

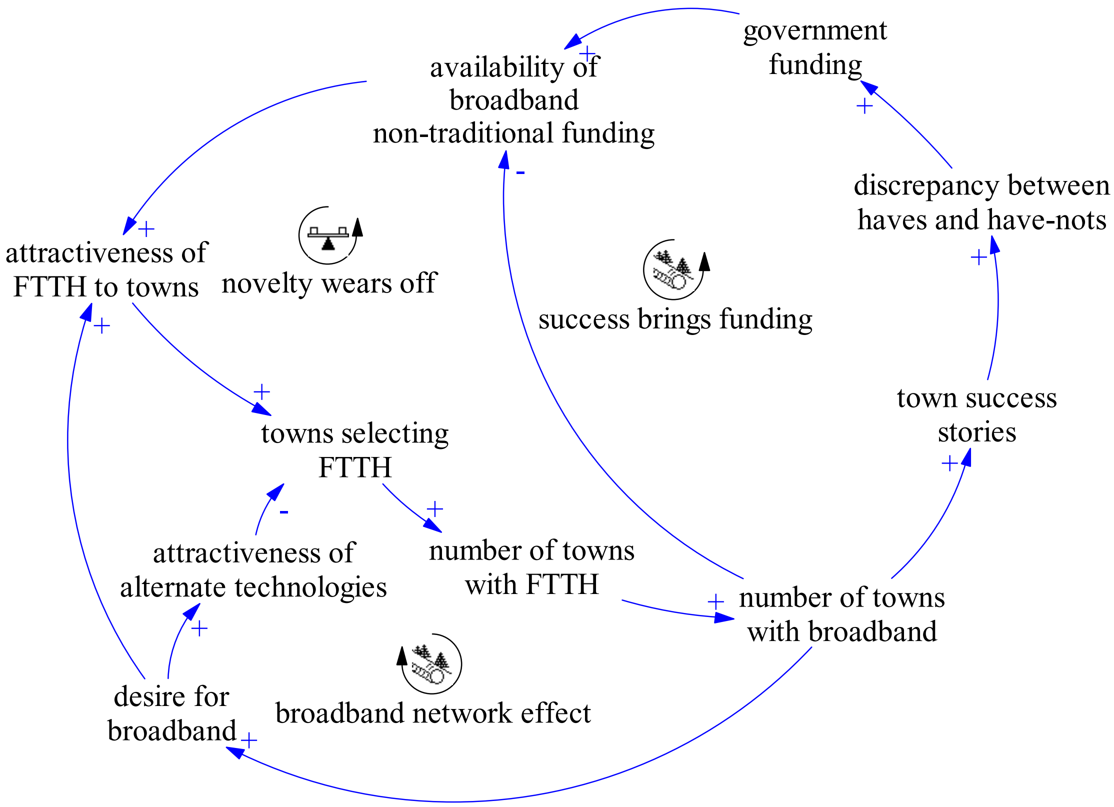

Figure 5.3: Government Funding in Rural and Municipal Deployments

Once rural or municipal regions have actually decided that they want to deploy broadband, they must then decide on a type of technology to deploy. This is represented in the "towns selecting FTTH" variable which tracks the communities that have chosen fiber-to-the-home as their broadband technology. Communities attempting to decide which technology to deploy weigh the attractiveness of fiber-to-the-home with the attractiveness of alternates to make their decision. The variable "attractiveness of FTTH to towns" is the same as in Figure 5.2 and is the point at which the government funding loop connects to the fiber-to-the-home costing loops.

5.4 Demand for Broadband and Fiber-to-the-Home

Other towns acquiring broadband are not the only influence on town demand for broadband. As shown in Figure 5.4, broadband demand from residents can put pressure on municipal and rural communities to upgrade their infrastructure. Increases in user demand can also make commercial broadband builds more attractive, however those users do not have direct influence on the plans of commercial companies in the way that residents in municipalities and rural communities do.

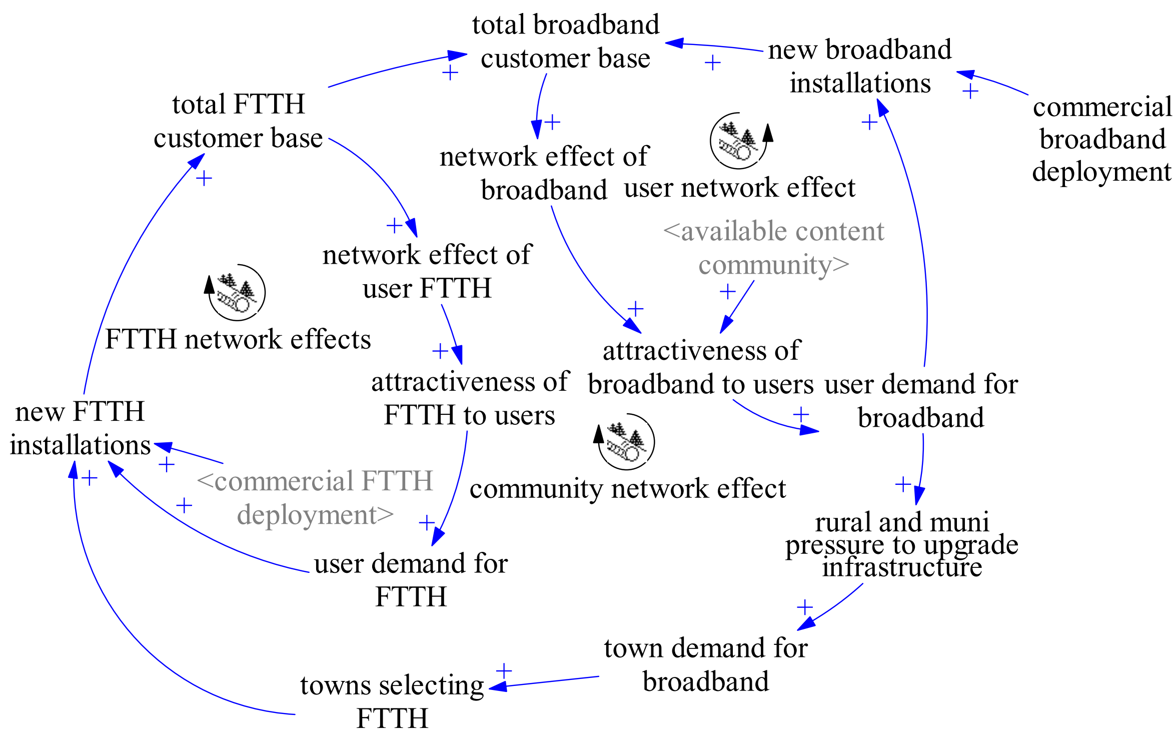

Figure 5.4: Network Effect Adoption Loops

The network effect loops shown in Figure 5.4 illustrate how demand for broadband and fiber-to-the-home grow as more users acquire the service. As the user base of broadband and fiber-to-the-home grows, so does the demand for service by other users. Growth in fiber-to-the-home subscribership drives both demand for fiber-to-the-home and demand for broadband, since an increase in fiber-to-the-home subscribers is an increase in broadband subscribers.

Increases in the broadband customer base cause demand for broadband service to increase. In areas where service is already available, increased demand results in more customers signing up for service. In rural and municipal communities that do not yet have service, the increase in demand means more pressure on the community to acquire some form of broadband infrastructure. Some of these communities will acquire fiber-to-the-home service leading to more fiber-to-the-home subscribers and broadband subscriber and to an increase in the network effect of both broadband and fiber-to-the-home. The variable "towns selecting FTTH" is the same as in Figure 5.3 and is the point at which the network effect loops link to the government funding loops.

The variable "attractiveness of broadband to users" in Figure 5.4 increases as a variable called "available content community" increases. That variable is also shown in Figure 5.5 as part of the content related adoption loops ad is where the network effect loops link to those relating to content.

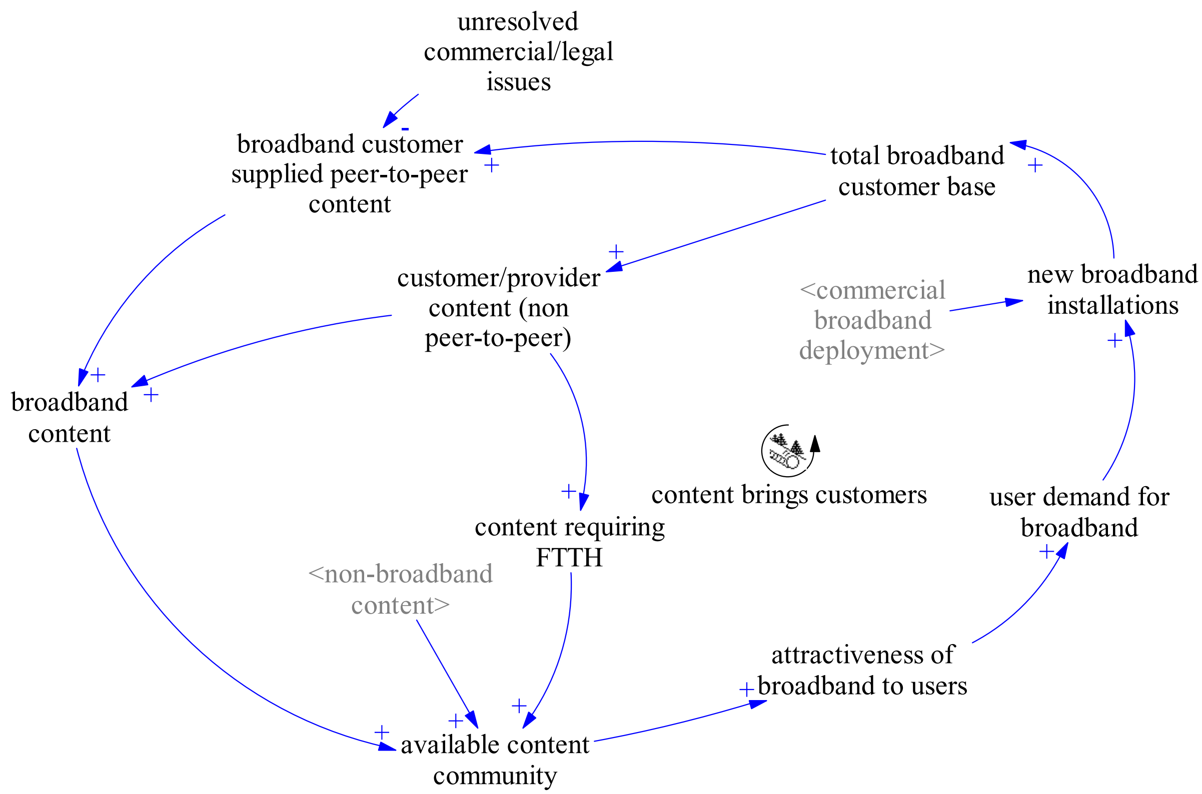

Figure 5.5: Content Related Adoption Loops

As illustrated in the survey on how much the average dialup user is willing to pay for broadband service discussed in Chapter 3, users of content that is better served via broadband are willing to pay a higher monthly fee. Content, or something that makes a broadband connection worthwhile to a user, is an important component of broadband adoption. In Figure 5.5 the effect of content on attractiveness is shown by the "available content community" influencing the "attractiveness of broadband to users." As the available content increases, broadband becomes more attractive, and user demand for broadband increases. The increase in demand results in increased broadband installations for those users that have broadband available. The model rolls the content demand effects into the price effect on adoption. Attempts to calibrate FCC deployment data along with the survey data resulted in adoption levels that were far too low, suggesting that the survey data was suspect and not necessarily representative of adoption patterns.

The growing broadband customer base results in an increase in available content. The content comes from the broadband users themselves, the broadband service provider, or other content providers. Broadband users supply content in the form of peer-to-peer content, typically video and music, best shared over a broadband connection, and also content that does not require broadband such as static web pages. Broadband service providers in response to the increasing customer base and customer demand for content may provide both content requiring broadband and non-broadband content. Content providers, such as Napster or Apple with its iTunes service, that are not affiliated with broadband service providers also exist and provide more content in response to increases in the customer base and demand for content.

Peer-to-peer services are distributed file sharing programs. Any user running the program can be either a server (distributing content) or a client (downloading content) or both. Currently there are unresolved legal issues related to digital rights management and the sharing of copyrighted material over peer-to-peer services. Both the Motion Picture Association of America (MPAA) and the Recording Industry Association of America (RIAA) have begun demanding the removal of copyrighted material from peer-to-peer servers and even in some cases filing lawsuits against those that are sharing copyrighted material. If these issues are not resolved, they may have a negative effect on the broadband content provided by the user community thus slowing the growth of content and also the growth of the user community.

Increases in content also increase the likelihood of content or a combination of content that is better served via fiber-to-the-home. There is also the potential for the development of a “killer application” requiring speeds only available through fiber-to-the-home connections that will be in high demand, similar to World Wide Web growth in the mid 1990s.

The increasing content and increasing customer base place growing demands on the network infrastructure and on the bandwidth required between providers. If this increasing demand for bandwidth is not met with appropriate increases in available bandwidth, network congestion may occur. Congestion leads to poor performance of network applications and especially interactive applications, such as gaming which may cause users to leave the service and discourage new subscribers resulting in a decrease in broadband demand. Due to lack of data on congestion and the effect of congestion on users, the model assumes that providers will appropriately manage and expand their networks to minimize this effect.

5.5 Summary

This chapter presented a detailed discussion of the formulations used in the system dynamics model. Cost of providing fiber-to-the-home service is the primary consideration for commercial deployments and it also plays a significant role in the decisions of municipalities and rural providers to deploy. Municipalities and rural providers that do not already have service can also be swayed by the demands of the residents and the feeling of being left behind and left out due to similar areas acquiring service.

Commercial providers of telephone service have an advantage in many regions, because they have been upgrading their infrastructure from copper to fiber lines as copper fails. Their cost of providing service is proportionality lower because they do not have to build an entirely new network to provide fiber-to-the-home service. Municipal utilities may also have a similar advantage, because many have deployed fiber networks to use as monitoring for power distribution networks. Municipal utilities also have an economies of scope advantage in that building a fiber network gives them the ability to monitor their distribution systems and in many cases they already have appropriate billing systems set up.

Government funding plays a large role in municipal and rural area builds. The low cost loans that are provided are technology neutral and act as an additional incentive to communities already under pressure from residents and feeling left out of commercial builds. Broadband networks are seen as keys to prosperity and economic growth for many of these areas, so as more communities acquire service, the pressure on communities that do not yet have service increases.

User adoption is governed strongly by awareness of the service, through knowing other people that have the service, and also media attention on broadband services. As more users have the service, it is seen as having more utility and as a "must have" for those that do not. Increases in the user base also cause increases in available content which in turn makes service desirable to still more customers.

The effects of cost, government funding and user adoption all interact in the complex tangle shown in Figure 5.6.

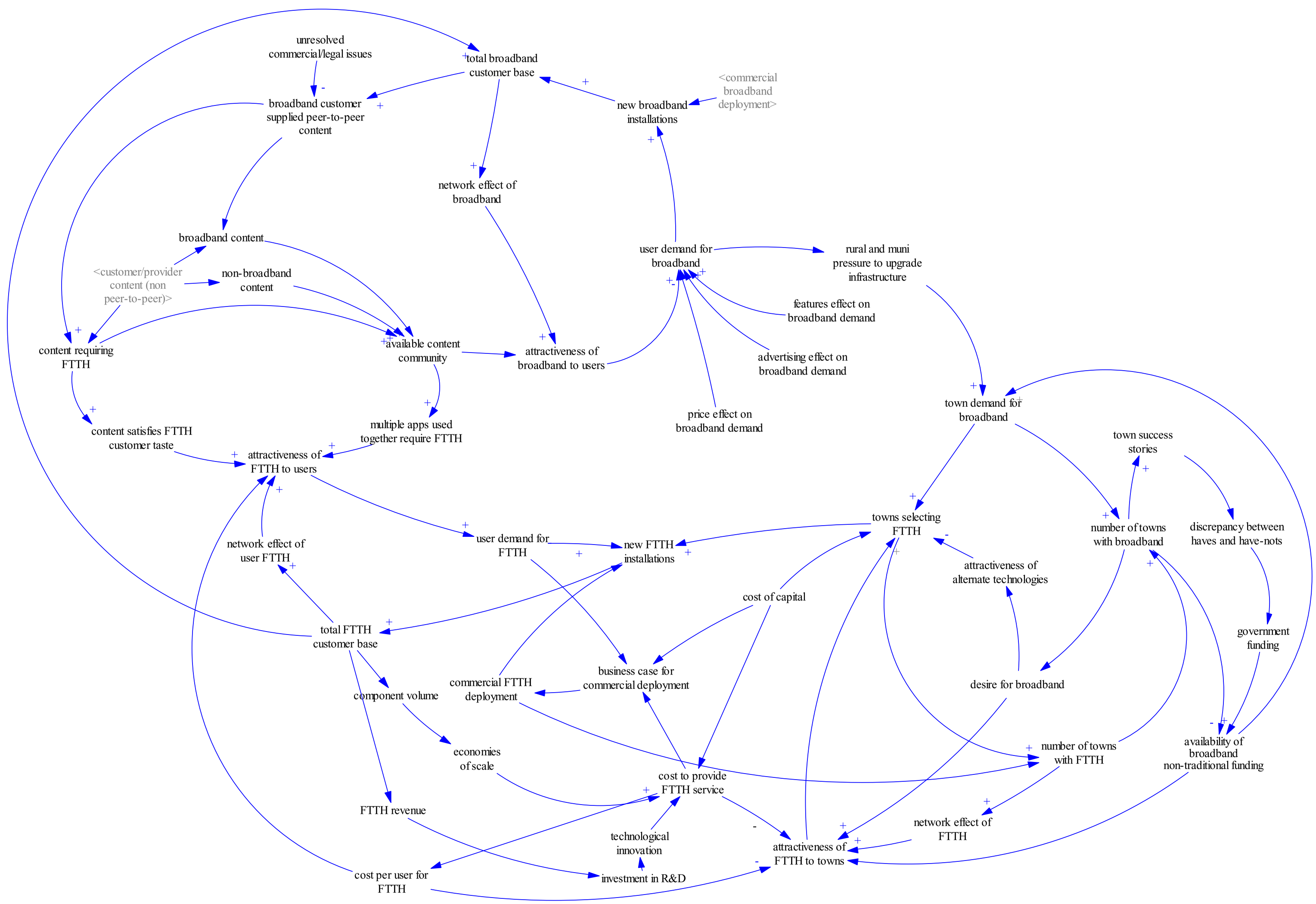

Figure 5.6: Overview of Linked Together Loop Diagrams

Chapter 6: Model Results

This chapter explores the results of the model under different deployment scenarios. The settings used to produce the model runs shown in the figures in this chapter can be found in Appendix 5. The model runs use the terms rlec (rural), telco (commercial), and muni (municipal) to mean specific types of deployments. Rlec or rural deployments are deployments in rural areas, regardless of if this deployment is conducted by a community in conjunction with a publicly owned utility, a large commercial entity such as a regional Bell operating company (RBOC), or a small commercial entity such as a rural local exchange carrier (RLEC). Telco or commercial deployments are deployments to suburban areas by a large carrier such as an RBOC. Muni or municipal deployments are deployments by a suburban municipality in conjunction with a publicly owned utility to that municipality.

6.1 Model Base Case

The graphs shown in this section are the base case of the model using the initial values as described in Chapter 5. The equations of the complete model including the values corresponding to the base case can be found at the end of Appendix 5.

The first two graphs, Figure 6.1 and Figure 6.2, show how the deployment of broadband and fiber-to-the-home to communities proceeds through the thirty year run of the model. The starting point of the model is summer 2004 data for deployment of cable modem, DSL, and fiber-to-the-home service to communities.

Cable modem and DSL service, labeled as 'other broadband' in Figure 6.1, are deployed to far more communities than fiber-to-the-home at the start of the simulation. Communities may adopt either fiber-to-the-home or other broadband during the run of the model. Initially there is growth in other broadband and slower growth in fiber-to-the-home deployment. The growth in fiber-to-the-home deployment levels off around year eleven of the model run with additional growth occurring around year eighteen.

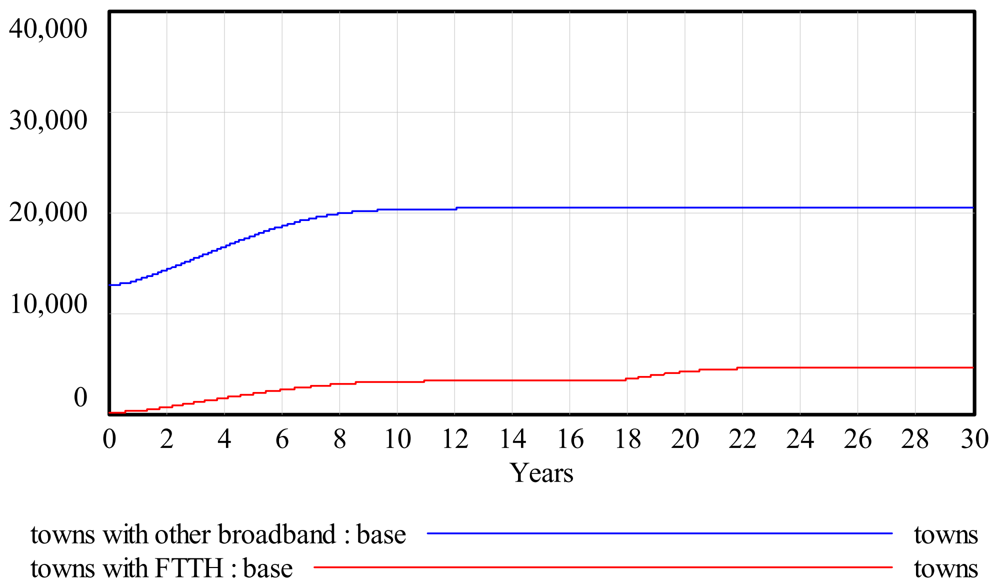

Figure 6.1: Town Broadband Deployment – Base Case

Figure 6.2 illustrates the type of deployments that make up the growth in fiber-to-the-home deployments. Initially, rural communities are the significant contributor to the growth rate. Municipal communities are a very small contributor to the growth in fiber-to-the-home deployments since the majority of suburban municipal communities already have some form of broadband service. Municipal deployments are barely visible as just slightly larger than zero in Figure 6.2 because of the scale of the graph. The increase in fiber-to-the-home deployments seen near year seventeen of the model run is due to suburban commercial deployments becoming viable.

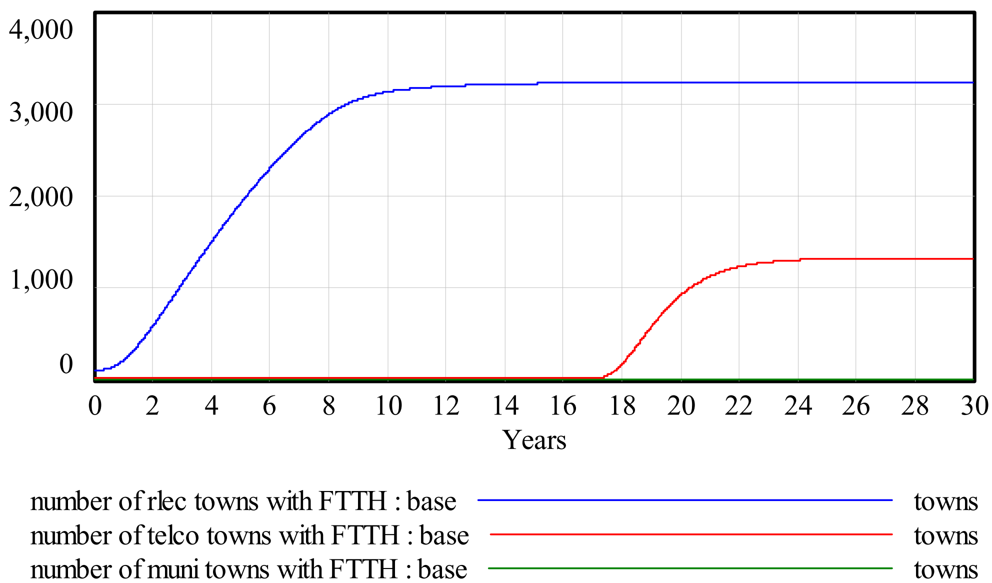

Figure 6.2: Fiber-to-the-Home Town Breakdown – Base Case

As shown in Figure 6.3, broadband adoption tracks the town availabilities with a slight delay. Customers begin subscribing to the service as it becomes available, and the network effect of additional customers being added to the service causes the number of subscribers to grow to a saturation point.

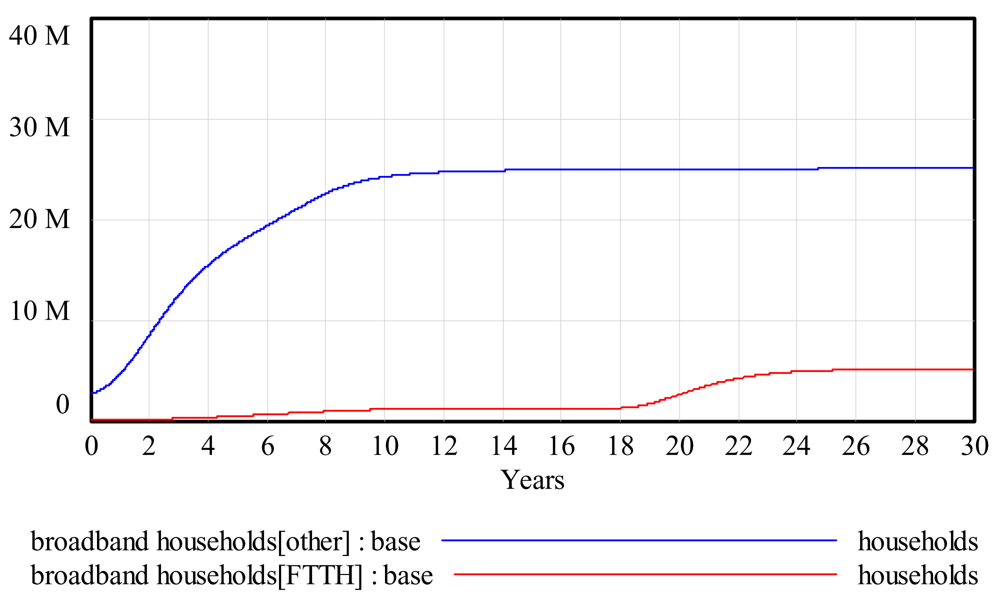

Figure 6.3: Household Broadband Adoption – Base Case

Figure 6.4 and Figure 6.5 illustrate the dynamics that cause commercial deployment to occur. Initially, deploying fiber-to-the-home in either rural or suburban regions is costly. Deployment to suburban communities is more expensive because of the need to support more potential customers and deploy more equipment and fiber to support those customers. The cost of deployment falls over time as the providers replace failing copper in their access networks with fiber and also as technological innovation drives the cost downward.

Deployment and recovery costs for competitive providers are also shown in Figure 6.4 and Figure 6.5. The scenario depicted in these graphs is of a competitive provider (CLEC) providing service in a region that does not already have service from an incumbent. The model assumes that competitive carriers do not have existing fiber as part of their access network infrastructure, so the cost of deployment is closer to that of a greenfield build. The result is a cost of deployment that is slightly higher than that for an incumbent carrier.

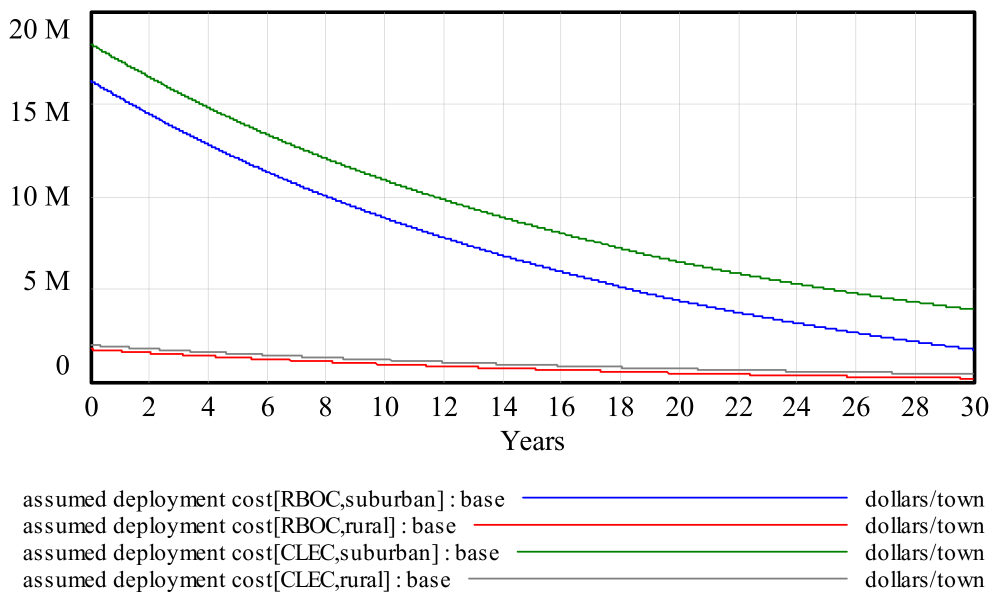

Figure 6.4: RBOC and CLEC Suburban and Rural Deployment Costs – Base Case

As the total cost to provide service falls, so does the monthly rate that would need to be charged to a customer to recover cost, as seen in Figure 6.5. Initially deployment of fiber-to-the-home is costly, and the amount that an incumbent or a competitive carrier would need to charge a customer just to recover the cost of deployment in the five year recovery time frame is well over the average cost of cable modem service in the United States ($42.09) (Warren Communications News Inc., 2004). Eventually the rate falls enough to be below the monthly consumer charge for cable modem service, and telecommunications providers build fiber-to-the-home since at that point it is cost competitive. The cost calculation neglects the operating costs, though those are tracked elsewhere in the model. It is assumed that the service provider is willing to take a loss initially to be the first provider to enter a region and that some of the costs may be recoverable through other optional services such as web hosting, fees for hostnames, or addresses for additional computers in a household.

Competitive carriers have a higher cost of deployment and thus a higher breakeven recovery fee as shown in Figure 6.5. The necessary cost per household for a competitive carrier to recover the deployment cost is about $50 higher for both rural and suburban deployments.

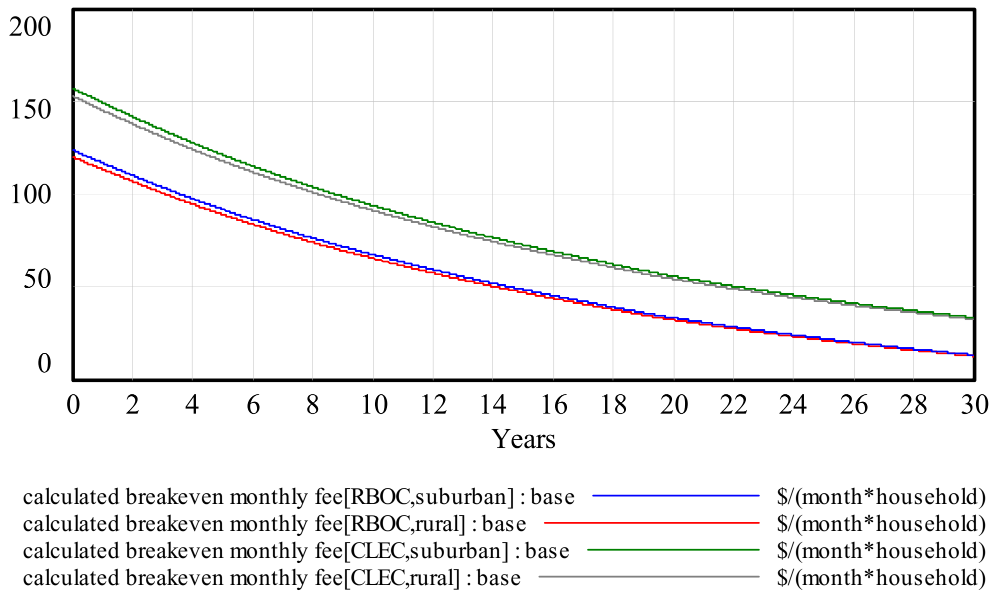

Figure 6.5: RBOC and CLEC Breakeven Monthly Fee – Base Case

The charts also illustrate that service to suburban customers is a slightly more difficult problem than providing service to rural customers from a cost perspective. Deployment in rural regions becomes cost effective sooner than in suburban regions. This is due in part to the fact that while rural installations are more spread out, they require less equipment overall than suburban installations. In many cases, suburban populations are also spread out over a fairly large geographic region, and require additional equipment to be able to support the total population.

If a competitive and an incumbent carrier compete with parallel fiber-to-the-home networks, the resulting breakeven monthly fee to recover costs in a five year time frame is shown in Figure 6.6. Since the model splits the original market between the two carriers, the monthly recovery cost doubles. This suggests that competing parallel fiber-to-the-home networks may not be viable, since the infrastructure is costly, and the market is limited.

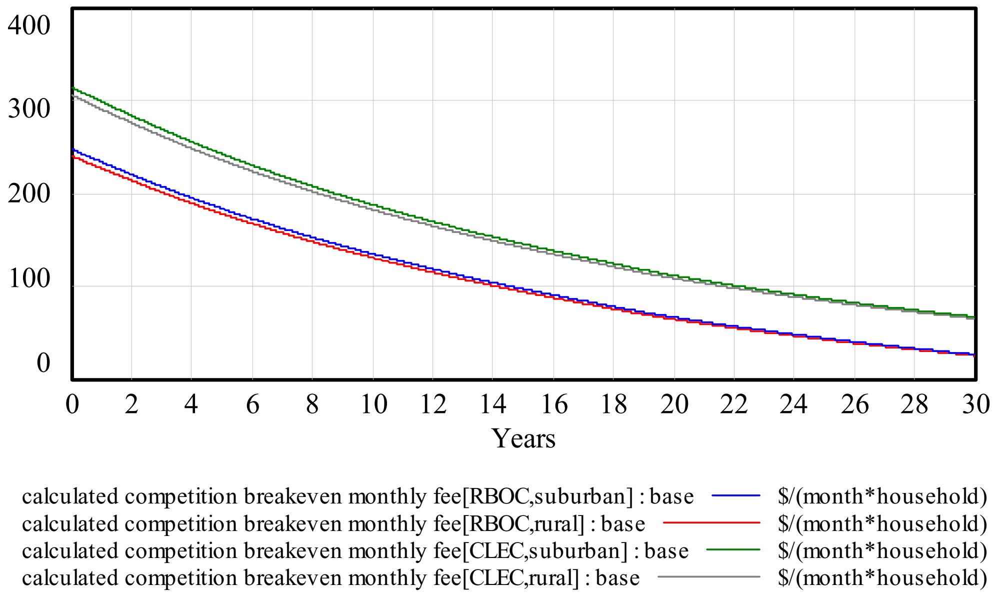

Figure 6.6: RBOC and CLEC in Competition Breakeven Monthly Fee – Base Case

6.2 Variations on the Base Case

The base case model runs suggest several variations: higher pricing for service; building additional fiber into the access network in anticipation of deployment of fiber-to-the-home; and generating additional demand for the service thereby increasing the take rate.

Fiber-to-the-home is designed to be able to provide voice, video, and data service. Assuming that it will only compete with cable modem service is too restrictive. The model is run again, setting competitive price to $80 to account for both video and data service. This change results in suburban commercial deployments significantly earlier, in year seven of the model run as opposed to year seventeen.

The resulting broadband availability curve is shown in Figure 6.7. Deployment starts significantly sooner than in the base case, so unserved suburban areas and households have service available to them much sooner. The model assumes that telecommunications carriers stop deploying DSL to unserved communities once fiber-to-the-home becomes economical. The result is more communities with fiber-to-the-home service than in the base case, as shown in Figure 6.8.

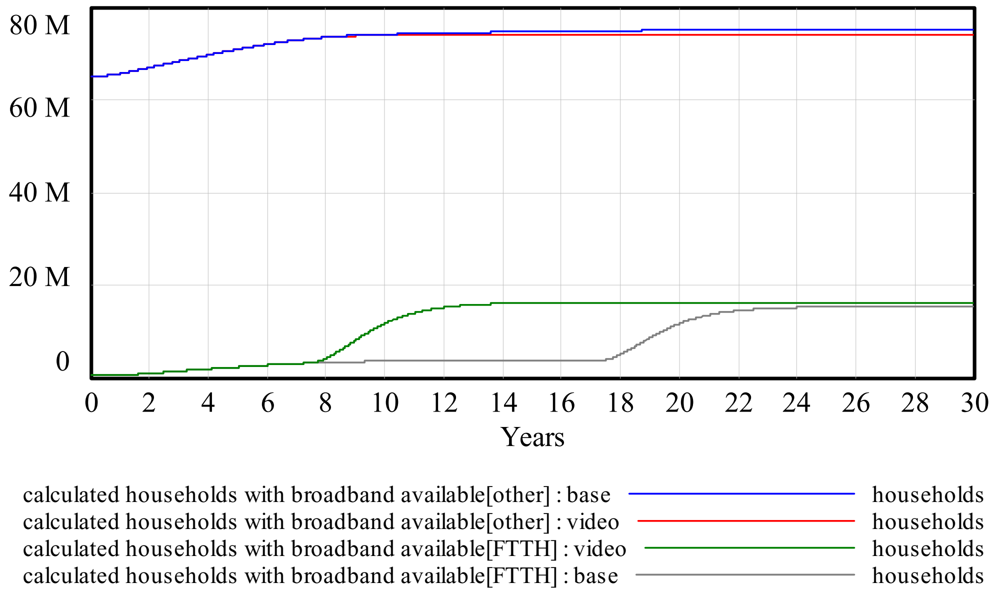

Figure 6.7: Household Broadband Availability – Video Pricing vs. Base Case

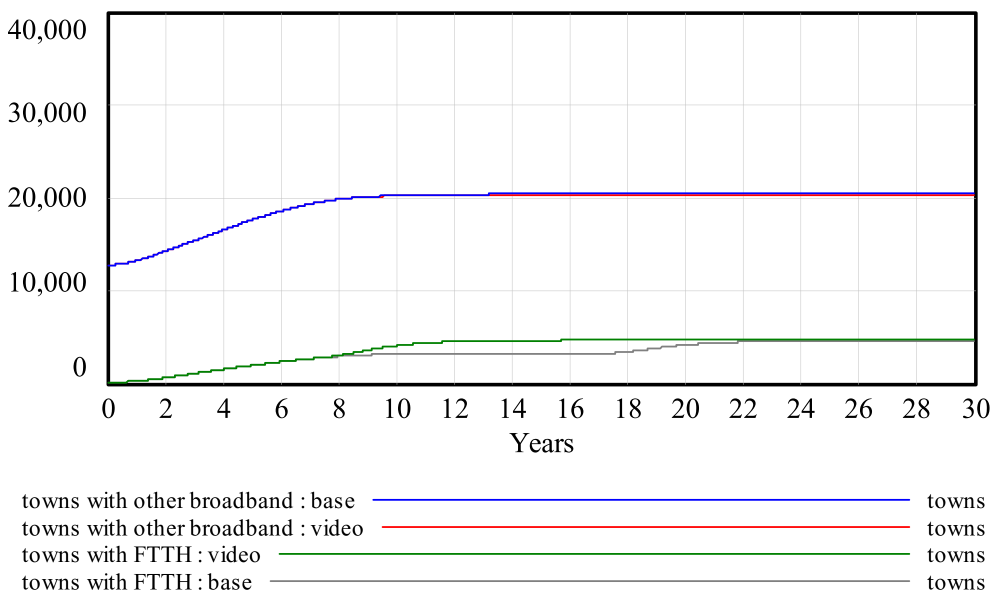

Figure 6.8: Community Broadband Deployment – Video Pricing

Commercial service providers can also accelerate deployment to areas without service by investing in their infrastructure in ways that would make deployment cost effective sooner. One of the key methods for bringing cost down is for the carrier to upgrade more of its local loop infrastructure to fiber. In many regions this would make DSL service unavailable to customers, however, in the regions that are being studied, incumbents are not providing DSL service over these lines. In its Triennial Review, the FCC left it up to the states to decide whether or not the incumbent could retire old copper cabling. However, there appear to be no regulations that prohibit the incumbent from installing and using fiber cable in place of existing copper. The existing regulations only specify that in the event of the copper cable being retired, the incumbent would be required to provide two voice grade channels to competitive carriers for the provision of local exchange service over the local loop fiber (Federal Communications Commission, 2003a). This is the identical regulatory scheme that would be in effect for a full scale fiber-to-the-home deployment. If the replacement rate of copper in the local loop is increased from 5% to 10% per year, deployment occurs in year thirteen of the model run. This slight increase in the growth rate of fiber in the local loop results in commercially viable deployment four years sooner than in the base case.

Table 6.1 shows the effect of all the model runs discussed thus far on the year that suburban commercial deployment begins. The table also includes the effect of a video and data competitive price combined with the effect of an increase in the rate of fiber installation in the local loop. The combination causes deployment to be commercially viable in suburban areas six years from the start date of the model. While this is still slow, it is three times faster than the base case of the model run.

Table 6.1: Suburban Commercial Deployment Trigger – Video and Increased Fiber

	Deployment Year
base case	17
fiber increase	13
video pricing	7
fiber increase and video pricing	6

Commercial viability is also sensitive to the initial take rate. If the take rate is assumed to be 50% rather than the model default of 30%, commercial suburban deployment occurs in year ten of the model run. This is seven years sooner than in the base case. Unlike the amount of fiber in the network or the types of services that an installation will be providing, the popularity of the service to the consumer is not under the direct control of the service provider. This is the notion of the "killer application" or a combination of applications that make fiber-to-the-home service a "must-have" for the consumer. Service providers can have some influence over this by developing services for their networks, or through marketing to help stimulate demand. Service providers may have difficulty in attracting application development by other companies until there is a critical mass of users of fiber-to-the-home service for those companies to market their applications to.

The adoption graph for households with a 50% initial take rate is shown in Figure 6.9. The corresponding deployment graph for fiber-to-the-home to communities is shown in Figure 6.10. The change results in more households adopting fiber-to-the-home due to its greater availability, primarily in rural communities.

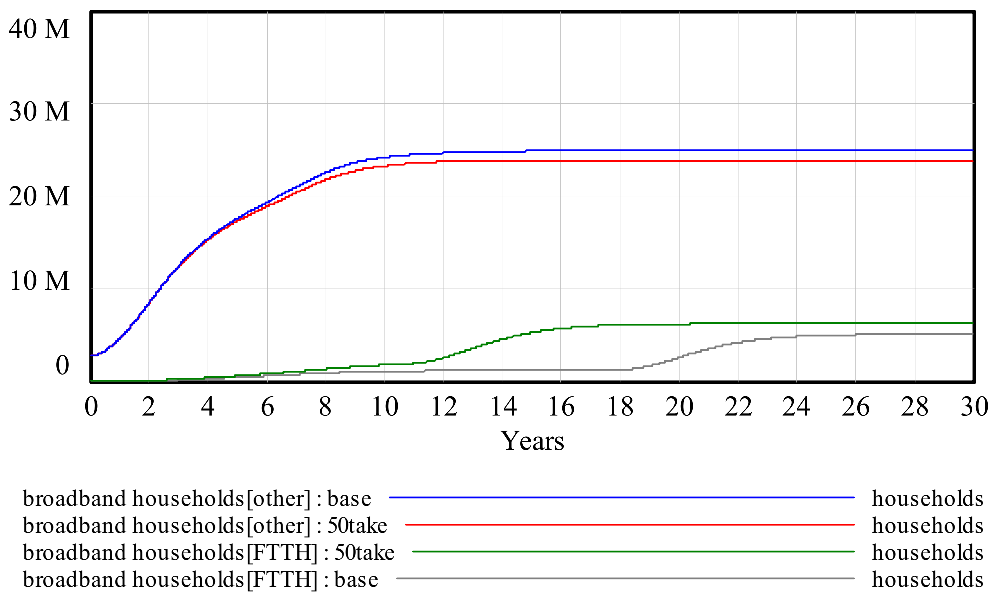

Figure 6.9: Household Broadband Adoption – 50% Take Rate

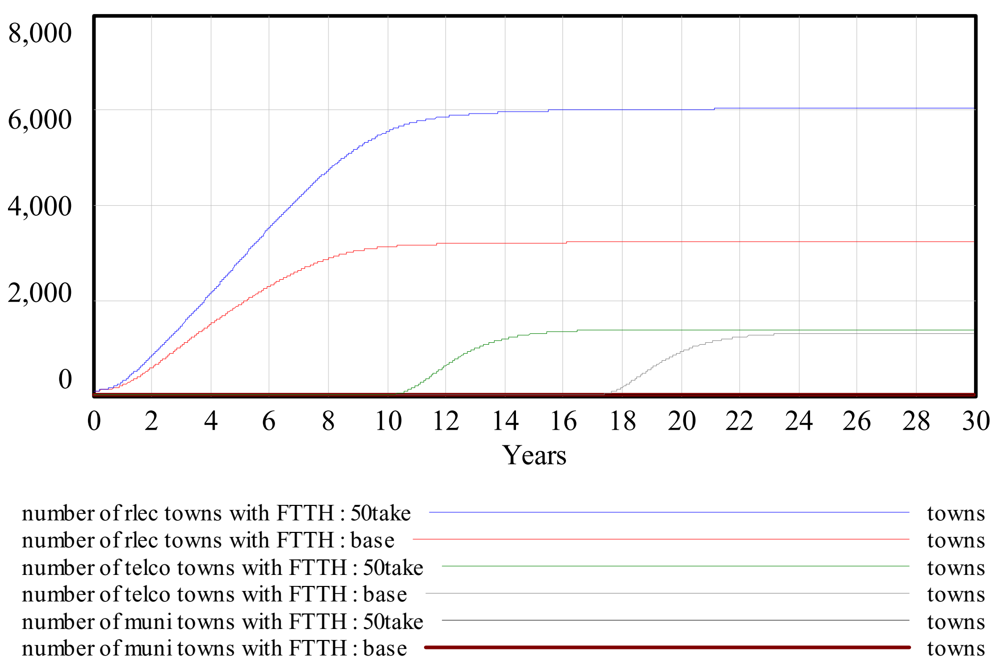

Figure 6.10: Fiber-to-the-Home Town Breakdown – 50% Take Rate

6.3 Municipal Deployments

As discussed in Chapter 3, suburban municipalities are well ahead of their commercial carrier served counterparts in the availability of broadband. Figure 6.11 shows the deployment of broadband to suburban municipalities through the model run. Fiber-to-the-home represents about thirty percent of the remaining deployments, due to its higher cost than other forms of broadband.

Figure 6.12 shows the effect that a twenty year bond has on the necessary recovery fee. As shown in the figure the monthly fee is significantly lower than for commercial deployments. However, a twenty year time frame is nearly four times the expected longevity of some of the equipment. The technology will probably have to be replaced at least once in that time frame, either because it has failed or because new desirable features are available in newer pieces of equipment. Thus a twenty year bond on this sort of infrastructure build may not make good financial sense.

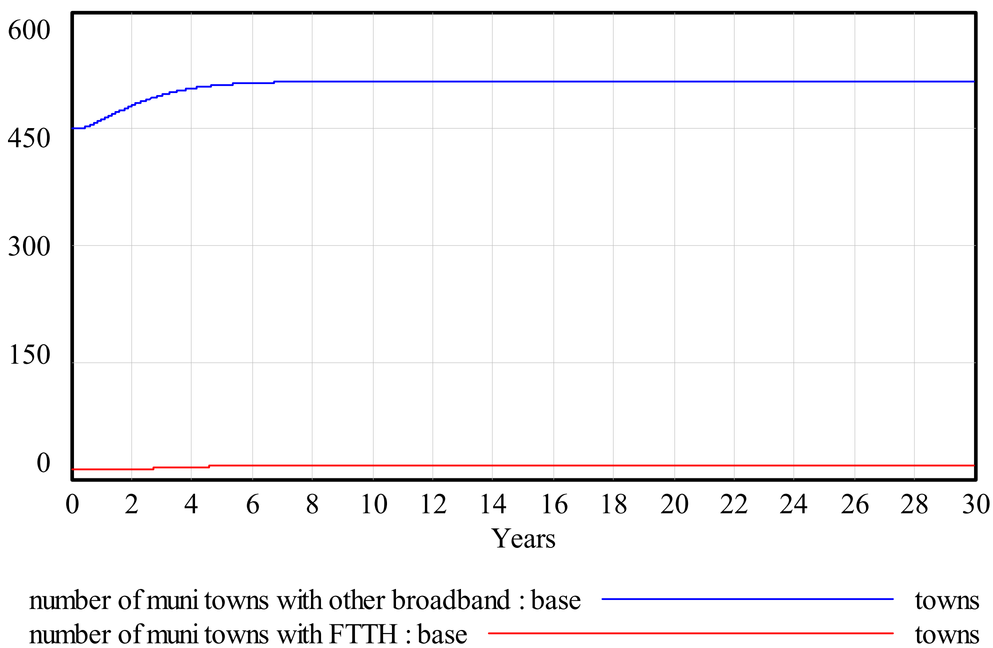

Figure 6.11: Municipal Town Breakdown – Base Case

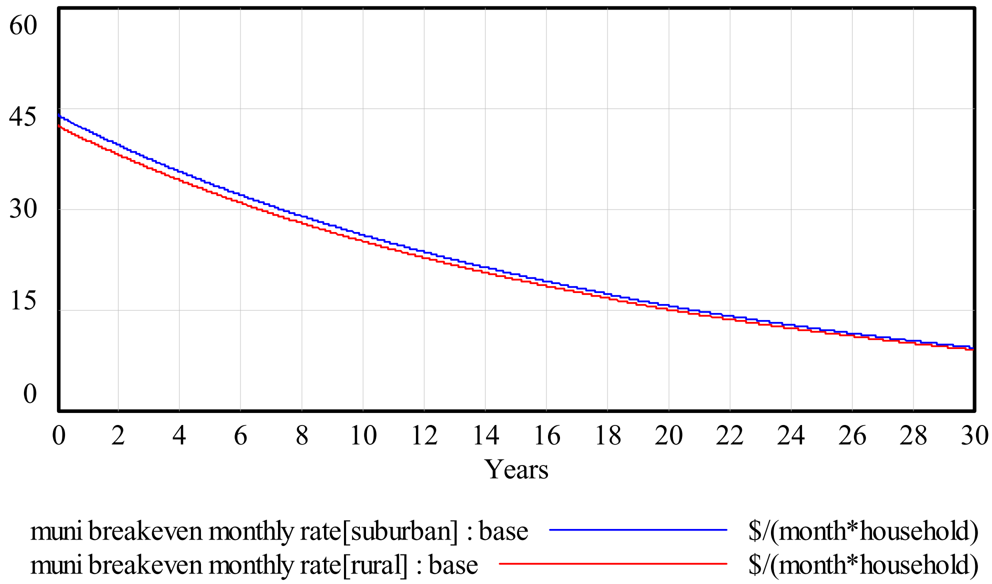

Figure 6.12: Municipal Breakeven Monthly Fee

More and more states have been passing laws restricting municipal deployment of broadband services. Restricting municipalities from deploying service results in the community service availabilities shown in Figure 6.13 and the corresponding household adoption graph shown in Figure 6.14. The figures show that restricting deployment by municipalities results in a delay in broadband availability for areas where commercial deployment is not already viable.

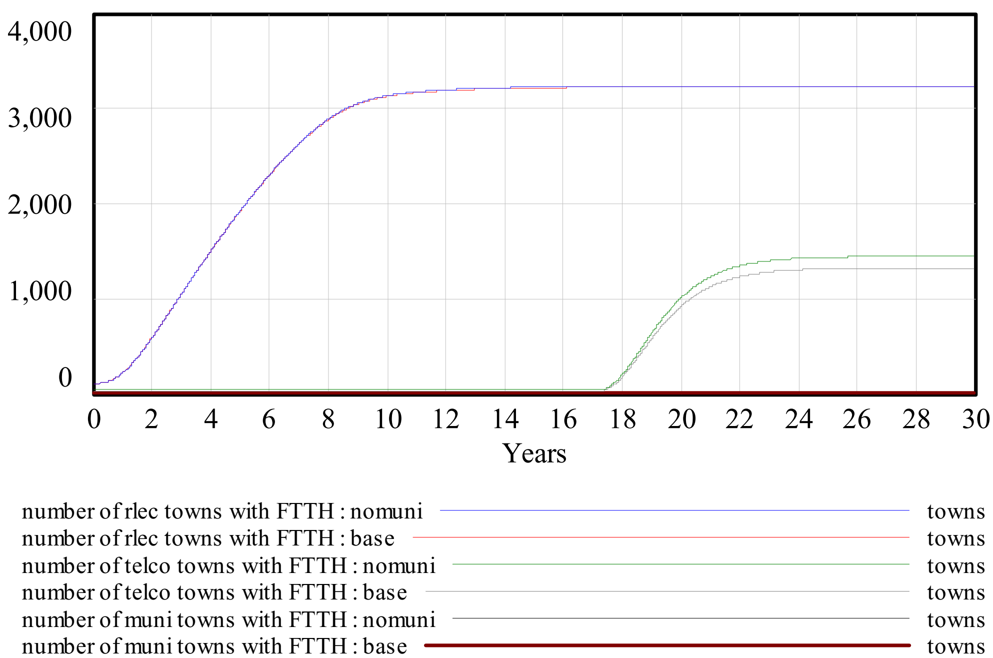

Figure 6.13: Fiber-to-the-Home Town Breakdown – No Municipal Deployments

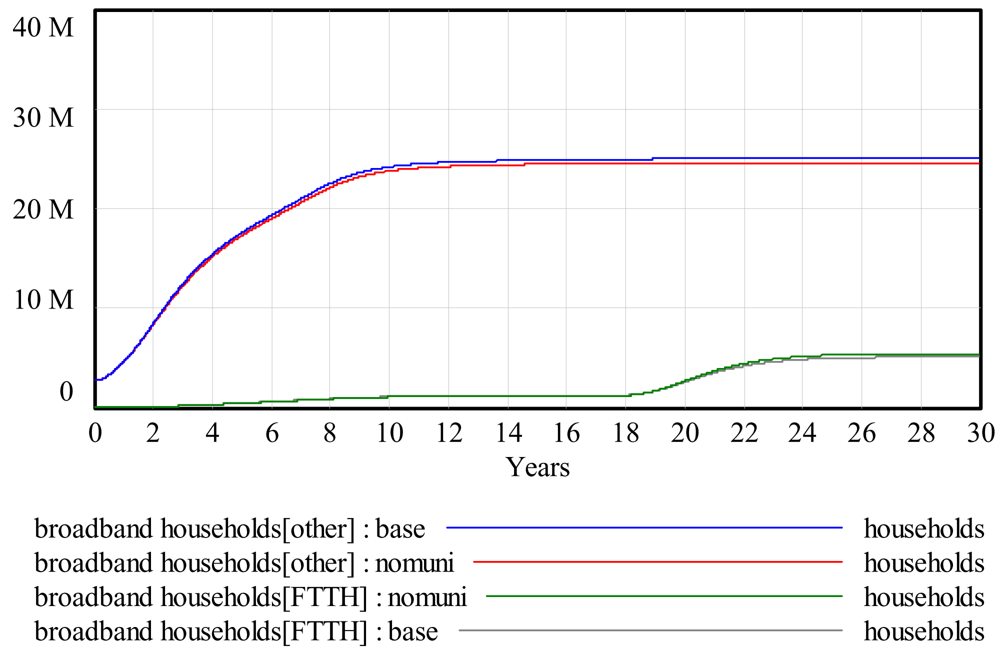

Figure 6.14: Household Broadband Adoption – No Municipal Deployment

6.4 Rural Deployments

Rural deployments rely heavily on funding available from the Rural Utilities Service to bring service to rural regions. The funding is technology neutral, so the model assumes that the amount given to any community is the average of the funding necessary to provide DSL service to the region and the funding necessary to provide fiber-to-the-home service to the region. The model also assumes that as more and more rural communities have service, providing funding to encourage deployment becomes less necessary, so the available funding is scaled back.

Figure 6.15 shows both the number of possible funded rural communities and the number of funding applicants over the length of the model run. The number of communities that can be funded increases as the cost of fiber-to-the-home falls over time, until a critical number of communities have service and then funding is scaled back. The number of applicants desiring funding is higher than the number of possible funded communities. The model assumes that some small portion of the communities are able to obtain enough outside funding to go ahead with deployment on their own, but the others just wait and apply again in the next cycle. In this respect, RUS funding acts as a delay on service availability.

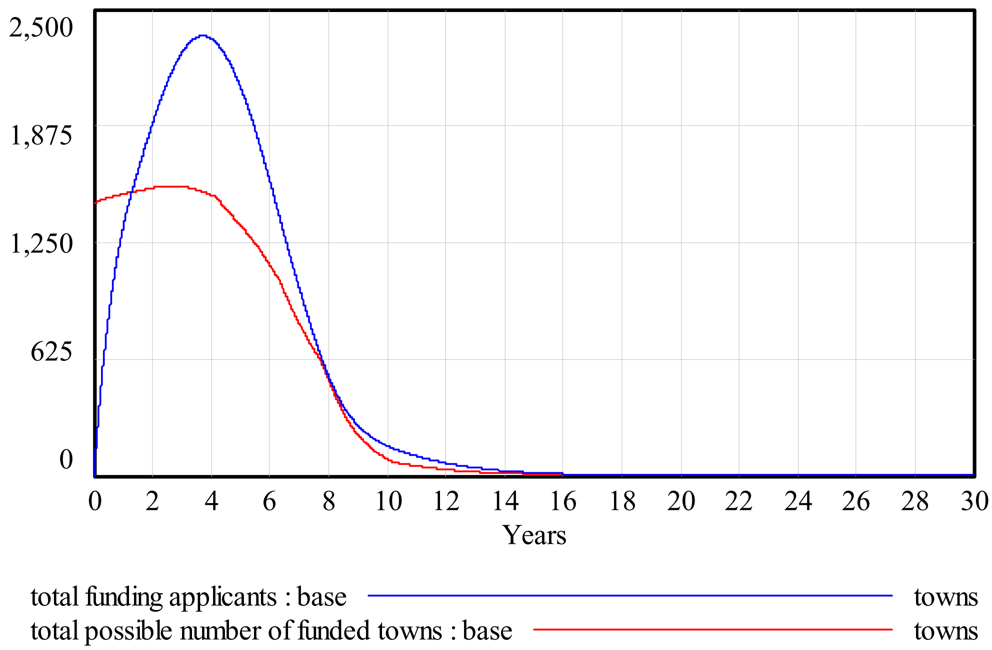

Figure 6.15: RUS Possible Funded Towns and Funding Applicants

The corresponding deployment of broadband service to rural communities is shown in Figure 6.16. In the simulation, it takes about nine years for service to reach most of the remaining rural communities. The growth of fiber-to-the-home deployment lags that of other broadband primarily due to the cost of the infrastructure.

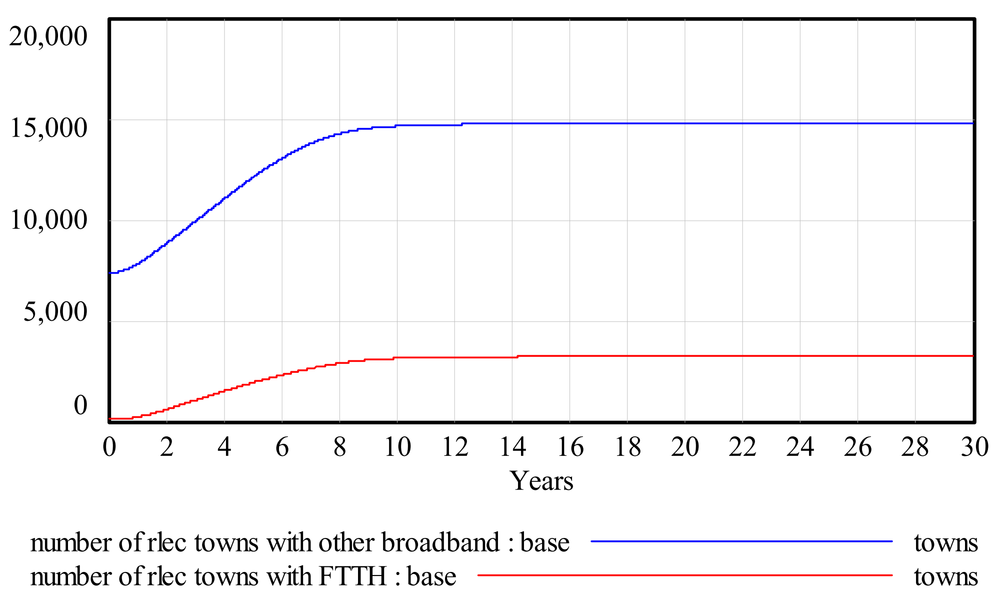

Figure 6.16: Rural Broadband Breakdown – Base Case

6.5 Effects of Deployment Scenarios on the Supply Chain

Figure 6.3 shows the characteristic trend of the user adoption market for broadband under the base scenario. Initially, deployment is slow, few people have the service and only rural communities and a few municipal suburban communities are deploying fiber-to-the-home. After the cost of deployment decreases to a point where commercial deployment is viable, the rate of deployment accelerates and so does the rate of adoption. Adoption of fiber-to-the-home then grows to a limit.

The assumptions used in the model to go from customers to transceiver deployments are as follows:

- deployments are 50% active and 50% passive;
- active deployments use the same type of transceiver at the remote terminal as at the customer premise;
- there is a five year equipment renewal rate;
- the equipment being deployed has greater capacity than required for customers; and
- standardized transceivers can be used at the customer premise for passive deployments and at both the customer premise and the remote terminal in active deployments.

The transceiver deployment graph that results from the market assumptions and the transceiver assumptions is shown in Figure 6.17. This graph shows that transceiver volume grows as deployment is happening, but then drops off to a replacement rate for equipment that fails. As shown in the figure, a standardized transceiver for fiber-to-the-home deployment sees a faster growth rate and a higher peak, and a similar decline to replacement rate.

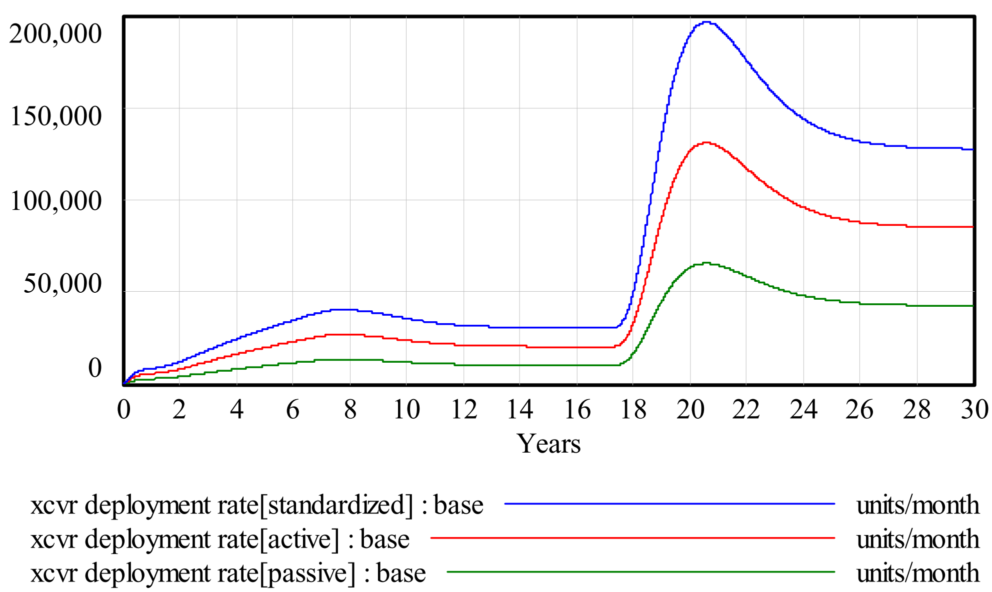

Figure 6.17: Transceiver Deployment – Base Case

The graph shows two peaks, the first corresponds to the deployment rate associated with rural and municipal deployment of fiber-to-the-home and the second much larger peak corresponds to commercial suburban deployment. For the transceiver industry, the graph means relatively low, but slowly growing volumes, then a rapid ramp up and decline to replacement. The rapid growth followed by a decline is a boom and bust cycle that leaves the industry with significant unused capacity by the end of the cycle.

The growth and decline to replacement is due to fiber-to-the-home deployments not requiring the leading edge in transceiver technology. Users are not demanding bandwidth anywhere near the capacity of the transceivers. This gives the carriers the ability to upgrade bandwidth by making changes in software without needing to replace equipment. The capacity of the equipment is much higher than current demand, and even near-future foreseen demand.

Laws limiting municipal deployments result in the transceiver deployment rate shown in Figure 6.18. Preventing municipalities from deploying broadband results in the consumer getting service later, but in more fiber-to-the-home customers overall, and higher transceiver volume in the peak of the deployment. While higher volume is temporarily good for the optoelectronics industry, this scenario still results in a sharp decline in volume, leaving excess capacity.

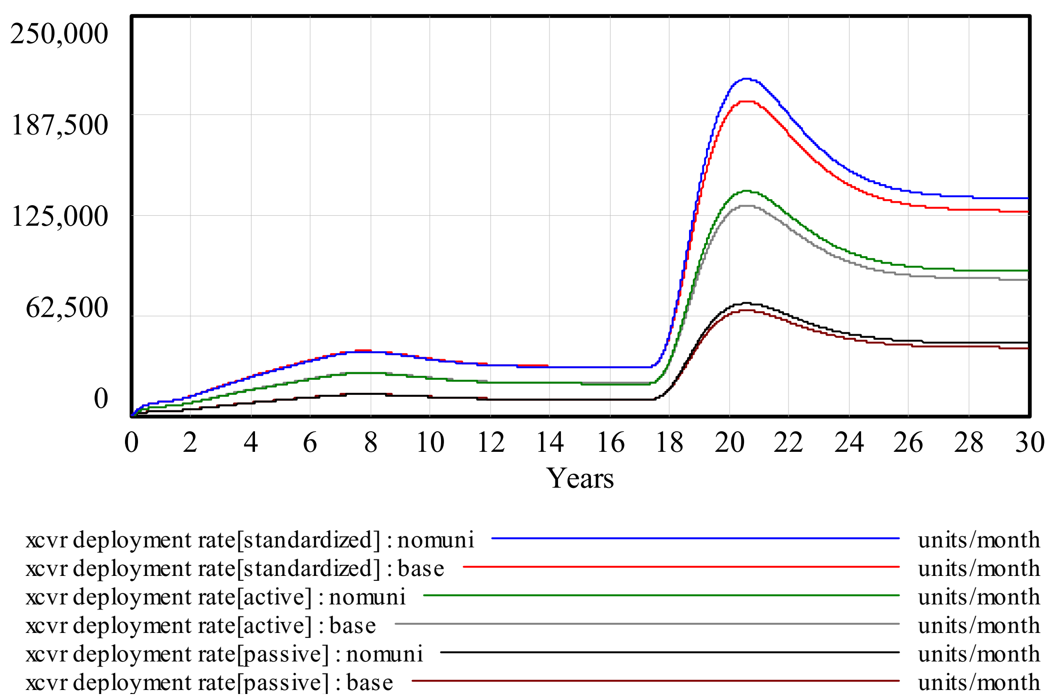

Figure 6.18: Transceiver Deployment – Base Case vs. No Municipal Deployment

Commercial deployments happening sooner such as in the video pricing scenario and the 50% take rate scenario result in the transceiver deployment rate shown in Figure 6.19 and Figure

6.20. The peak is slightly higher and is shifted sooner in time. Changing the timing of the deployment does not help the boom and bust pattern.

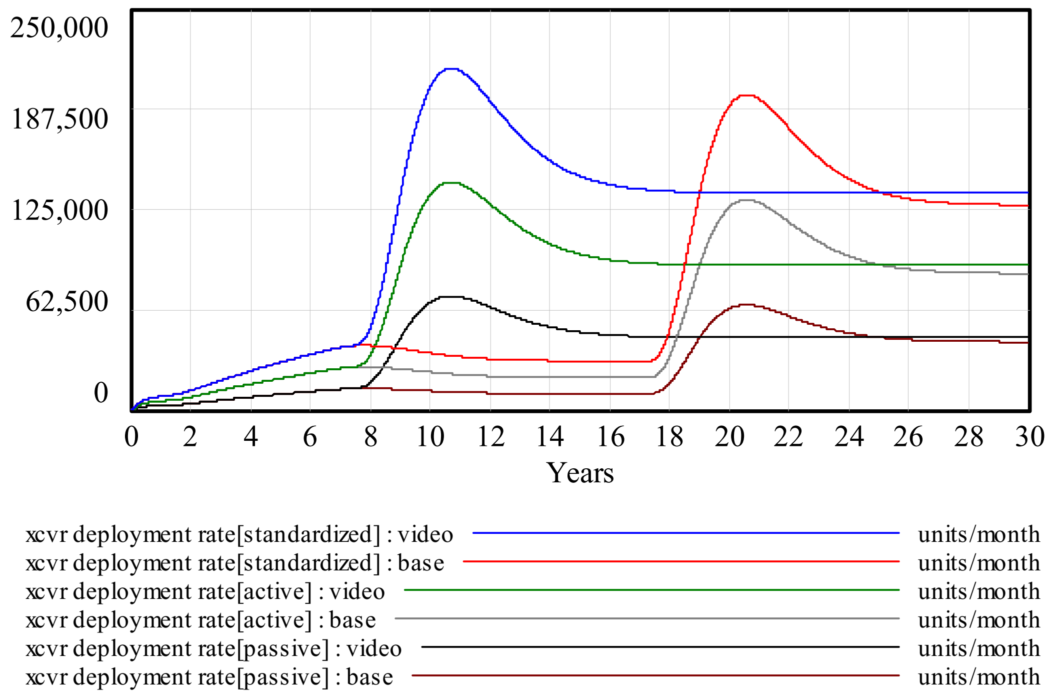

Figure 6.19: Transceiver Deployment – Base Case vs. Video Pricing

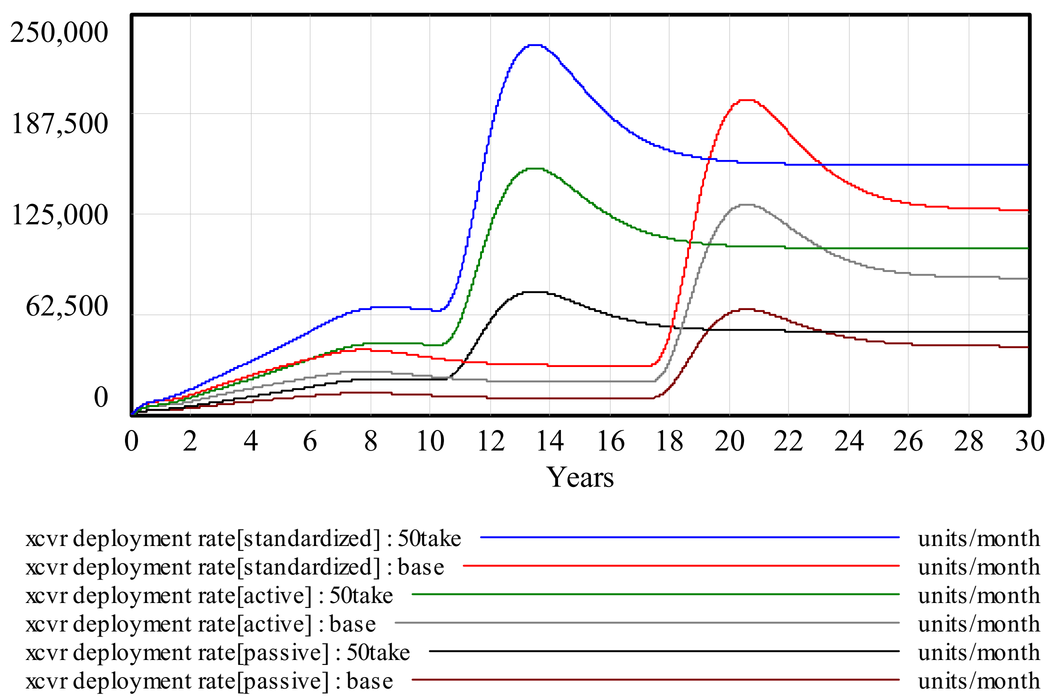

Figure 6.20: Transceiver Deployment – Base Case vs. 50% Take Rate

All deployment scenarios explored thus far result in a boom and bust cycle for the transceiver industry. The next section explores the extremes of that cycle, and possible strategies to mitigate it.

6.5.1 Availability in Three Years

On March 26, 2004, President George W. Bush called for universal affordable access to broadband technology by 2007 (Keto, 2004). For the purposes of the model, this means that all of the communities that do not have broadband, as demonstrated by the cable and DSL data, will deploy it within three years.

To implement this policy in the model, several changes needed to be made. Since the statement did not specify how this policy would be achieved, a separate community deployment model section was written that bypasses all decision processes by communities, telecommunications companies, and rural carriers to deploy broadband. As an extreme case test of the effects rapid universal access would have on the fiber-to-the-home supply chain, this run of the model assumes that all new deployments beyond the initial values are fiber-to-the-home deployments. The three year mandate expressed by President Bush included no details about how the policy would be achieved, so the model simply assumes that deployment happens to all communities that do not currently have broadband in the three years following the issuance of the mandate.

In a real world scenario this would be analogous to the government forcing the RBOCs to deploy broadband through some sort of incentive similar to the Universal Service Fund for telephony. Since the RBOCs are more heavily regulated than the cable companies, they are the logical choice for a government mandate. In most cases, the areas that do not already have broadband service are out of reach of traditional DSL, thus fiber-to-the-home would be the technology of choice. Assuming that all new deployments are fiber-to-the-home serves as a somewhat extreme case test of the effects rapid universal access would have on the fiber-to-the-home supply chain. The broadband availability resulting from the community deployment rate used in the default run of the mandate test scenario is shown in Figure 6.21.

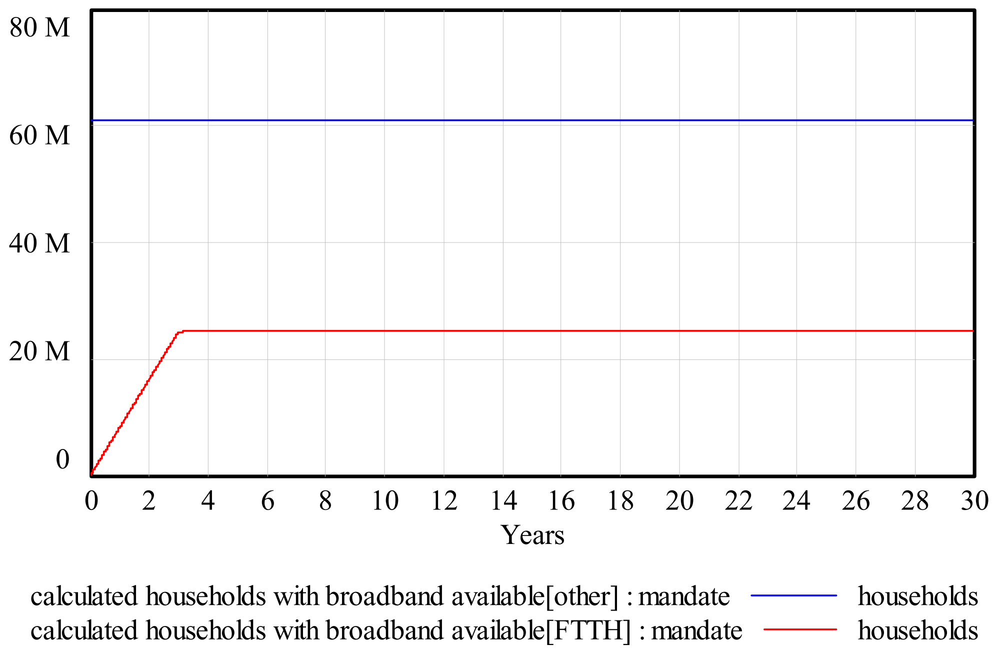

Figure 6.21: Broadband Availability – Three Year Mandate

Figure 6.22 shows the corresponding trend of user adoption for broadband. Initially, adoption is slow. Few people have broadband service, and even fewer have fiber-to-the-home service, so there is not a strong network effect, and marketing drives user adoption.

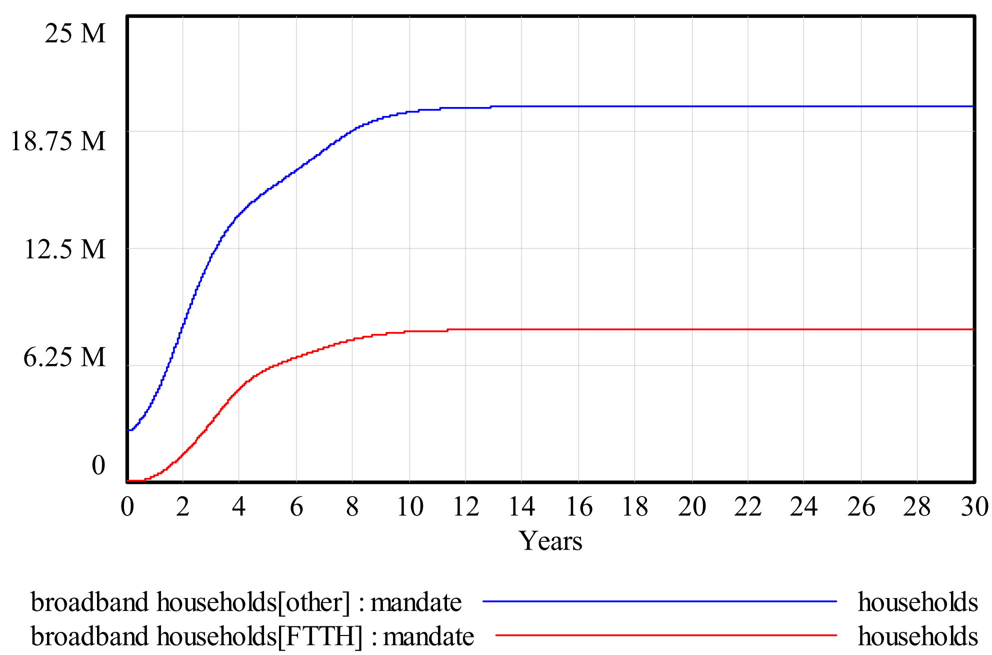

Figure 6.22: Consumer Adoption Trend – Three Year Mandate

The model assumes that the network effect that governs adoption is for all broadband, thus if a fiber-to-the-home customer interacts with a person that only has some other form of broadband available, that person is likely to adopt the broadband service available to them. The model also assumes that new customers are more excited about their broadband service than customers that have had the service for a while, or customers that are returning to the service after having left it. So a new customer is more likely to attract an additional subscriber to the service then a customer that has had the service for a while. As can be seen in the graph, once a critical number of users have signed up for service, adoption grows rapidly. The rate of adoption begins to slow once all communities have service available, and then reaches a limit.

The transceiver deployment graph under the mandate scenario is shown in Figure 6.23. This graph shows that transceiver volume grows as deployment is happening, but then drops off to a replacement rate for equipment that fails.

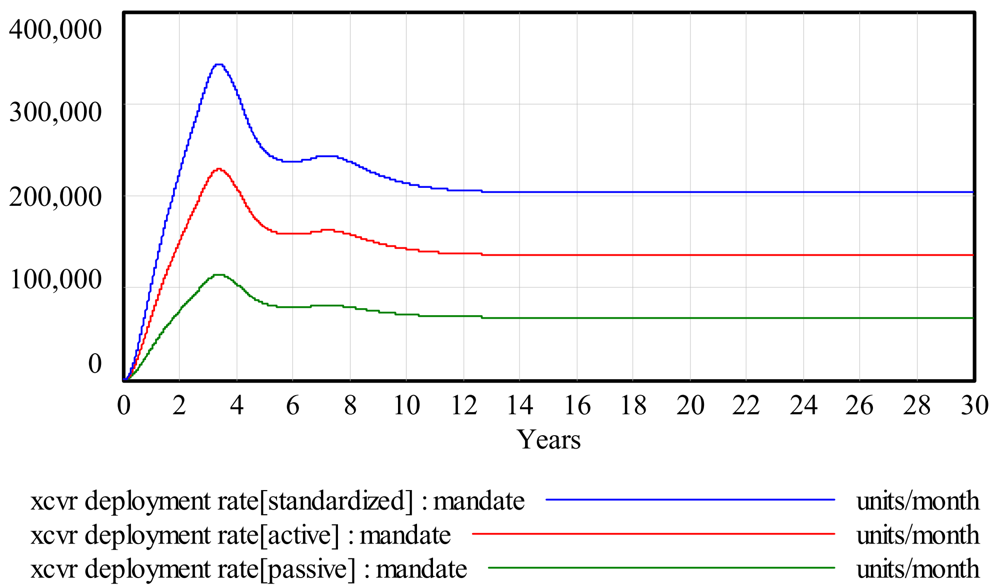

Figure 6.23: Transceiver Deployment – Three Year Mandate

As shown in the figure, standardizing transceivers for fiber-to-the-home deployment sees a faster growth rate and a higher peak, and a similar decline to replacement rate. Standardizing a transceiver just for the fiber-to-the-home market is not enough to prevent the growth and decline. This sort of growth and decline can be devastating to an industry, since it requires the industry to build up capacity to meet demand, however that demand is not sustained. The excess capacity is likely to cause financial difficulties in the industry and failure of individual firms.

Since the rapid growth and decline comes about due to a fictitious policy that assumes that telecommunications carriers will be able to rapidly deploy fiber-to-the-home, it is necessary to explore the effects of a slower deployment rate on the transceiver industry. A slower deployment rate, while not in the consumer or regulator's interests, may help mitigate the growth and decline and also better reflect the constraints of an actual infrastructure build.

6.5.2 Slowed Fiber-to-the-Home Deployment

If the deployment of fiber-to-the-home is slowed to a ten year deployment rate, still requiring that all of the communities that do not currently have broadband build fiber-to-the-home, the customer growth rate looks like that shown in Figure 6.24. As shown in the graph, it takes significantly longer for consumers in areas that do not already have broadband to adopt broadband technology. Delaying the deployment of broadband also causes adoption by people in the areas that already have it to slow slightly, since fewer customers cause the network effect to not be as strong.

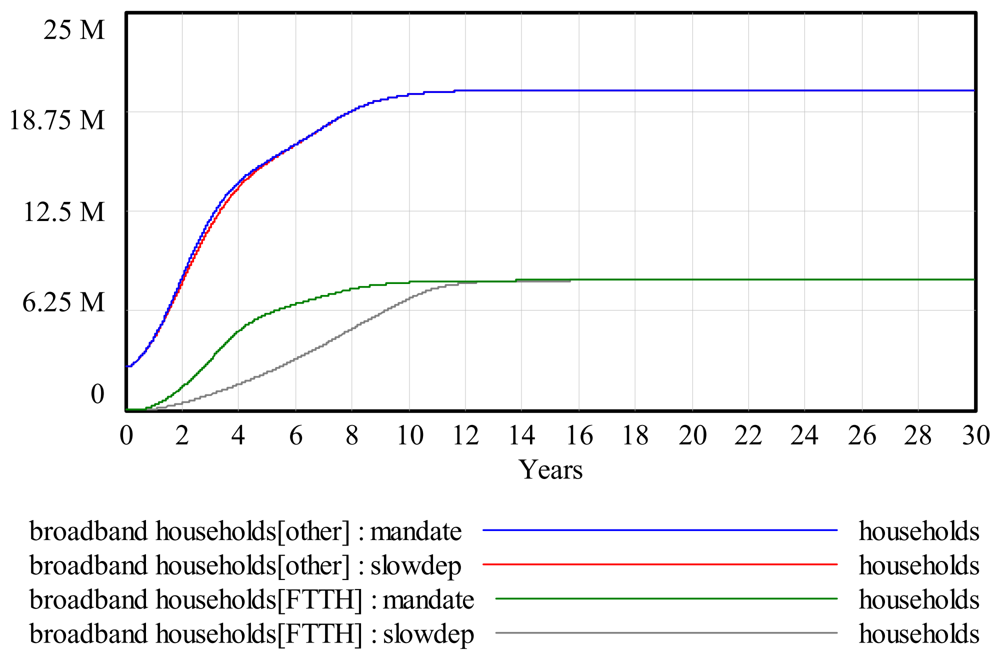

Figure 6.24: Household Adoption – Three Year Versus Ten Year Deployment Schedule

The slower infrastructure build rate and adoption rate results in the transceiver deployment rate shown in Figure 6.25. As shown in the figure, slowing the deployment rate does make the peak less dramatic and also lengthens the build-up period before the peak. Slowing the deployment rate even further, to a twenty year infrastructure build time, results in the user adoption rate shown in Figure 6.26. The corresponding transceiver deployment graph is shown in Figure 6.27. Delaying the deployment completion time even further from ten years to twenty years drastically reduces the peak seen under the three year mandated deployment schedule.

A slower deployment rate may be better for industry health in the short term because it delays the drop to a renewal rate and reduces that drop. However, it also results in much smaller overall production volumes for the industry and is far worse from a consumer perspective. Consumers have to wait much longer to be able to obtain broadband service, which is not in the interest of the consumer or of the policy makers.

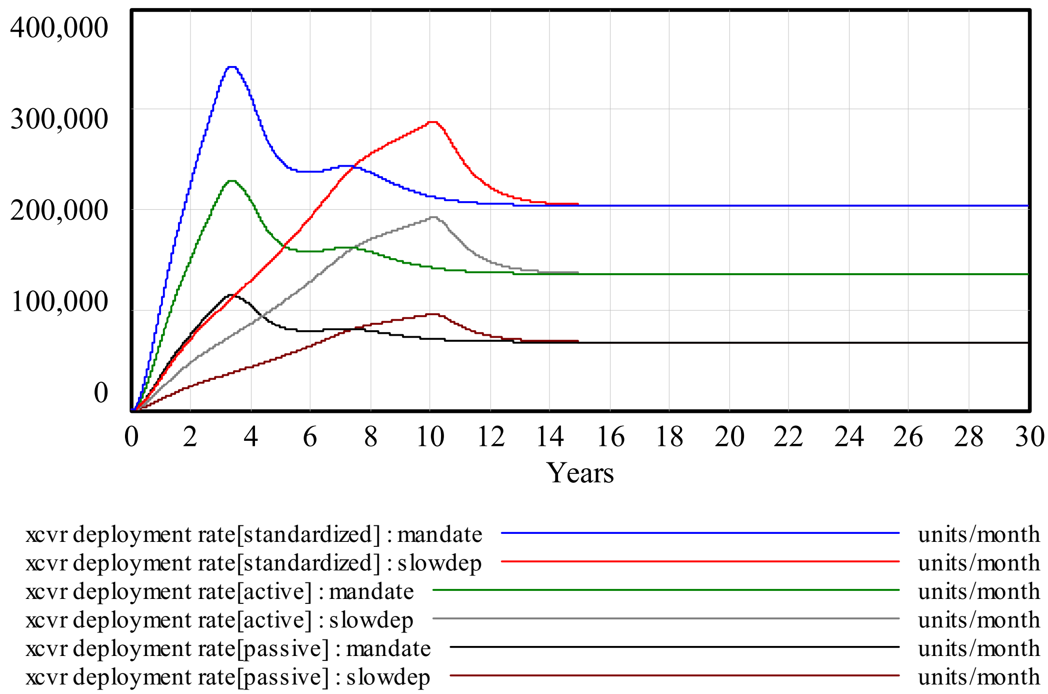

Figure 6.25: Transceiver Deployment –Ten Year Deployment Schedule

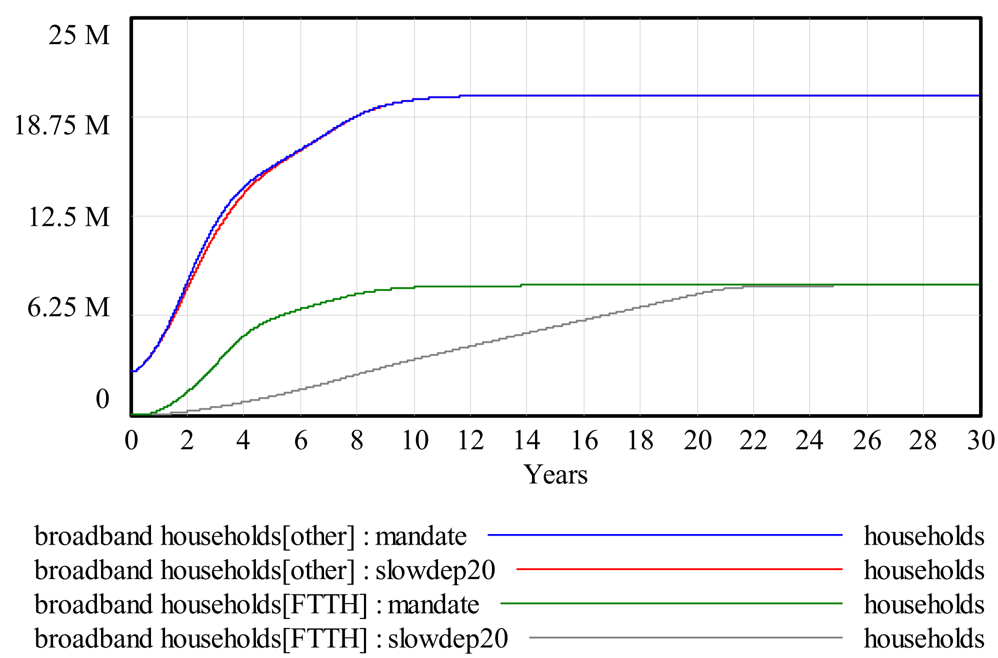

Figure 6.26: Household Adoption – Twenty Year Deployment Schedule

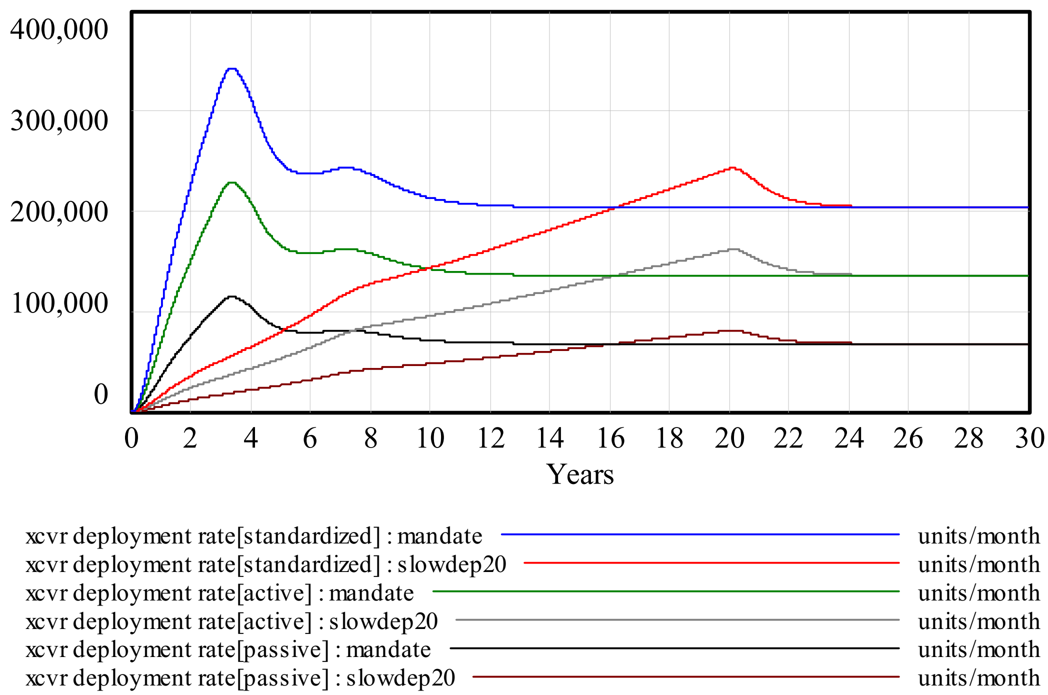

Figure 6.27: Transceiver Deployment – Twenty Year Deployment Schedule

6.5.3 Disposable Equipment and High Churn

Another potential way to prevent the ramp up and decline in transceiver deployment rate is a high customer turnover rate along with disposable customer premise equipment. If customer premise equipment cannot be redeployed by the service provider after a customer cancels service, that piece of equipment is disposed of. Any new customer additions or re-additions of former customers then require a new piece of customer premise equipment and a new transceiver.

The results of disposable equipment under the original set of conditions for a three year mandated deployment schedule are shown in Figure 6.28. This deployment assumes a thirty-five percent churn rate (Credit Suisse First Boston Equity Research, 2003). The churn rate is the fraction of customers that leave the service provider annually. The default assumption is that fiber-to-the-home will have a churn rate similar to that of cable modem service since the characteristics of the installation are similar.

As seen in the chart, forcing service providers to discard customer equipment with a thirty-five percent customer turnover rate is extremely beneficial to the transceiver industry. The peak still happens, but since the customer turn over rate is fairly high, much of the deployed equipment gets discarded before it fails, so new equipment deployment overwhelms the replacement rate.

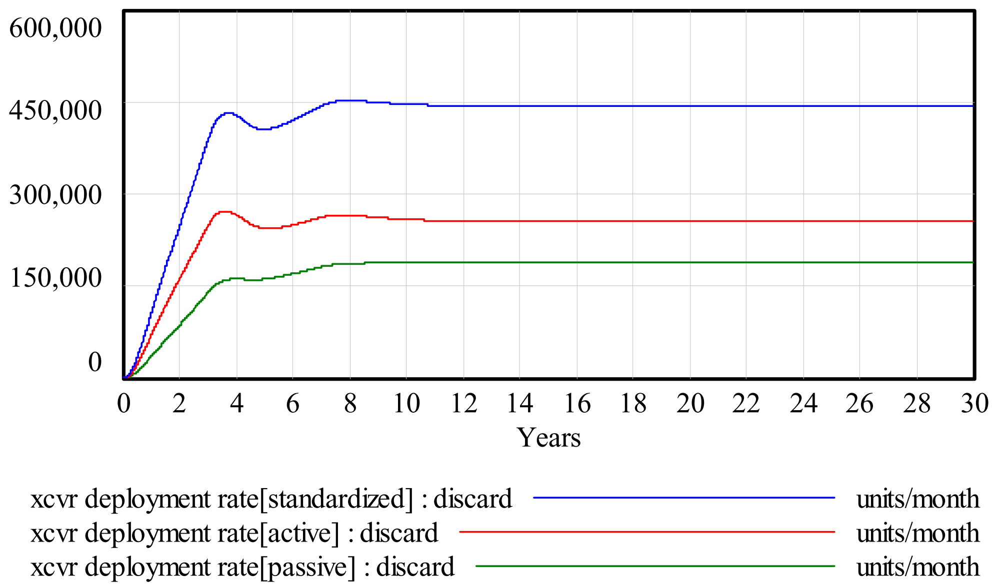

Figure 6.28: Transceiver Deployment – Disposable Customer Premise Equipment

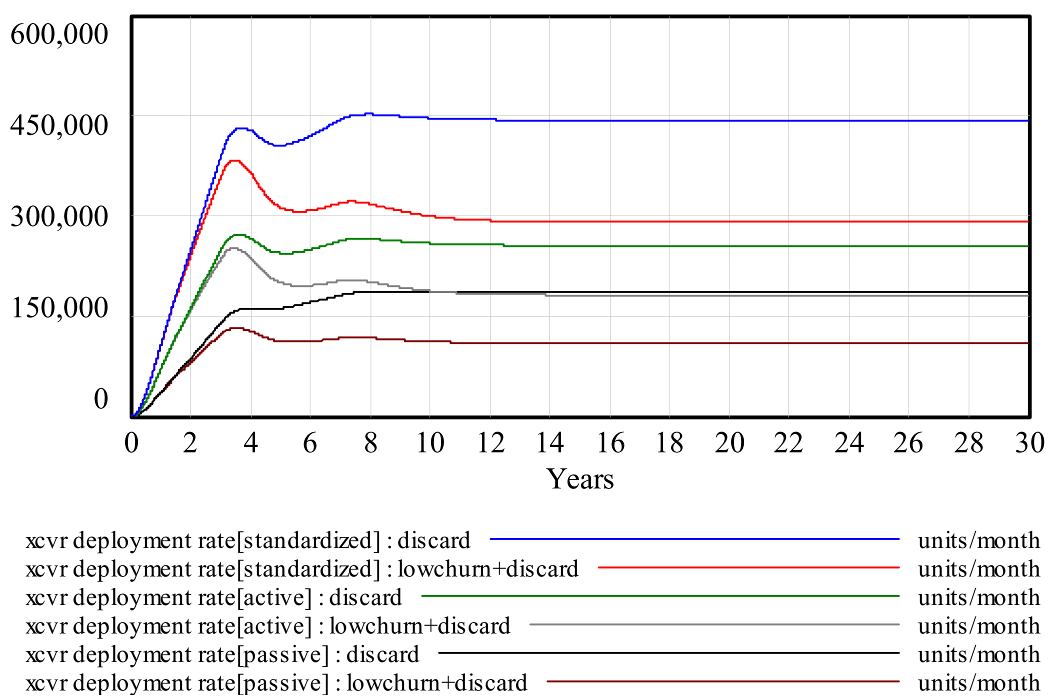

Figure 6.29: Transceiver Deployment – Disposable CPE Ten Percent Churn

A high customer churn rate is costly to the service provider since there is a cost associated with acquiring each new customer. Service providers are investing significant effort into improving customer satisfaction to reduce the churn rate. The effect of a churn rate lowered to ten percent is shown in Figure 6.29. As can be seen in the chart, the interest of the service providers in lowering churn is in direct conflict with the interest of the transceiver industry in eliminating the growth and decline. Even with disposable equipment, the lower churn rate offsets the benefit gained by requiring that any returning customer get a new piece of customer premise equipment.

6.6 Government Funding of Commercial Deployments

This scenario of the model explores allowing commercial deployments of fiber-to-the-home to obtain low cost loans from the government for their builds. The loan rate is set to four percent, which corresponds to the treasury rate for five year bonds, since the cost recovery period is held constant at five years. The result can be seen in Table 6.2. As shown in the table, the loan has a much smaller effect on deployment than any other factor considered. This suggests that loans to commercial carriers for deployment are not the best use of government funding. Regulators could better serve their interests of making broadband available by allowing telecommunications to freely compete with cable operators for the provision of video service and rearchitecting regulation to be based on the service provided, not on the type of entity providing the service.

Table 6.2: Suburban Commercial Deployment Trigger – All Factors

	Deployment Year
base case	17
4% federal loan	15
10% yearly local loop fiber growth	13
50% initial take rate	10

6.7 Deployment Under a Resale Scenario

Resale of lines to competitors is an issue that is frequently raised in telecommunications regulation. The model tests the effects of the resale of the fiber local loop despite the requirement to unbundled fiber infrastructure having been removed from the list of unbundled network elements in the Triennial Review Order.

A pricing scheme that is very similar to that employed for unbundled copper local loops results in deployment in year eighteen of the model run. As discussed in Chapter 4, the model assumes that the price recovered from resale of a line is 65% of the price that the provider would otherwise charge for the line. This run of the model assumes that the competitor is able to acquire 15% of the incumbent's customers. The required resale of fiber lines in this scenario results in commercial carriers delaying their decision to deploy fiber-to-the-home beyond the deployment time seen in the base case.

The default TELRIC run assumes that only fifteen percent of the RBOCs customers would take service from a competitor via resold lines. If that assumption is relaxed and fifty percent of the RBOCs customers take service via resold lines, deployment is delayed even further as shown in Table 6.3.

Table 6.3: Suburban Commercial Deployment Trigger – TELRIC Lines

	Deployment Year
base case	17
15% TELRIC	18
50% TELRIC	19.5

6.8 Future Work

While the model was being developed, several areas for future study were identified. Many of those areas revolve around data issues. The model uses cost estimates from CMU for the majority of the infrastructure costing. Those cost estimates are based on an average number of households in the communities that are significantly higher than those obtained from the Census data. To make up for the discrepancy, the CMU cost data is scaled linearly for use in the model. It is likely that the costs would not scale linearly with the number of households in the service area, and a better estimate of how costs scale might yield somewhat different results in when deployment becomes cost effective for telecommunications companies. The cost estimates also do not include incremental innovation and cost reduction associated with innovation. The model assumes an overall five percent per year reduction. A better idea of which elements of the deployment are subject to innovation effects and the magnitude of those effects would provide a better estimate of how deployment costs change over time.

The optoelectronics industry claims that it can support whatever volume fiber-to-the-home generates. A useful addition to this modeling work would be to explore that assumption and model production capacity for the industry and the effects of product manufacturing and delivery delays on the deployment. While the industry may be able to meet any demand generated by fiber-to-the-home deployment, in the interest of industry health, firms may decide not to ramp up capacity far enough to serve the peak demand shown in many of the transceiver deployment graphs in this chapter. The effect of such a decision could be included in the model and explored through additional simulation scenarios.

Difficulties with the use of the Yankee Group survey data on price and content sensitivity of users were revealed in the attempts to calibrate the model to the FCC's data on user adoption of broadband. The Yankee Group data is from 2002, and it is quite likely that as the popularity of the Internet has grown and more users have left dialup Internet service for broadband, their price and content sensitivity has changed. A better estimate of the effect that price and content has on users would allow these effects to be separated in the model and evaluated individually.

The model assumes that all rural communities can obtain funding from the Rural Utilities Service. This causes broadband adoption by rural communities to be limited by the amount of funding available. While this funding limitation would still exist if fewer communities were attempting to get funding for deployment from RUS, the model likely overestimates that effect. An estimate of the number of rural communities serviced by rural local exchange carriers would allow the rural communities to be split into RBOC deployments and rural and municipal rural deployments that are eligible for RUS funding.

The focus of the model is on communities that do not currently have service. From some of the recent deployment patterns of companies such as Verizon to communities like Keller, Texas, it appears that fiber-to-the-home deployments are occurring to communities in regions that already have either partial or complete DSL service. Given the economics of fiber-to-the-home deployment discussed earlier in this chapter, these deployments appear designed to be in direct competition with cable providers for voice, video, and data service. Splitting the portion of the model that accounts for other broadband deployments into deployments served by DSL and by cable modem providers would allow the model to have a broader scope and examine the characteristics of competition between cable and fiber-to-the-home.

Chapter 7: Conclusions

7.1 Introduction

Chapters 2 through 4 described factors affecting fiber-to-the-home deployment. Chapter 5 gave an overview of the model and how the factors were incorporated into model building. Chapter 6 presented the results of various runs of that model. This chapter focuses the learnings from model development and results into key areas that need to be addressed for broadband service to reach regions that do not have service and to make fiber-to-the-home a viable technology. The areas are: a better understanding of the current state of deployment so that regulation that encourages adoption is possible; recognition of the conflicts of interest that are present in the fiber-to-the-home supply chain and actions that can be taken to resolve those conflicts; and a better understanding of the effects that potential regulatory policies have on deployment. The chapter concludes with recommendations to policy makers.

7.2 Implications for Monitoring Deployment

The Federal Communication Commission's data on deployment drastically overstates broadband service availability.

As shown in Chapter 3, of the 18,403 rate centers associated with wireline carriers, 65% do not have DSL service. Correlating the rate centers with the communities they serve shows that 5,261, or 21%, of communities identified by the 2000 U.S. Census have DSL service. The FCC does not track DSL capability as it relates to rate centers, switches, or central offices. The ARMIS infrastructure report does track switches with ISDN capability, so there is some precedent for tracking specific switch capabilities.

Exploring data on cable deployment combined with Census places, shows an additional 7,699 places with cable service that do not have DSL service as discussed in Chapter 3. This brings the percent of places with some form of broadband service (in most cases advanced services lines) to 51%. Aside from requesting the number of advanced and high-speed services customers from cable providers, the FCC does not track cable infrastructure deployment.

The data discussed in Chapter 3 slightly understates deployment since it neglects satellite, wireless broadband, and even fiber-to-the-home subscribers, but according to the FCC's own numbers those types of service represent a small fraction of total lines (7.6%).

The FCC publishes data on the state of high-speed and advanced services line deployment every six months. According to the data for the period ending June 30, 2004, 94% of U.S. zip codes have the presence of high-speed subscribers (Federal Communications Commission, 2004b). In its report the FCC suggests that the existence of subscribers in 94% of zip codes may not directly translate to service availability. Yet, it still uses this subscriber number to form its conclusion that deployment to all Americans is proceeding in a reasonable and timely manner.

The FCC needs to track DSL capability of central offices.

Measuring the status of deployment of high-speed and advanced services lines solely by the presence of those lines in a particular zip code appears to drastically overstate the availability of these services. The communities that the cable and DSL data sets identify as without service tend to be in rural regions where zip codes are large geographic regions. The FCC may be able to obtain a better picture of the state of availability of broadband service to all Americans by tracking lines along with tracking the state of the infrastructure that provides that service. Along with tracking ISDN capability of switches, the FCC could track the DSL capability of central offices.

The FCC needs to track the state of cable infrastructure capability and deployment.

The lack of tracking of cable infrastructure also presents a problem. Since cable modem service is a primary method of providing high-speed and advanced services lines (83% as of June 2004), a metric of deployment needs to include some idea of what percentage of cable networks are actually capable of providing the service. The FCC's social contracts with cable providers to encourage them to upgrade their networks were a step in the right direction, but without better monitoring there cannot be a clear picture of the real availability of service across the United State.

The FCC needs to track fiber in the local loop.

The FCC used to monitor the percentage of fiber in the subscriber plant. This data was published in the end of year Fiber Deployment Update. The last update, published in 1999 discussed the presence of fiber in the subscriber networks of local telephone companies and competitive providers (Kraushaar, 1999). While the presence of fiber in the subscriber network is not a direct indicator of the presence of high-speed or advanced services lines, it does provide a measure of the difficulty of transitioning to a network that can provide voice, video, and data service. The more fiber in the access network, the less costly it becomes for a provider to provide higher speed services to the subscriber, either via remote DSLAMs or via fiber-to-the-home.

The FCC needs better measurements of the availability of broadband in a region. A single subscriber in a zip code meaning service is available in that zip code is too simplistic and appears to drastically overstate availability. To have an accurate understanding of the state of broadband deployment in the United States, the FCC needs to start monitoring DSL and cable infrastructure and reinstate tracking of fiber in the access network.

The FCC should also consider revising its definition of high-speed and advanced services lines to a more forwarding looking definition that changes as bandwidth demands change.

7.3 Implications for the Optoelectronics Industry

Fiber-to-the-home is not a panacea for an already struggling optoelectronics industry.

The optoelectronics industry, along with the entire telecommunications sector has seen significant investment and market capitalization decline since the boom years of the late 1990s. Figure 7.1 shows gross investment in the telecommunications sector from 1992 through 2002 (Hassett & Kotlikoff, 2002). This graph shows the peak of the telecommunications bubble and the start of its decline.

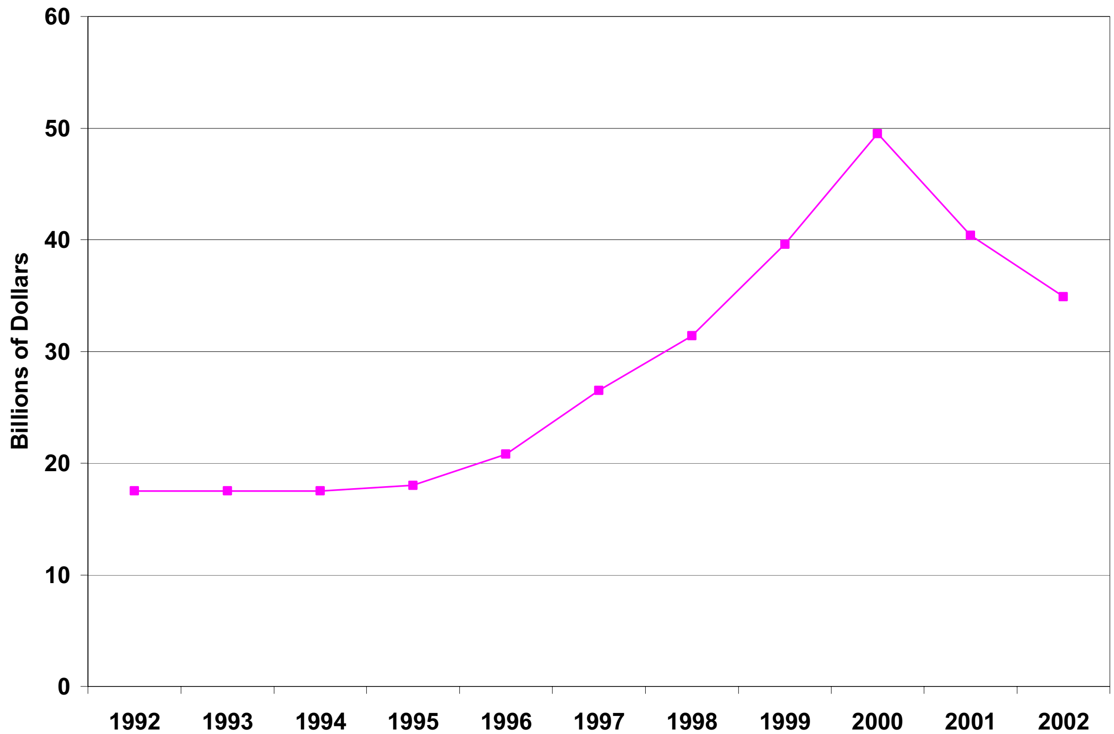

Figure 7.1: Telecom Gross Investment

Figure 7.2 shows the market capitalization weighted index of companies that the Dow Jones considers as being in the fixed line telecommunications sector from 2000 through 2005 (MarketWatch, 2005). This index includes companies such as BellSouth, RCN, SBC, Sprint, and Verizon. The decline corresponds to that shown in Figure 7.1 and the low market capitalization continues through to the present day.

Figure 7.2: Dow Jones Fixed Line Telecommunications Index

The Light Reading Index was put together to track the state of telecommunications equipment and component suppliers starting in the year 2000 (Light Reading Inc., 2005). The index is market capitalization weighted and shows a similar trend to the Dow Jones fixed line telecommunications index. The component supplier industry also has not yet recovered from the downturn that began in the middle of the year 2000.

Figure 7.3: Light Reading Index of Optical Manufacturers

The industry is already facing financial difficulty and fiber-to-the-home deployments do not require the cutting edge in technology, especially at the customer premise. As shown in Chapter 2, all of the existing standards deliver far more bandwidth than the consumer can currently use. The systems are designed so that providers can implement upgrades in bandwidth through software, without having to swap out components. For transceiver manufacturers this means that once initial deployment is passed, the driver for replacement will be equipment failure as opposed to technology upgrade leaving excess capacity from the deployment ramp up.

In current broadband deployments, customer premise equipment has an expected life of five to seven years. This time frame is far shorter than the twenty-year standard for long-haul components, yet it is still too long to prevent overcapacity once networks are deployed. Service providers have reduced their reliability expectations for equipment deployed at the customer premise to be more in line with that of consumer electronics than of long-haul equipment.

The optoelectronics industry needs to look beyond the telecommunications market to standardization across markets.

Regulators at the federal, state, and local level have an interest in promoting telecommunications technology and ensuring that the technology becomes available to all consumers. When these regulators set policy they examine the problem from the perspective of the consumer and consumer choice. This results in policies that are designed to benefit consumers from a price and service perspective, and also to assist new entrants in providing competition in the market.

Rarely do telecommunications policies look beyond the consumer and the telecommunications companies to the effects on the remaining portions of the supply chain. The optoelectronics industry is at the opposite end of the supply chain from the consumer and thus subject to consequences of telecommunications regulation. Recent broadband policies have been designed to promote the rapid expansion of broadband services to the consumer and also to promote facilities-based competition. However, rapid deployment of broadband translates down the supply chain to a need for large production capacity that gets used in the initial network build, and then sits mostly idle, used primarily to replace equipment that has failed.

The regulatory viewpoint of watching out for the good of the consumer is unlikely to change. The industry needs to explore ways to protect itself from the cyclical nature of the telecommunications industry and prevent situations of overcapacity and excess inventory.

The transceiver industry has the ability to slow the deployment of fiber-to-the-home by increasing prices, however a price increase has the additional effect of forcing communities to cheaper technologies. The end results are fewer telecommunications transceivers being deployed and lower volume for the industry as a whole.

Customer premise equipment that could not be redeployed in the event a customer left the service coupled with a high turnover rate of customers would help mitigate the fall to replacement shown in many of the transceiver deployment rate graphs in Chapter 6. However, this could potentially be devastating for the telecommunications provider, since a high turnover rate means less cost recovery of the expenditure to acquire the customer and lower revenue. Equipment that could not be redeployed would also increase the cost to acquire any individual customer and the cost of the service as a whole. An option of equipment that is disposable is not entirely in the control of the transceiver manufacturer, since in many cases they do not manufacture the customer premise equipment itself, just the transceiver used in that equipment. Therefor such a transceiver industry policy would require the buy-in of all equipment manufacturers and telecommunications providers to be viable, and there is no incentive for cooperation on this particular issue. Customer turnover rates are also not in direct control of the transceiver industry; they depend on the ability of the provider to attract and retain customers.

Facilities-based competition with multiple providers building fiber-to-the-home networks would perhaps mitigate the boom and bust cycle. However, the networks are costly, and to date the majority of facilities-based competition has not been occurring in identical technologies. For example, broadband is currently provided over traditional phone networks (DSL), cable networks (cable modem service), and in some cases wireless networks.

Standardization across markets is one of the potential solutions that is under control of the transceiver industry and also good for industry health. A standard transceiver that can be used across markets would protect the industry from the cycles associated with telecommunications deployments and opens up the potential of appealing to additional markets.

7.4 Implications for Regulations

Building fiber-to-the-home infrastructure is costly and cost recovery is difficult, especially in regions that do not currently have service. Exploration into possible policy directions to help bring broadband service to these regions has resulted in the following insights for the policy making process.

Low-cost government loans help rural deployments, not suburban commercial deployment.

Low-cost federal loans for commercial providers do not have a substantial effect on the building of fiber-to-the-home to unserved suburban regions. The provision of video service over fiber-to-the-home facilities, the building of fiber into the local loop, and increases in demand for service have a far greater effect on bringing service to unserved suburban regions. Removing remaining policy barriers that would prevent traditional telecommunications providers to compete with cable providers for video service should be explored. The Triennial Review Order has already removed the disincentive of adding fiber to the local loop by removing the requirement for resale of that fiber. Regulators should also be wary of any policies that would discourage demand and the development of applications that increase demand.

The Rural Utilities Service needs sufficient funding to meet demand.

The Rural Utilities Service provides loans to rural regions for the construction of broadband facilities. The research suggests that RUS may not have enough funding to serve demand for service in these regions. This lack of sufficient funding could cause a substantial delay in providing service to rural areas and warrants additional investigation.

Laws prohibiting municipal entities from deploying broadband are not in the consumer interest.

Laws prohibiting municipalities from providing service also result in a delay in service availability to those regions. Lawmakers need to carefully balance the interests of competitive providers with those of the consumers in architecting laws on municipal entry into service provision.

Current regulation ignores the true state of broadband competition.

The addition of a requirement to resell fiber lines to competitors only makes cost recovery harder and delays deployment. Removing this requirement in the Triennial Review Order was a step in the correct direction, however, the Order did not seem to recognize the true nature of competition in the broadband service arena. DSL service already has an infrastructure competitor in many regions: cable modem service. As shown in Table 7.1, cable modem service exists in 74% of the regions that have DSL. Cable modem service is far ahead of DSL in the number of regions it serves, serving 45% of Census Places, with DSL serving a mere 16% of regions. Despite this disparity, and the clear dominance of cable modem service, regulation focuses on breaking any potential DSL monopoly. In the broadband data market, cable modem service and DSL are infrastructure-based competitors. Cable providers are also moving towards becoming infrastructure-based competitors for local exchange service with the provisioning of phone service over their lines.

Table 7.1: Cable and DSL Service Comparison

	Total	**Percent Overlap**
DSL Places	3,941	74%
Cable Places	11,433	25%

DSL is not an infrastructure-based competitor to cable when it comes to the provision of video service. The bandwidth necessary to provide video is not available due to the distance constraints of most DSL installations. Fiber-to-the-home is a true infrastructure-based competitor to cable for video service, it has the bandwidth necessary to deliver a wide variety of channels.

Regulators at all levels need to recognize that the nature of competition has changed due to the rapid technological evolution in the broadband market. Policies need to be re-evaluated to ensure that they are regulating to provide competition in the actual service that is being provided, not based simply on who is providing the service.

7.5 Recommendations for Policy Makers

Policy makers do not seem to understand the dynamics of broadband deployment well enough to make effective policy to encourage infrastructure-based competition. Much of the trial and error policy-making that has occurred has served as a deterrent to broadband deployment. Policy changes, along with better monitoring of broadband deployment, are necessary to develop effective policy to encourage infrastructure-based competition.

Regulation needs to focus on the state of competition for services, not on the nature of the service provider.

Infrastructure-based competition exists in many areas for broadband with currently existing cable modem and DSL service. Additional infrastructure-based competition for telephony is emerging as cable providers move into the provision of local exchange service over their networks. Infrastructure-based competition for data, video, and telephony is just beginning with the onset of fiber-to-the-home deployments and currently existing cable and cable modem service.

Policy makers need to recognize that cable is an infrastructure-based competitor for voice, video, and data service and move away from heavy regulation of providers based on who those providers are. The RBOCs are currently required to resell their DSL infrastructure, however, no such regulation exists for cable providers, who are the majority providers of broadband service. Regulation of DSL and the possible regulation of fiber-to-the-home have deterred the RBOCs from upgrading their infrastructure to fiber-to-the-home service. Removing requirements for unbundling fiber-to-the-home was a step in the right direction, however there are still questions of how current regulation on the provision of video by RBOCs will affect fiber-to-the-home deployment and services that will be provided over the network.

Due to the high cost of fiber-to-the-home networks, the RBOCs are in a good position to build those networks and provide infrastructure-based competition to cable providers. Regulation that deters them from providing that service is detrimental to the consumer.

This does not mean that regulation to encourage further competition is not warranted once infrastructure-based competition already exists. Once the technology is built and time has elapsed to allow for the cost recovery of that technology, regulators will need to reconsider if and how to regulate both cable networks and fiber-to-the-home networks to better serve the interest of the consumer. There is a balance to be struck between stimulating growth in applications and the customer base, and having a chilling effect on network upgrades and additional builds. Improved monitoring that includes information on infrastructure for all competing providers will help with striking that balance.

Laws restricting deployment to unserved regions need to be modified or removed.

Despite the RBOCs being in a good position to build fiber-to-the-home networks, there are some areas where the economics makes building that service difficult. Consumer interests are in conflict with recent and proposed changes to state laws that remove the ability of municipal entities to provide broadband service when there is no commercial provider. Policy makers at the federal and state level need to recognize this problem and ensure that the laws are written to promote the deployment of broadband service to unserved areas, not stifle it.

Appendix 1: Technical Standard Details

Additional technical information that was used to help direct the development of the model is provided in this Appendix. For further details please see the standards documents from the IEEE and the ITU.

1.1 IEEE 802.3ah

The standard defines six different physical layer signaling systems based on bit rate, direction, and number of fibers. Three of the signaling systems are for 100 Mbps operation and three are for 1 Gbps operation. Parameters for the signaling systems are specified for a maximum bit error rate of 10^{-12}.

For 100 Mbps operation over two fibers, the standard specifies the extended long wavelength laser (100Base-LX10). The bidirectional long wavelength downstream (100Base-BX10-D) and upstream (100Base-BX10-U) lasers are for 100 Mbps operation over a single fiber. Transceiver characteristics for the three 100 Mbps signaling systems are found in Table A-1.1.

Table A-1.1: 100 Mbps Transceiver Characteristics, IEEE 802.3ah

	Signaling System	100base-Lx10	100base-Bx10-D/U
	Wavelength	1310 nm	1550 nm / 1310nm
Transmitter:	Mean Launch Power (min)	-15 dBm	-14 dBm
	Mean Launch Power (max)	-8 dBm	
	Extinction Ratio (min)	5 dB	6.6 dB
Receiver:	Sensitivity (max)	-25 dBm	-28.2 dBm

For 1 Gbps operation, the signaling system over two fibers is the extended long wavelength laser (1000Base-LX10). The bidirectional long wavelength downstream (1000Base-BX10-D) and upstream (1000Base-BX10-U) lasers are for 1 Gbps operation over a single fiber. The transceiver characteristics for 1 Gbps operation can be found in Table A-1.2.

Table A-1.2: 1 Gbps Transceiver Characteristics, IEEE 802.3ah

	Signaling System	1000Base-LX10	1000Base-BX10-D/U
	Wavelength	1310 nm	1490 nm / 1310 nm
Transmitter:	Mean Launch Power (min)	-9 dBm	
	Mean Launch Power (max)	-3 dBm	
	Extinction Ratio (min)	6 dB	
Receiver:	Sensitivity (max)	-19.5 dBm	

1.2 ITU-T G.985

The optical path loss class defined in the Recommendation is Class S, or a minimum loss of 0 dB and a maximum loss of 15 dB with a power penalty of 1 dB. This results in a 7.3 km transmission distance with a 6 nm root mean square (RMS) spectrum width to guarantee a power penalty not exceeding 1 dB. Class A and B, which are for transmission within 20 and 30 km, are for further study.

Transmission characteristics of interest are shown in Table A-1.3 for Class S. The parameters shown in the table are identical for the ONU and OLT; they differ only in their send and receive wavelengths. The nominal bit rate is 125 Mbps, but the effective bandwidth is 100

Mbps due to the line coding scheme. The system is designed for a bit error ratio of less than 10^{10}.

Table A-1.3: Transceiver Parameters, G.985

		Class S
Transmitter:	**Nominal Bit Rate**	125 Mbps
	Mean Launch Power (min)	-14 dBm
	Mean Launch Power (max)	-8 dBm
	Extinction Ratio	more than 8.2 dB
Receiver:	**Sensitivity (min)**	-30 dBm

1.3 Ethernet PON (EPON)

Similar to the Ethernet active optical networks, standards are being developed with the assistance of the EFM Alliance in the IEEE 802.3ah Task Force.

The physical layer signaling systems for EPON are the PON downstream (1000Base-PX10-D) and upstream (1000Base-PX10-U) laser 10 km and the PON downstream (1000Base-PX20-D) and upstream (1000Base-PX20-U) laser 20 km. Transceiver parameters for these signaling systems are found in Table A-1.4 and Table A-1.5.

Table A-1.4: 10 km EPON Transceiver Parameters, IEEE 802.3ah

	Signaling System	1000Base-PX10-D	1000Base-PX10-U
	Wavelength	1490 nm	1310 nm
Transmitter:	**Mean Launch Power (min)**	-3 dBm	-1 dBm
	Mean Launch Power (max)	+2 dBm	+4 dBm
	Extinction Ratio (min)	6 dB	
Receiver:	**Sensitivity (max)**	-24 dBm	

Table A-1.5: 20 km EPON Transceiver Parameters, IEEE 802.3ah

	Signaling System	1000Base-PX20-D	1000Base-PX20-U
	Wavelength	1490 nm	1310 nm
Transmitter:	**Mean Launch Power (min)**	+2 dBm	-1 dBm
	Mean Launch Power (max)	+7 dBm	+4 dBm
	Extinction Ratio (min)	6 dB	
Receiver:	**Sensitivity (max)**	-27 dBm	-24 dBm

1.4 G.983.1

The specifications for some ONU and ONT parameters are dependent on the attenuation range as defined by G.982. These parameters will include values for Class A (5-20 dB attenuation range), Class B (10-25 dB attenuation range), and Class C (15-30 dB attenuation range). The parameters in the standard are based on worst-case values over the range of standard temperature and humidity operating conditions and include ageing effects. They are based on a design objective of a bit error ratio not worse than $1x10^{-10}$ for the extreme case of optical path attenuation and dispersion.

An excerpt of OLT transceiver parameters for both 155 Mbps and 622 Mbps are found in Table A-1.6. The parameters are identical for both one and two fiber systems, aside from several maximum launch power values where the two fiber parameters are listed in parentheses.

Table A-1.6: OLT Transceiver Parameters, G.983.1

	Nominal Bit Rate	155 Mbps		622 Mbps		
	Class	**B**	**C**	**A**	**B**	**C**
Transmitter:	**Mean Launch Power (min)**	-4 dBm	-2 dBm	-7 dBm	-2 dBm	
	Mean Launch Power (max)	+2 dBm (+1 dBm)	+4 dBm (+3 dBm)	-1 dBm (-2 dBm)	+4 dBm (+3 dBm)	
	Extinction Ratio	more than 10 dB				
Receiver:	**Sensitivity (min)**	-30 dBm	-33 dBm	-28 dBm		-33 dBm

Table A-1.7: ONU Transceiver Parameters, G.983.1

	Nominal Bit Rate	155 Mbps		622 Mbps		
	Class	**B**	**C**	**A**	**B**	**C**
Transmitter:	**Mean Launch Power (min)**	-4 dBm	-2 dBm	-6 dBm	-1 dBm	
	Mean Launch Power (max)	+2 dBm (+1 dBm)	+4 dBm (+3 dBm)	-1 dBm	+4 dBm	
	Extinction Ratio	more than 10 dB				
Receiver:	**Sensitivity (min)**	-30 dBm	-33 dBm	-28 dBm		-33 dBm

An excerpt of ONU transceiver parameters are found in Table A-1.7. As with the OLT transceiver, the parameters are identical for one and two fiber systems, aside from several maximum launch power values where the two fiber parameters are listed in parentheses. As seen in Table A-1.6 and Table A-1.7, the listed OLT and ONU transceiver characteristics are identical at 155 Mbps. In a dual fiber system, this means the identical transceiver could be used at both the OLT and ONU. For a single fiber system, the listed parameters are identical, but the operating wavelengths are different.

At 622 Mbps, for a single fiber system there is a difference of 1 dBm of minimum mean launch power for all Class attenuation ranges. For a dual fiber system, there is also a 1 dBm difference of maximum mean launch power. The OLT and ONU receivers are identical.

1.5 G.983.3

The transmission extinction ratio remains the same as in G.983.1. Tentative values for minimum mean launch power of the transmitter and minimum receiver sensitivity are provided in Appendix I of the Recommendation and an excerpt of those values are shown in Table A-1.8 and Table A-1.9 for the Basic Band. A note for each of the Class C upstream values (the ONU transmitter and the OLT receiver at both 155 Mbps and 622 Mbps), mentions that those values are best estimates and subject to change in the future.

Table A-1.8: OLT Transceiver Parameters, G.983.3

	Nom Bit Rate	155 Mbps			622 Mbps		
	Class	**A**	**B**	**C**	**A**	**B**	**C**
Transmitter:	**Mean Launch Power (min)**	-7.5 dBm	-2.5 dBm	-0.5 dBm	-5.5 dBm	-0.5 dBm	
	Mean Launch Power (max)	-3 dBm	+2 dBm	+4 dBm	-1 dBm	+4 dBm	
	Extinction Ratio	more than 10 dB					
Receiver:	**Sensitivity (min)**	-28.5 dBm	-31.5 dBm	-34.5 dBm	-28.5 dBm		-33.5 dBm

Table A-1.9: ONU Transceiver Parameters, G.983.3

	Nom Bit Rate	155 Mbps			622 Mbps		
	Class	**A**	**B**	**C**	**A**	**B**	**C**
Transmitter:	**Mean Launch Power (min)**	-7.5 dBm	-5.5 dBm	-3.5 dBm	-7.5 dBm	-2.5 dBm	
	Mean Launch Power (max)	0 dBm	+2 dBm	+4 dBm	-1 dBm	+4 dBm	
	Extinction Ratio	more than 10 dB					
Receiver:	**Sensitivity (min)**	-28.5 dBm		-31.5 dBm	-26.5 dBm		-31.5 dBm

As shown in the tables, most of the similarities for the OLT and ONU transmitter and receiver parameters that existed in G.983.1 no longer exist in G.983.3. The extinction ratio is the only thing that all transmitters have in common. For 155 Mbps in Class A, the OLT and ONU transmitter minimum launch power and receiver parameters are identical; however the maximum launch power differs by 3 dBm. All other parameters differ between the OLT and ONU transmitters and receivers.

1.6 G.983.4

T-CONTs are used to manage the upstream bandwidth and carry reports of their status to the OLT. The T-CONT can carry traffic corresponding to multiple virtual channels/paths and of various service classes. Multiple queues are aggregated into a single logical buffer by the T-CONT which transmits based on grants received from the OLT. Each ONU can have multiple

T-CONTs for different supported services. Multiplexing of various virtual paths/channels into a T-CONT is programmable.

Five different T-CONT types are described in the Recommendation.

1. Type 1 is for fixed bandwidth traffic only. Bandwidth is allocated with a fixed rate and controlled cell transfer delay.
2. Type 2 is for assured bandwidth, fixed average bandwidth over a specified time interval, only. This guarantees the average transmission rate, but not cell transfer delay and variation.
3. Type 3 supports assured and non-assured bandwidth. The assured bandwidth and maximum bandwidth of this T-CONT is a provisioned value, while the non-assured bandwidth is dynamically assigned.
4. Type 4 has best-effort bandwidth only, thus does not have any guaranteed bandwidth. Its bandwidth is dynamically assigned out of bandwidth that has not already been allocated as fixed bandwidth, assured bandwidth, and non-assured bandwidth to T-CONTs. This T-CONT has a provisioned maximum bandwidth.
5. Type 5 is a superset of all other T-CONT types. It has provisioned fixed, assured, and maximum bandwidth, while non-assured bandwidth and best-effort bandwidth are dynamically assigned. This T-CONT can be downgraded to one or more of the other T-CONT types.

1.7 G.984.2

As in G.983.1, the parameter values specified in the Recommendation are based on worst-case values over the range of standard temperature and humidity operating conditions and include ageing effects. They are based on a design objective of a bit error ratio not worse than 1×10^{-10} for the extreme case of optical path attenuation and dispersion. The specifications for some ONU and ONT parameters are dependent on the attenuation range as defined by G.982. These parameters will include values for Class A, Class B, and Class C attenuation ranges.

Table A-1.10: Downstream Parameters, G.984.2

	Nom Bit Rate	1244 Mbps			2488 Mbps		
	Class	**A**	**B**	**C**	**A**	**B**	**C**
OLT Transmitter:	**Mean Launch Power (min)**	-4 dBm	+1 dBm	+5 dBm	0 dBm	+5 dBm	+3 dBm
	Mean Launch Power (max)	+1 dBm	+6 dBm	+9 dBm	+4 dBm	+9 dBm	+7 dBm
	Extinction Ratio	more than 10 dB					
ONU Receiver:	**Sensitivity (min)**	-25 dBm		-26 dBm	-21 dBm		-28 dBm

Parameters of interest for the downstream and upstream directions are shown in Table A-1.10, Table A-1.11, and Table A-1.12. Unlike the tables in the other sections, due to the many asymmetrical options of this system, parameters are grouped by direction instead of by device. All parameters are identical for a one and two fiber system, aside from the operating wavelengths as mentioned above and several maximum launch power values where the two fiber parameters are listed in parentheses.

Table A-1.11: Upstream Parameters under 1 Gbps, G.984.2

	Nom Bit Rate	155 Mbps			622 Mbps		
	Class	**A**	**B**	**C**	**A**	**B**	**C**
ONU Transmitter:	**Mean Launch Power (min)**	-6 dBm	-4 dBm	-2 dBm	-6 dBm	-1 dBm	
	Mean Launch Power (max)	0 dBm (-1 dBm)	+2 dBm (+1 dBm)	+4 dBm (+3 dBm)	-1 dBm	+4 dBm	
	Extinction Ratio	more than 10 dB					
OLT Receiver:	**Sensitivity (min)**	-27 dBm	-30 dBm	-33 dBm	-27 dBm		-32 dBm

The power leveling referred to in Table A-1.12 is for the prevention of overload at the OLT receiver for speeds above 1244 Mbps. A table for parameters for 2488 Mbps upstream is absent because those parameters are listed as for further study in the recommendation. Parameters for power leveling at 2488 Mbps in the upstream are also for further study.

Table A-1.12: Upstream Parameters, 1244 Mbps, G.984.2

	Nom Bit Rate	**1244 Mbps**			**1244 Mbps with power leveling**		
	Class	**A**	**B**	**C**	**A**	**B**	**C**
ONU Transmitter:	**Mean Launch Power (min)**	-3 dBm	-2 dBm	+2 dBm	-2 dBm		+2 dBm
	Mean Launch Power (max)	+2 dBm	+3 dBm	+7 dBm	+3 dBm		+7 dBm
	Extinction Ratio	more than 10 dB					
OLT Receiver:	**Sensitivity (min)**	-24 dBm	-28 dBm	-29 dBm	-23 dBm	-28 dBm	-29 dBm

Appendix 2: Current Vendors and Technologies

Listings of current vendors of fiber-to-the-home equipment were obtained through the membership lists of FSAN, the EFM Alliance, and the PON Forum, along with information from Google searches. Vendors seem to be at various stages of developing their products – some with product offerings, and others in the conceptual stages of development with white papers detailing some of their plans. The information below consists of public web site information with some phone clarification from many of the vendors gathered in July and August of 2003. All of the system vendors that provide both central office and customer premise equipment also market a product for the monitoring and management of the system which are not discussed here. Through this process, some vendors of fiber optic related products usable in fiber-to-the-home systems were also identified. Their products and offerings are discussed in Appendix 3.

2.1 Active Ethernet

The companies listed below provide or are developing products for active Ethernet fiber-to-the-home implementations. Many of the products listed below operate under the currently in force IEEE 802.3 standards for Ethernet over fiber: 1000Base-LX and 10/100Base-F. The specifications from IEEE 802.3 for 1000Base-LX over single-mode fiber are very similar to those being developed for 1000Base-LX10 by IEEE 802.3ah. It is expected that once the IEEE 802.3ah is finalized and incorporated into IEEE 802.3, the products will be modified to conform.

2.1.1 Accton

Accton fiber-to-the-home products do not seem to be sold in the United States and little information aside from a white paper on Accton's web site discusses them in any detail. The company itself is based in Taiwan. The central office equipment includes the ES3526S with 24 100Base-FX ports and the ES3714 with up to 96 10/100Base-FX ports or 24 Gigabit Ethernet ports. For customer premise equipment Accton provides the EC3002 media converter with one 100Base-FX (SC) port and one 10/100Base-T port.

2.1.2 Cisco Systems

Cisco's products for fiber-to-the-home are the products that are currently sold as part of their metro access Catalyst 4000 series product line with the addition of a line card for EFM and the ONT 1000 series product line for residential subscribers. The system as deployed in Grant County, Washington provides Gigabit Ethernet service to subscribers and operates over single-mode fiber. The EFM line card is a 48-port 1000Base-LX Gigabit Ethernet card operating over single-mode fiber. Five of these line cards can be installed into the Catalyst 4000 series placed in the distribution network for a total of 240 ports. The Catalyst 6500 series provides the central office portion of the system as deployed in Grant County.

The ONT 1031 is the first product in the ONT 1000 product line and provides conversion from 1000Base-LX to 10/100/1000Base-T at the customer premise. The system provides voice, video, and data services to subscribers.

2.1.3 Harmonic

Harmonic markets a product called the CURBswitch which is environmentally hardened and does not require air-conditioned locations in the field. The CURBswitch is designed to be deployed between the central office and the customer premise. It is an active Ethernet device with a 1 Gbps uplink to the central office over one or two single-mode fibers. The device supports up to six downlink cards, with each card providing four 100 Mbps two fiber connections, four a total of 24 subscriber connections. The CURBswitch supports three different uplink configurations: a 1310 nm uplink with a 10 km reach over two fibers; a 1550 nm uplink with a 40 km reach over two fibers; and a 1550 nm uplink over a single fiber with a 25 km reach. The downlink configuration over single-mode fiber is a 15 km reach over two fibers, or a 10 km reach over one fiber.

The media converter for fiber-to-the-home operates over two single-mode fibers and provides the residential customer with a 10/100Base-T Ethernet connection and an analog receive capability. For business customers, the customer premise equipment provides four 100Base-T Ethernet ports.

2.1.4 Telco Systems

Telco Systems markets customer premise equipment for active Ethernet called the Edgegate CPE. The device supports up to four voice ports and eight or 16 10/100Base-T Ethernet ports. The uplink can be over either two single-mode fibers at 1310 nm with a reach of 10 km or over one single-mode fiber at anywhere from 1470-1610 nm at 20 nm increments with a reach of 80 km. The uplink is a 1 Gbps link, and can use any off-the-shelf transceiver. The unit can be environmentally hardened to be deployed outdoors, and the outdoor configuration also supports RF video.

2.1.5 World Wide Packets

The LightningEdge solution from World Wide Packets is an active Ethernet fiber-to-the-home network consisting of the Access Distributors, Access Concentrators, and Access Portals. The Access Portals can be configured to provide uplink via fiber or copper from the customer premises; however only the fiber configuration is discussed here.

The LightningEdge Access Distributor is the central office component of the system. It can support up to 168 Gigabit Ethernet ports. Bandwidth to the end user is configurable from 32 kbps to 1 Gbps with a supported burst rate of 3 Gbps. The reach is configurable as 10 km, 20 km, or 80 km, depending on the transceiver used.

The LightningEdge Access Concentrator sits between the central office and the customer premise. Its primary purpose is to connect Access Portals located in floors of offices or apartment buildings. The unit provides up to 24 100 Mbps fiber connections for subscriber Access Portal connections. The reach on the 100 Mbps connection is 10 km and operates over two single-mode fibers.

The LightningEdge Access Portal is designed for deployment at the customer premise. They are available in both environmentally hardened and indoor versions for any deployment scenario. The units provide up to six 10/100 Mbps Ethernet ports and two POTS lines. An RF connector module is available for video services. Battery backup is also available. The Access Portals come with either 100 Mbps or 1 Gbps fiber uplinks for connection to an Access Concentrator or Access Distributor, respectively.

2.2 EPON

The following companies are developing and marketing EPON systems. Since the EPON standard is under development, the majority of them claim compliance with the developing standard. The extent of their compliance with the standard is unclear, though it is expected that as the standard is finalized the systems will evolve to be in compliance.

2.2.1 Alloptic

Alloptic has a fiber-to-the-home product line called GigaForce. The GigaForce fiber-to-the-home solution is a Gigabit EPON which can provide up to 1 Gbps symmetrical service. The product line also includes the option to provide RF video services over the fiber optic plant through the tvGEAR family of products – the unit performs the optical to electronic conversion necessary to allow connection to existing in home coax wiring.

The central office equipment, the edgeGEAR 2000 supports up to eight OLT cards that can connect up to 16 Gigabit EPON networks each. The homeGEAR Ultra is the single-family residence product. It provides the customer with up to four POTS RJ-11 jacks, a single RJ-45 10/100Base-T interface, and four RJ-9 coax connectors for RF video services. For multi-tenant dwellings, the homeGEAR 1000 has four10/100Base-T interfaces, four POTS jacks, and four RJ-9 coaxial connectors. The product line also consists of the mduGEAR 224, with 24 10/100Base-T jacks, up to 24 POTS connectors, two T1/E1 ports, and an optional RJ-9 RF video connector designed to provide service to apartment complexes and high-rise buildings.

2.2.2 Salira

Salira markets an EPON system that delivers 1.25 Gbps of symmetrical bandwidth to the customer. The system can be deployed with ONUs at the customer premise, or with the ONUs deployed to the curb and used to support multiple customers. A split ratio of 16 customers per PON and a range of 20 km are supported.

The equipment that makes up the system consists of the Salira 2500 central office OLT and the 2300 ONU. The Salira 2500 OLT supports up to 224 2300s or 14 PONs. Communication is over a single fiber with downstream transmission is at 1550 nm and upstream transmission at 1310 nm. The Salira 2300 ONUs comes with one Gigabit Ethernet port and one eight port 10/100Base-T Ethernet module and two configurable port bays. The bays can house any combination of an eight port 10/100Base-T Ethernet module and a four port T1/E1 module.

The ONUs in their currently marketed form are unlikely to be deployed to the single home residential customer simply due to the large number of ports that would be provided per customer and likely go unused. The system appears to be geared mostly towards data service and also towards legacy T1 and frame relay service, though it can likely support both voice and video over IP.

2.2.3 Wave7 Optics

Wave7 Optics markets an EPON system with a video overlay. The components of the system include the Last Mile Core, Last Mile Tap, and the Last Mile Gateway. The Last Mile Gateway comes in variants for the single family residential customer, customers in multiple dwelling units, and also corporate office customers. The system supports customer data rates of 64 kbps to 500 Mbps provisioned in 256 kbps increments.

The marketing literature claims a reach of 80 km for the system, well beyond the 20 km of the specified standard. This distance is achieved by placing a third-party switch in the central office and running Gigabit Ethernet over fiber for up to 60 km to the Last Mile Core Unit, located somewhere between the subscriber and the central office. The PON then runs the remaining 20 km to the customer site. This architecture allows for a much greater reach than PONs that run from the central office.

The Last Mile Core unit support up to 96 Last Mile Gateways and is environmentally hardened and designed to be strand, pedestal, or vault mounted. It connects to the central office via up to four Gigabit Interface Converters.

The Last Mile Tap is a drop closure designed for field splicing of the drop cable to the customer premises. It supports up to three feeder cables and four, six, or eight subscribers. The supported split ratios are 1x8, 1x6, 1x4, and 1x2. This device is located between the Last Mile Core and the Last Mile Gateway.

As previously mentioned the Last Mile Gateway consists of three different products: Residential, Multi-Quad, and Business. The Residential variant provides two 10/100Base-T connections for data, an RJ-9 connection for broadcast video, and two or four POTS lines. The Multi-Quad unit is designed to support up to four customers and provides a total of four 10/100Base-T connections, four RJ-9 broadcast vide connections, and four or eight POTS lines. The Business unit provides one 10/100/1000Base-T connection, four 10/100Base-T connections, four broadcast video connections, four or eight POTS lines, and from one to four T1/E1s. A Last Mile Multiplexer is used in conjunction with the Business Last Mile Gateway to carry T1/E1 signals over the last mile back to the central office. The Last Mile Gateway receives the T1/E1 signals as TDM over IP and converts them back to T1/E1 format at the central office. Each unit can support up to 16 T1/E1 lines.

2.3 APON

The following systems all conform to some of the G.983 series of Recommendations. The majority of systems comply with G.983.3 as far as transmission wavelengths are concerned and are single fiber systems. Paceon is the exception and complies with G.983.1 for its transmission wavelengths. Information on compliance with G.983.1 or G.983.3 for the Optical Solutions and Terawave systems described in this section was unavailable.

2.3.1 Alcatel

Alcatel has both a fiber-to-the-home product offering and a series of products for installation of outdoor fiber optic plant. The fiber optic plant offerings are discussed in Appendix 3.

Alcatel's 7340 Fiber-to-the-User (FTTU) System is an ATM-based PON consisting of the Home Optical Network Terminal (H-ONT) for residential customers, the Business Optical Network Terminal (B-ONT) for business subscribers, the Packet Optical Line Terminal (P-OLT) and the Video Optical Line Terminal (V-OLT) in the central office. The PON is single fiber, complying to the G.983.1 and 983.3 standards with a 32 subscriber split per fiber, an asymmetrical 622 Mbps downstream and 155 Mbps upstream, and a 20 km reach. The voice and data services use 1490 nm in the downstream direction and 1310 nm in the upstream direction, with broadcast video overlay at 1550 nm. An optical coupler is used to combine the video and data onto a single fiber. Subscribers can receive data service at rates of 64 kbps to 20 Mbps with higher rate bursting capability. Some documentation claims a 40Mbps data rate; the discrepancy has not yet been resolved with Alcatel.

The H-ONT is in an environmentally hardened enclosure designed to be deployed on the outside of the residential subscriber's home. The unit provides the customer with four RJ-11 connectors for telephone (POTS) service, one coaxial F connector for video service and Internet service via either a 10/100Base-T interface or via the 10Mbps Home Phoneline Networking Alliance (HPNA) protocol supported on the POTS interfaces. The H-ONT obtains power from a UPS which provides up to eight hours of battery backup operation for lifeline phone service in the event of a power failure.

The B-ONT is an expanded version of the H-ONT providing more user-side interfaces and designed to be deployed indoors. It provides eight POTS connections, four RJ-45 interfaces providing T1 services, and also one 10/100Base-T RJ-45 interface for data. Like the H-ONT, it provides a single coaxial F connector for video services and also has battery backup in the event of a power failure. Up to 16 B-ONTs are supported per PON.

The central office components of the system include the P-OLT and the V-OLT. The P-OLT supports 16 PON line termination slots, with two PON connectors per slot. Each PON can support up to 32 ONTs, with a limit of 16 B-ONTs per PON. The V-OLT provides video overlay services to the PON.

2.3.2 Iamba Networks

Iamba Networks markets the iAxelent product line as a BPON solution. The product line consists of the XL1000 Multi-Service Optical Access Concentrator and the XL400 Mini-OLT in the central office. The customer premise units are the XL200B Business ONT and the XL200R

Residential ONT. The system supports 32 or 64 users per PON over a single fiber. The XL400 provides a single BPON interface, while the XL1000 supports up to 60 PONs.

The XL200B for business customers provides Ethernet and TDM services for the business customer with 10/100Base-T, DS1, POTS and RF video. The XL200R for residential customers provides Ethernet, POTS, and cable TV connections for the residential customer. Video service is provided by a separate unit in the central office and operates at 1550 nm.

2.3.3 LG Electronics

LG Electronics, a Korean company, markets the StarDLC-6400 ATM-PON product family. As its name suggests, the system is an APON system, however it is not an APON system in the traditional sense. The ONUs are designed to provide xDSL (they are "DSLAM integrated" according to the product literature), or leased line service to customers. The system can provide voice, video, and data services to customers. The PON runs over a single fiber and is asymmetrical with 622 Mbps at 1490 nm in the downstream direction and 155 Mbps at 1310 nm in the upstream direction. Video overlay is provided at 1550 nm in the downstream direction. The range of the PON is 20 km with a splitting ratio of 32 users per PON. The product line consists of the StarDLC-6410 OLT, StarDLC-6420, 6430, and-6440 PON ONUs, and the StarDLC-6470 and 6480 AON ONUs. The AON ONUs are a point-to-point active architecture, they are also DSLAM integrated, but little technical information is available, they are mentioned here for completeness.

The StarDLC-6420 ONT has one slot for an access interface card. The available cards can support 32 ADSL subscribers, 16 VDSL subscribers, 12 G.SHDSL subscribers, 24 POTS lines, 8 10/100baseT lines or 4 T1/E1 lines. This is the smallest of the ONUs and all other ONUs utilize the same interface cards, so the number of possible services is a multiple of what the 6420 can provide. The 6430 small capacity ONU supports three access interface cards, while the large capacity 6440 ONU supports 16. The StarDLC-6410 OLT can support up to 16 PONs and the system allows for dynamic bandwidth allocation.

2.3.4 Optical Solutions

Optical Solutions' initial offering, the FiberPath 400 product family, is an APON system. The current offering, FiberPath 500, is a GPON product, and will be discussed in more detail in the GPON section.

The customer premises equipment includes the FiberPoint 402 and 404 for the residential customer. The units provide up to four POTS lines, cable television, and high speed data services. The business unit is the FiberPoint 440. The unit provides support for four or eight POTS lines, four 10/100Base-T Ethernet ports, and four CATV ports.

The central office equipment is the FiberDrive 400. It can serve 1,152 customers per chassis, which is four PONs per board, nine boards per chassis and 32 customers per PON.

2.3.5 Paceon

Paceon's product offering is a BPON system with the ADS2000 in the central office, the AONT-B200 ONT for business customers, and the AONT-R100 ONT for residential customers. The system supports 32 users per PON with a reach of 20 km.

The ADS2000 supports 155 Mbps upstream and downstream over a single fiber. The system operates in compliance with G.983.1, G.983.2, and G.983.4 using 1310 nm in the upstream and 1550 nm for downstream transmission. Up to 32 PONs can be supported by a single ADS2000.

For business customers, the AONT-B200 provides two slots for any combination of a four-port DS1 card, a single port 10/100Base-T Ethernet card, and a four port POTS card. The unit also supports battery backup for power outages.

The residential AONT-R100 ONT provides residential customers with a POTS connection, a 10/100Base-T Ethernet connection and video. No printed product literature seems to be available for this device.

2.3.6 Quantum Bridge

Quantum Bridge teamed with Motorola provides a BPON FTTH/FTTB solution. The system includes Motorola's ONT 1000 for single family residential units, Quantum Bridge's QB622 and QB155 business ONTs, and QB5000 and QB3000 central office OLTs. Voice, video, and data services are provided using DWDM over a single fiber with 1490 nm for downstream voice and data, 1550 nm for downstream video, and 1310 nm for voice and data upstream. A range of 20 km and a 32 user split per PON are supported.

Motorola's ONT 1000 is designed for single family residential locations. On the user side, the ONT provides one 10/100Base-T interface, four standard POTS jacks and a single coaxial F-connector. The first POTS port can also be used to provide 10Mbps network service via the HPNA protocol. The ONT operates at 622Mbps downstream and 155Mbps upstream. The unit is environmentally hardened and designed to be mounted on the outside of the home. It also allows for a transformer or external UPS to provide line protection for telephony in the event of a power outage. The device literature states that it is compliant with G.983.1, G.983.2, G.983.3, and G.983.4.

Quantum Bridge's QB622 and QB155 operate at 622Mbps and 155Mbps upstream, respectively to provide services to businesses. They provide two factory configurable slots with options of an 8 port 10/100Base-T Ethernet module, 8 port POTS module, 8 port DS1/E1 module, or DS3 ATM module. The devices are environmentally hardened for deployment outdoors.

The QB5000 OLT supports up to 32 PONs per chassis. The PONs may contain any combination of 32 residential or business subscribers, thus serving up to 1024 end-users per chassis. The OLT supports configurable rate limiting so Ethernet bandwidth can be sold in 4kbps increments. The QB3000 is a smaller version of the QB5000 OLT. Supporting up to 16 PONs per chassis it is designed for locations where the full PON distribution density is not required. It can also be deployed outdoors in an environmentally controlled location to extend PON services beyond the usual 20 km distance limitation.

2.3.7 Terawave

The system marketed by Terawave is a 622 Mbps APON. The system consists of the TW600 central office OLT and three different Integrated Network Terminals (INTs) for business customers. The system can provide voice, video, and data service. The marketing literature mentions a fiber-to-the-home solution in passing; however fiber-to-the-home products are still under development.

2.3.8 Vinci Systems

Vinci Systems is developing ONTs for PONs that will be software upgradeable to support any of the PON standards that are currently being defined. Currently the ONTs operate as part of an APON and support all the speeds defined in G.983. The ONTs support 1490 nm in the downstream and 1310 nm in the upstream, and also 1550 nm for downstream video service. Voice, video, and data services are supported over a single fiber. The products include the V-142 ONT for residential customers and the V-182 small business ONT.

The V-142 residential ONT is environmentally hardened and can be installed outside the residence in an outdoor enclosure, or indoors in a wall-mounted enclosure. The ONT can be provided with or without battery backup. Four POTS interfaces, two 10/100Base-T Ethernet interfaces, and a cable television interface to provide voice, video, and data service to the end user.

The V-182 small business ONT is also environmentally hardened for flexibility in installation locations. The device provides all of the interfaces of the V-142 with some additional interfaces. These additional interfaces are four POTS interfaces, two T1/E1 interfaces, a single coin phone interface, and a single DDS (dataphone digital service) interface for connections up to 56 kbps.

2.4 GPON

Similar to the EPON standard, the GPON standard is still under development. Two standards governing the characteristics of a GPON, G.984.1 and G.984.2, have been approved and a third, G.984.3, defining the transmission characteristics of the GPON is still under development. As with the other standards that are under development, it is expected that the systems below will evolve to meet the standard as it develops.

2.4.1 FlexLight Networks

FlexLight's GPON product offering consists of the Optimate 2500LT in the central office and the Optimate 2500NT at the customer premise. The system operates over one or two fibers at 2.488 Gbps in the downstream and 1.244 Gbps in the upstream. It has an over 30 km reach and each PON can support up to 64 ONTs.

Designed primarily for business customers, the Optimate 2500NT ONT is a six slot chassis that supports four or eight Ethernet RJ-45 ports per slot or four or eight T1/E1 ports per slot. The ONT supports a maximum of 40 FastEthernet ports and a maximum of 40 T1/E1 ports.

2.4.2 Optical Solutions

The FiberPath 500 system can be deployed as either a GPON or a BPON solution. As a GPON, the system supports 1.2 Gbps in the downstream and 622 Mbps in the upstream. As a BPON, the system supports 622 Mbps in the downstream and 155 Mbps in the upstream. The customer premises product line consists of the FiberPoint 502, 504, 522, and 524 ONTs for residential subscribers and the FiberPoint 560 for business customers and multiple dwelling units. The FiberPath 500 OLT is the central office equipment in the product line.

All ONT devices have battery backup for eight hours of lifeline telephony in the event of a power failure. The ONTs can be environmentally hardened for external deployment. All residential FiberPoint ONTs provide at least two POTS lines and one 10/100Base-T connection. The numbering of the ONTs is based on the number of POTS lines and whether or not the device has an RF video port. The last number in the product line reflects the number of POTS lines the unit provides and the second number reflects whether or not it has an RF connector – a two signifies an RF connection and a zero signifies no RF connector. Thus the base model with two POTS lines and no RF video connector is the 502 and the device with four POTS lines and an RF connector is the 524. The FiberPoint 560, for business customers and multiple dwelling units, provides up to 20 POTS lines, four 10/100Base-T Ethernet connections, and four CATV ports.

The FiberDrive OLT is the central office portion of the FiberPath 500 product line. It can support 36 PONs with 32 customers.

2.5 Other

The companies listed below are developing hybrid solutions (fiber and copper) and are likely to also develop an all-optical offering at some point in the future.

2.5.1 Calix

Calix currently has product offerings that are fiber and copper, but is working on a fiber-to-the-home offering in the early 2004 time frame. It is unclear if that offering will take the form of an active or passive fiber-to-the-home product.

2.5.2 Hatteras Networks

Hatteras Networks is developing an EFM product called Access Class Ethernet. This product is targeted towards carriers and is designed to operate over a fiber and copper infrastructure.

2.5.3 Scientific Atlanta

Scientific Atlanta markets digital set-top boxes and headend equipment for the cable television industry. They have recently developed a product called the Explorer 4200E Home Gateway which is designed for APON-based fiber-to-the-home systems that support G.983.3. The device allows for video on demand and analog and digital video services. It accepts video broadcast along an RF data path and communicates back to the headend via an Ethernet port. Scientific Atlanta is currently developing additional fiber-to-the-home products that will likely support voice, video, and data services; however no information is available on these products at this time.

Appendix 3: Fiber-to-the-Home -Related Products

Over the course of searching for vendors of fiber-to-the-home equipment through the various fiber-to-the-home organization web sites and using web search engines, several vendors of fiber-to-the-home-related products were discovered. They include vendors of outside plant infrastructure and of components. They are listed here for completeness in documenting the research, but the list is not intended to be comprehensive.

3.1 Alcatel

Along with its 7340 FTTU system, Alcatel carries a series of outdoor plant products and solutions. The primary product line for fiber-to-the-home is the Alcatel 6620 FTTU outside plant product family. The product contains single-mode fiber for feeder, distribution, and drop cabling in a variety of forms including loose tube, flex tube, ribbon, and micro-unitube. Associated splitters, splice closures, distribution cabinets, connectors, and drop closures complete the necessary elements for fiber-to-the-home outdoor plant. Alcatel provides solutions for fiber installation that include alternate rights of way. These solutions allow fiber to be installed in sewers, aerially along with power lines, along highways, in medium-pressure natural gas lines, in subways and tunnels, and in mini trenches or subducts – virtually anywhere that a right of way exists.

3.2 Corning Cable Systems

Corning Cable Systems has the Evolant series of products for the access network. This includes fiber optic cabling, enclosures, optical splitters/couplers, and other outside plant equipment. They also provide training in the installation and handling of fiber optic cabling and have an equipment rental program.

3.3 Ericsson

Ericsson markets fiber optic cabling to be installed using their Ribbonet installation method. The fiber is installed by blowing fiber through a pre-installed microduct. The product line includes fiber cabinets, closures, microducts, fiber optic cabling, and installation tools.

3.4 Hellerman-Tyton

Hellerman-Tyton is a supplier of fiber enclosures, fiber cable assemblies, splice enclosures, fiber connectors, and other products associated with cable management and drop cabling. While these products were not designed specifically for use in fiber-to-the-home deployments, fiber-to-the-home outdoor plant carries no additional requirements that would prevent the use of these products.

3.5 Infineon

Infineon is a fiber optic component supplier. Their products include the BIDI product line for fiber-to-the-home applications. The product line includes a transceiver capable of receiving a wavelength for data and an analog wavelength for applications such as PONs or EFM networks with video overlay. Transmission can be on the same wavelength as the data wavelength, or on another wavelength. The device is designed to operate over a single single-mode fiber connection. The data rates supported range from 155 Mbps to 1.25 Gbps.

3.6 Passave

Passave manufactures ASICs for use in Gigabit EPONs or point-to-point Ethernet fiber networks. They have two products on the market: the PAS5001 and the PAS6001. The PAS5001 is for use in EPON OLTs and the PAS6001 is for use in EPON ONU/ONTs. The chips provide support for TDM services, VoIP, and IP video services.

3.7 Scientific Atlanta

Scientific Atlanta is also in the process of modifying its Prisma II Extended Reach Transmitter for fiber-to-the-home applications. The product will be a point to multi-point offering but has not yet been released.

3.8 Teknovus

Teknovus manufactures Ethernet chipsets. The EthernetPlus chipset allows for the support of TDM traffic over point-to-point optical Ethernet links. The EthernetPON product line has a chipset for the ONU and the OLT for fiber-to-the-home EPON implementations.

Appendix 4: Patents

The patent search of the complete patent database from 1790 to the present was conducted using the search interface at http://patft.uspto.gov/netahtml/search-bool.html. The patents listed here include all of those that met the criteria and were in the database at the end of February 2004.

Table 4.1 includes patents that matched one of the following search terms and were related to telecommunications: "passive optical network", "passive optical networks", "PONs", "PON", "fiber to the home", "FTTH", "active optical network", "active optical networks", "EPON", "APON", or "GPON." The term "PON" produced many spurious hits due to its use as an abbreviation for "Power On" and also due to authors with the last name of "Pon". After a complete list of patents was obtained, the patents were sorted by patent class, and the spurious patents were removed from the list. This left the 656 patents listed by patent number and title in Table A-4.1.

Table A-4.2 shows a list of all the assignees (patent holders) for the 656 patents and the number of patents each assignee holds. Table A-4.3 shows a list of the patent classes that the 656 patents fall under and a count of the number of patents in each class.

Table A-4.4 is a list of all patents found by searching for "FPLD" or "Fabry Perot Laser Diode" in the patent database. Table A-4.5 and Table A-4.6 show the assignees and classes, respectively, for the FPLD patents.

Table A-4.1: Fiber-to-the-Home -Related Patents, Not Including FPLD

Patent	Title
4,170,401	Passive error compensating device for optical alignment
4,367,921	Low polarization beam splitter
4,940,306	Star network optical transmission system
4,977,593	Optical communications network
4,978,189	Hybrid optical isolator, circulator or switch, and systems utilizing same
5,012,484	Analog optical fiber communication system, and laser adapted for use in such a system
5,020,049	Optical sub-carrier multiplex television transmission system using a linear laser diode
5,034,334	Method of producing a semiconductor laser adapted for use in an analog optical communications system
5,062,152	PCM signal coding
5,063,595	Optical communications network
5,086,470	Scrambling in digital communications network using a scrambled synchronization signal
5,097,529	Space-saving optical fiber cable closure
5,107,360	Optical transmission of RF subcarriers in adjacent signal bands
5,109,458	Cable seal
5,111,475	Analog optical fiber communication system, and laser adapted for use in such a system
5,113,466	Molded optical packaging arrangement
5,119,223	Bidirectional light waveguide (LWG) telecommunication system and method for wavelength separation mode (bidirectional wavelength separation mode (WDM) between a central telecommunication location and plurality of decentralized telecommunication locations
5,121,389	Regenerative node for a communications network
5,123,066	Molded optical package utilizing leadframe technology
5,133,039	Aerial fiber optic cable case
5,138,635	Network clock synchronization
5,142,532	Communication system
5,144,669	Method of communicating digital signals and receiver for use with such method
5,146,079	Broadband optical receiver with active bias feedback circuit
5,146,531	Ultraviolet radiation-curable coatings for optical fibers and optical fibers coated therewith
5,153,762	Method and apparatus for recovering AM channell signals distributed on an optical fiber
5,153,764	Control of optical systems
5,168,498	Mobile communications system
5,173,899	TDMA communications network of transmitting information between a central station and remote stations
5,175,778	Integrated optic waveguide coupler with reduced wavelength sensitivity
5,175,782	Optical fiber coupler of improved signal distribution characteristics
5,185,844	Closure for optical fiber connective arrangements and method of providing same
5,191,456	Efficient feeder fiber loading from distribution fibers
5,210,631	Transmission of AM-VSB video signals over an optical fiber
5,224,113	Semiconductor laser having reduced temperature dependence
5,231,465	High efficiency fiber absorber and method for attenuating pump light in a broadband fiber optic light source
5,237,591	Circuit for digitally adding loss to a signal
5,241,409	Communications network with switching distributed among a central switching node and optical input and output sub-networks
5,241,552	Compensated laser structure for analog communication applications
5,245,459	Optical communications systems
5,253,104	Balanced optical amplifier

Patent	Title
5,260,996	Current limited electronic ringing generator
5,263,105	Connector assembly for connecting an optical fiber cable to a socket
5,268,979	Achromatic overclad fiber optic coupler
5,272,555	Bidirectional optical transmission method and apparatus therefore
5,272,556	Optical networks
5,285,305	Optical communication network with passive monitoring
5,285,468	Analog optical fiber communication system, and laser adapted for use in such a system
5,287,366	Binary modulation of injection lasers
5,291,493	ISDN interface
5,293,264	Transmission system for the polarization-insensitive transmission of signals
5,299,044	Ranging method for use in TDMA systems on tree-and-branch optical networks
5,301,050	Subscriber loop testing in a fiber-to-the-curb communications network
5,301,054	Transmission of AM-VSB video signals over an optical fiber
5,305,402	Tunable optical filters
5,307,434	Article that comprises a laser coupled to an optical fiber
5,311,344	Bidirectional lightwave transmission system
5,315,675	Optical tap having a v-shaped recess within the range of from 152.degree. t o .degree.
5,321,541	Passive optical communication network with broadband upgrade
5,321,777	Fibre modulators
5,323,255	Transceiver arrangement using TDM to transmit assigned subcarrier waveforms
5,323,408	Regulation of preconduction current of a laser diode using the third derivative of the output signal
5,323,474	Lossless optical signal splitter including remotely pumped amplifier
5,325,223	Fiber optic telephone loop network
5,331,449	Optical fiber tree and branch network for AM signal distribution
5,335,408	Method of making a water blocked optical fiber cable
5,337,175	Optical communications system for the subscriber area with optical amplifiers
5,341,365	Passive optical network
5,343,286	OTDR having optically switched amplified output onto test fibre to suppress optical amplifier noise between OTDR pluses
5,349,457	Fiber optic telephone loop network
5,352,712	Ultraviolet radiation-curable coatings for optical fibers
5,353,143	Optical receiver
5,353,285	Time slot management system
5,355,362	Digital loop carrier system
5,365,368	Efficient bi-directional optical fiber amplifier for missile guidance data link repeater
5,367,394	Test apparatus
5,373,386	Transmission/reception circuit in a passive optical telecommunication system
5,398,129	Passive optical telecommunication system for narrow band and broadband integrated services digital networks
5,400,162	Optoelectronic multibit beamsteering switching apparatus
5,402,479	Method and apparatus for translating signaling information
5,408,462	Protection switching apparatus and method
5,410,343	Video-on-demand services using public switched telephone network
5,412,415	Distribution of digitized composite AM FDM signals
5,416,628	Multilevel coherent optical system
5,425,027	Wide area fiber and TV cable fast packet cell network
5,434,984	Priority based access control arrangement

Patent	Title
5,440,416	Optical network comprising a compact wavelength-dividing component
5,442,702	Method and apparatus for privacy of traffic behavior on a shared medium network
5,443,227	Switching control for multiple fiber-guided missile systems
5,444,710	Telecommunications systems
5,446,571	Manchester code optical code recognition unit
5,448,663	Optical coupler
5,453,737	Control and communications apparatus
5,453,865	Monitoring system
5,453,980	Communication network and computer network server and interface modules used therein
5,453,988	Passive optical network
5,455,671	Optical circuit for a measuring system for measuring the reflection sensitivity of an optical transmission system
5,457,560	Fiber optic telecommunication system employing continuous downlink, burst uplink transmission format with preset uplink guard band
5,461,504	Opto-electronic circuits
5,469,283	Optical system for connecting customer premises networks to a switching center of a telecommunication network providing interactive and non-interactive services
5,469,440	Communications network and method
5,473,636	Data discriminating circuit and an optical receiver using the same
5,473,696	Method and apparatus for combined encryption and scrambling of information on a shared medium network
5,477,366	Optical transmission system
5,479,286	Optical fibre communications system
5,483,368	Optical communication system suitable for selective reception of multiple services
5,483,369	Communication systems using passive RF routing
5,485,300	Optical transmitter and power setting method in optical transmitters for use in optical networks
5,491,573	Optical signal transmission network
5,491,574	Optical signal transmission network
5,491,575	Passive optical telecommunication system
5,493,435	Optic switching
5,497,438	Optical transmission and reception module having coupled optical waveguide chips
5,499,244	Packet data reciever with sampled data output and background light cancellation
5,499,309	Method of fabricating optical component including first and second optical waveguide chips having opposed inclined surfaces
5,500,755	Compensation device
5,500,757	Optical receiving system
5,502,587	Network comprising a space division photonic switch and a terminal which forms an output signal from an input signal
5,503,369	Optical fibre customer lead in
5,504,606	Low power optical network unit
5,509,003	TDM data communications network wherein each data frame is divided into respective lower rate sub-frames for respective sets of substations, and main station and substation for use therein
5,509,077	Method for data security in a digital telecommunication system
5,519,830	Point-to-multipoint performance monitoring and failure isolation system
5,521,734	One-dimensional optical data arrays implemented within optical networks
5,525,929	Transimpedance amplifier circuit with feedback and load resistor variable circuits
5,527,835	Organic solvent and water resistant hydrolytically stable ultraviolet radiation curable coatings for optical fibers

Patent	Title
5,528,281	Method and system for accessing multimedia data over public switched telephone network
5,528,579	Added bit signalling in a telecommunications system
5,528,596	Telecommunications systems
5,528,637	Synchronizing circuit
5,530,583	Optical signal amplification apparatus and an optical fiber transmission system using the same
5,530,712	Method of and device for controlling the peak power of a laser transmitter in discontinuous optical transmission systems
5,531,064	Optical fiber cable containing ribbon fibers
5,536,529	Ultraviolet radiation-curable coatings for optical fibers and optical fibers coated therewith
5,537,241	Telecommunications system
5,538,791	Organic solvent and water resistant, thermally, oxidatively and hydrolytically stable radiation-curable coatings for optical fibers, optical fibers coated therewith and processes for making same
5,539,448	Video server that adapts video signals from memory to a format compatible with a communication system in a video-on-demand network
5,541,756	Apparatus and method for routing optical signals through wavelength-coding in a self-routed wavelength addressable network
5,541,757	Optical fiber cable service system provided with video on demand service
5,541,962	Transmission timing adjusting device
5,543,951	Method for receive-side clock supply for video signals digitally transmitted with ATM in fiber/coaxial subscriber line networks
5,548,432	Passive optical network switchable between an operational mode and a diagnostic mode
5,548,678	Optical fibre management system
5,550,577	Video on demand network, including a central video server and distributed video servers with random access read/write memories
5,550,666	Wavelength division multiplexed multi-frequency optical source and broadband incoherent optical source
5,553,186	Fiber optic dome closure
5,555,332	Applicator and associated method for inserting guide pins in a fiber optic connector
5,559,624	Communication system based on remote interrogation of terminal equipment
5,559,625	Distributive communications network
5,568,301	Optical communication system with secure key transfer
5,570,442	Design and manufacture of an optimized waveguide-type multiple branched star coupler
5,572,349	Communications system
5,572,612	Bidirectional optical transmission system
5,574,584	Wavelength division multiplexing passive optical network with bi-directional optical spectral slicing
5,579,308	Crossbar/hub arrangement for multimedia network
5,579,321	Telecommunication system and a main station and a substation for use in such a system
5,579,421	Optical integrated circuits and methods
5,581,387	Optical data communications network with a plurality of optical transmitters and a common optical receiver connected via a passive optical network
5,581,388	Method of and device for the fine synchronization of aim cells in optical ATM nodes
5,581,554	Multiple access telecommunication network
5,581,557	Method used in a communication network for determining access of user stations to a main station thereof
5,587,403	Organic solvent & water resistant hydrolytically stable ultraviolet radiation curable coatings for optical fibers
5,588,076	Optical fibre management system

Patent	Title
5,589,704	Article comprising a Si-based photodetector
5,590,140	Clock recovery extrapolation
5,590,234	Fiber optic splice organizers
5,592,554	Method for data security in a digital telecommunication system
5,594,237	PIN detector having improved linear response
5,594,576	Optical serial bus interface
5,594,578	Optical communications system including doped optical fiber filter
5,598,287	Multiple access telecommunication network
5,600,469	Optical network unit implemented with low-cost line interface cards
5,606,555	Apparatus and method for operating and constructing an optical TDM/TDMA system having enhanced range
5,608,565	Bidirectional optical transmission system
5,613,210	Telecommunication network for transmitting information to a plurality of stations over a single channel
5,615,033	Optical signal transmission apparatus and method
5,617,501	Shield bond strain connector for fiber optic closure
5,619,360	Optical processing in asynchronous transfer mode network
5,619,504	Telecommunication system and a main station for use in such a system
5,623,363	Semiconductor light source having a spectrally broad, high power optical output
5,623,668	Method in a polling system for transmitting queue elements from multiple input queues to a single output with improved queue service performance
5,625,404	Method and system for accessing multimedia data over public switched telephone network
5,631,758	Chirped-pulse multiple wavelength telecommunications system
5,631,989	Fiber and active optical device interconnection assembly
5,636,202	Test system for detecting ISDN NT1-U interfaces
5,639,846	Ultraviolet radiation-curable coatings for optical fibers and optical fibers coated therewith
5,642,351	Wide area fiber and TV cable fast packet cell network
5,646,758	Optical time compression multiplexing transmission system
5,647,044	Fiber waveguide package with improved alignment means
5,648,958	System and method for controlling access to a shared channel for cell transmission in shared media networks
5,650,994	Operation support system for service creation and network provisioning for video dial tone networks
5,651,005	System and methods for supplying continuous media data over an ATM public network
5,652,813	Line bi-directional link
5,654,592	Power supply controller
5,655,068	Point-to-multipoint performance monitoring and failure isolation system
5,657,318	Phase-comparison bit synchronizing circuit
5,661,585	Passive optical network having amplified LED transmitters
5,668,652	Optical WDM (wavelength division multiplexing) transmission system and method for configuring the same
5,680,234	Passive optical network with bi-directional optical spectral slicing and loop-back
5,680,325	Network capacity creation for video dial tone network
5,680,490	Comb splitting system and method for a multichannel optical fiber communication network
5,680,546	Passive optical network structure with high fault tolerance
5,682,377	Transmission system for data cells in a local network
5,682,450	Fiber optic connector element
5,684,910	Buffered optical fiber having a strippable buffer layer
5,691,832	Coherence multiplexed transmission system

Patent	Title
5,694,234	Wavelength division multiplexing passive optical network including broadcast overlay
5,699,176	Upgradable fiber-coax network
5,703,504	Feedforward adaptive threshold processing method
5,703,988	Coated optical fiber and fabrication process therefore
5,706,111	Optical communications network
5,706,384	Optical fibre management system
5,708,753	Method of recovering from a fiber-cable cut using random splicing reconnection
5,710,648	Optical communication system and remote sensor interrogation
5,710,656	Micromechanical optical modulator having a reduced-mass composite membrane
5,712,906	Communications systems supporting shared multimedia session
5,712,982	TDMA point-to-multipoint transmission network with a multiframe which includes a single continuous stream of data subframes and a single free period for response-time measurements
5,719,874	Time-division-multiplexing method and apparatus
5,726,783	Optical fibre communication system
5,729,369	Method of tracking a plurality of discrete wavelengths of a multifrequency optical signal for use in a passive optical network telecommunications system
5,729,370	Method for upgrading a communications network
5,732,174	Bare fiber connector
5,734,770	Cleave and bevel fiber optic connector
5,740,210	Data discriminating circuit and a parallel data receiver using the same
5,740,295	Low fiber count optical cable
5,742,414	Multiplicity of services via a wavelength division router
5,744,514	Coated optical fibers having a reduced content of extractable and volatile material
5,745,618	Optical device having low insertion loss
5,745,619	Low-loss optical power splitter for high-definition waveguides
5,747,610	Polymer optical fibers and process for manufacture thereof
5,748,348	Optical communication system for cable-television signals and for subscriber-assigned signals
5,749,565	Optical fibre installation tool
5,754,319	Optical amplifier combiner arrangement and method for upstream transmission realized thereby
5,754,555	Subscriber network arrangement for connecting subscribers to a telephone network
5,754,632	Management of communications networks
5,758,004	Closure with cable strain relief
5,760,935	Optical communications network
5,760,940	Methods for monitoring optical path characteristics in an optical communication system
5,760,941	System and method for performing optical code division multiple access communication using bipolar codes
5,761,307	Method for securing data in a telecommunications system
5,764,765	Method for key distribution using quantum cryptography
5,764,826	PD/LD module and PD module
5,768,378	Key distribution in a multiple access network using quantum cryptography
5,774,244	Optical communications networks
5,777,765	Optical delay unit, optical line emulator including such a unit and methods realized by such an optical delay unit and by such an optical line emulator
5,781,587	Clock extraction circuit
5,786,913	Optical TDMA ring network with a central transmitting and receiving device

Patent	Title
5,786,923	Point-to-multipoint wide area telecommunications network via atmospheric laser transmission through a remote optical router
5,790,174	PSTN architecture for video-on-demand services
5,790,287	Optical communication system with improved maintenance capabilities
5,790,293	Systems for monitoring optical path characteristics in an optical communication system
5,793,507	Discretely chirped multiple wavelength optical source for use in a passive optical network telecommunications system
5,796,503	Optical communication system wherein optical beat interference at the center is reduced
5,796,767	Driver circuit of light-emitting device
5,796,792	Data identifying device and light receiver using the same
5,798,858	Method and apparatus for reducing adverse effects of optical beat interference in optical communication systems
5,801,867	DC-coupled receiver for shared optical system
5,802,225	Arrangement for transmitting digital data over an optical network of optical waveguides
5,802,283	Method and system for accessing multimedia data over public switched telephone network
5,805,752	Environment-proof fiber optic coupler
5,808,764	Multiple star, passive optical network based on remote interrogation of terminal equipment
5,808,766	Method for measuring a signal transmission delay time, central station, terminal station and network to perform this method
5,808,767	Fiber optic network with wavelength-division-multiplexed transmission to customer premises
5,809,030	Frequency division multiple access (FDMA) dedicated transmission system, transmitter and receiver used in such a transmission system
5,815,295	Optical communication system with improved maintenance capabilities
5,815,308	Bidirectional optical amplifier
5,815,498	Transmission system for ATM cells through a passive local network
5,815,616	Optical packaging assembly for reflective devices
5,818,125	Secondary source of energy system for powering communications hardware and services and associated method
5,822,102	Passive optical network employing upconverted 16-cap signals
5,822,104	Digital optical receiving apparatus
5,828,403	Method and system for selecting and receiving digitally transmitted signals at a plurality of television receivers
5,828,558	PWN controller use with open loop flyback type DC to AC converter
5,831,979	Method and apparatus for crossconnecting transmission members in the outside distribution plant of a telecommunications network for providing access to customer lines to a plurality of service providers
5,832,011	Laser
5,835,656	Coated optical fiber
5,838,473	Optical communications system
5,838,731	Burst-mode digital receiver
5,841,563	Method and system for efficient optical transmission of NTSC video
5,844,929	Optical device with composite passive and tapered active waveguide regions
5,847,855	Integrated coherent transceiver
5,852,505	Dense waveguide division multiplexers implemented using a first stage fourier filter
5,852,696	Packaged optical device
5,854,701	Passive optical network
5,854,703	Hybrid fiber coax communications network
5,857,048	Fourier-plane photonics package
5,857,050	Packaging for optoelectronic device

Patent	Title
5,858,051	Method of manufacturing optical waveguide
5,861,129	Polymer optical fibers and process for manufacture thereof
5,861,965	Optical communication system employing spectrally sliced optical source
5,864,413	Passive optical network for dense WDM downstream data transmission and upstream data transmission
5,864,415	Fiber optic network with wavelength-division-multiplexed transmission to customer premises
5,867,377	System and method for improving the efficiency of reserve battery-powered, partitioned power conversion systems under light load conditions
5,870,395	Wide area fiber and tv cable fast packet cell network
5,872,644	Fiber-optic access system for subscriber optical communication
5,872,645	Telecommunications network
5,875,274	Optoelectronic transmission-reception device
5,878,181	Optical non-linear branching element
5,880,864	Advanced optical fiber communications network
5,880,865	Wavelength-division-multiplexed network having broadcast capability
5,881,194	Radiation-cured matrix material; optical fiber ribbons containing same; and process for preparing said optical fiber ribbons
5,885,027	Transmission line installation
5,886,732	Set-top electronics and network interface unit arrangement
5,887,009	Confocal optical scanning system employing a fiber laser
5,887,092	Optical non-linear branching element with MZ interferometer
5,892,872	Network unit enclosure
5,894,477	Communications system
5,896,213	Optical fiber network system
5,896,474	Optical network having protection configuration
5,898,697	Arrangement for defining a transmission delay in a subscriber network
5,900,956	Optically encoded signals
5,905,586	Two-way optical fiber communication system having a single light source
5,905,715	Network management system for communications networks
5,905,831	Passive alignment frame using monocrystalline material
5,905,834	Combination loose tube optical fiber cable with reverse oscillating lay
5,907,417	Passive optical network with diagnostic loop-back
5,907,645	Liquid crystal ferroelectric electro-optical phase modulators which are insensitive to polarization
5,908,873	Peelable bonded ribbon matrix material; optical fiber bonded ribbon arrays containing same; and process for preparing said optical fiber bonded ribbon arrays
5,912,749	Call admission control in cellular networks
5,912,998	Optical network with repeater at a split-level of the network
5,914,976	VCSEL-based multi-wavelength transmitter and receiver modules for serial and parallel optical links
5,917,624	Method and system for applying fiber to the curb architecture using a broadband gateway at service locations, including homes
5,920,410	Access network
5,920,627	Encryption device and decryption device for information conveyed by asynchronous transfer mode cells
5,923,455	Data identifying device and light receiver using the same
5,923,688	Semiconductor laser
5,926,179	Three-dimensional virtual reality space display processing apparatus, a three-dimensional virtual reality space display processing method, and an information providing medium

Patent	Title
5,926,298	Optical multiplexer/demultiplexer having a broadcast port
5,926,472	Method and apparatus for crossconnecting transmission members in the outside distribution plant of a telecommunications network to provide a combined narrowband and broadband signal
5,926,478	Data transmission over a point-to-multipoint optical network
5,928,293	Method for generating a clock signal for use in a data receiver, clock generator, data receiver and remote controlled access system for vehicles
5,930,018	Method and apparatus for controlling communications in a passive optical network
5,930,412	Electro-optical component
5,933,264	Optical receiver, a tuner, and an optical network
5,935,491	Gradient-index polymer rods and fibers
5,936,578	Multipoint-to-point wireless system using directional antennas
5,936,752	WDM source for access applications
5,939,924	Integrating circuit having high time constant, low bandwidth feedback loop arrangements
5,940,387	Home multimedia network architecture
5,940,558	Optical packaging assembly for transmissive devices
5,940,564	Device for coupling a light source or receiver to an optical waveguide
5,943,124	Monitoring of an optical line
5,943,155	Mars optical modulators
5,946,438	Device for both-way transposition between optical signals and electrical signals, for a communications system
5,949,571	Mars optical modulators
5,953,318	Distributed telecommunications switching system and method
5,953,421	Quantum cryptography
5,956,038	Three-dimensional virtual reality space sharing method and system, an information recording medium and method, an information transmission medium and method, an information processing method, a client terminal, and a shared server terminal
5,960,445	Information processor, method of updating a program and information processing system
5,963,350	Optical telecommunications network
5,970,066	Virtual ethernet interface
5,970,078	Laser drive circuit
5,978,117	Dynamic reconfiguration of a wireless network using flexible wavelenght multiplexing
5,978,119	System and method for synchronizing an optical source and a router in a wavelength division multiplexed fiber optic network
5,978,374	Protocol for data communication over a point-to-multipoint passive optical network
5,982,516	Optical network with wavelength-dependent routing
5,982,791	Wavelength tracking in adjustable optical systems
5,985,685	Method for making optical device with composite passive and tapered active waveguide regions
5,991,058	Method and apparatus for a network comprising a fourier plane photonics package
5,991,068	Gain controlled optical fibre amplifier
5,999,290	Optical add/drop multiplexer having complementary stages
5,999,518	Distributed telecommunications switching system and method
6,002,680	Log-in method for a telecommunication network, main station and terminal station adapted to perform the method
6,005,861	Home multimedia network architecture
6,014,369	Method and apparatus for testing subscribers accommodated to service node in loop system
6,014,477	Article comprising a photostrictive switching element
6,016,320	Telecommunications system

Patent	Title
6,018,538	High speed non-biased semiconductor laser dione driver for high speed digital communication
6,018,690	Power supply control method, power supply control system and computer program product
6,020,885	Three-dimensional virtual reality space sharing method and system using local and global object identification codes
6,021,234	Interconnection apparatus having an electrical or optical signal bus
6,023,467	Operations and maintenance data flows over a point to multipoint broadband access network
6,026,144	Method for improving the administration of the telephone local loop plant
6,031,645	Bi-directional optical communications subscriber transmission system using a single wavelength
6,037,285	Infrared transmitting optical fiber materials
6,037,832	Temperature dependent constant-current generating circuit and light emitting semiconductor element driving circuit using the same
6,038,226	Combined signalling and PCM cross-connect and packet engine
6,044,122	Digital phase acquisition with delay locked loop
6,047,098	Plastic optical waveguide and optical switch using same
6,049,471	Controller for pulse width modulation circuit using AC sine wave from DC input signal
6,049,646	Integrated burster multiplexer duplexer device for multicore fibers
6,058,235	Line terminating device
6,065,061	Internet protocol based network architecture for cable television access with switched fallback
6,068,796	Sub-miniature optical fiber cables, and apparatuses and methods for making the sub-miniature optical fiber cables
6,072,612	WDM transmitter for optical networks using a loop-back spectrally sliced light emitting device
6,072,616	Apparatus and methods for improving linearity and noise performance of an optical source
6,075,239	Article comprising a light-actuated micromechanical photonic switch
6,075,628	Fault location in optical communication systems
6,078,394	Wavelength manager
6,078,589	Method and arrangements for the optimal use of switching--oriented and transmission--oriented resources of multimedia communication networks
6,078,661	Modular network interface device
6,078,708	Connection device for multiple-core optical fibres based on optical elements in free space
6,081,362	Optical receiver capable of responding to both burst and continuous signals
6,084,232	Optical receiver pre-amplifier which prevents ringing by shunting an input current of the pre-amplifier
6,085,007	Passive alignment member for vertical surface emitting/detecting device
6,088,368	Ethernet transport facility over digital subscriber lines
6,091,713	Method and system for estimating the ability of a subscriber loop to support broadband services
6,091,876	Extra length accommodation structure for optical fiber
6,097,523	Optical systems with one or more stabilized laser signal sources
6,097,736	Telecommunications network
6,101,183	Method and apparatus for crossconnecting transmission members in the outside distribution plant of a telecommunications network
6,108,112	Method and apparatus for failure recovery in passive optical network
6,115,163	Apparatus and method for reception of optical burst
6,115,469	Telephone line ring signal and DC power generator
6,118,565	Coherent optical communication system
6,122,335	Method and apparatus for fast burst mode data recovery
6,122,428	Radiation-curable composition for optical fiber matrix material

Patent	Title
6,124,956	Optical transmitter output monitoring tap
6,125,228	Apparatus for beam splitting, combining wavelength division multiplexing and demultiplexing
6,131,415	Method of making a fiber having low loss at 1385 nm by cladding a VAD preform with a D/d<7.5
6,134,037	Reduction of interferometer noise in an optical network
6,137,339	High voltage integrated CMOS driver circuit
6,137,607	Broadband communications method and apparatus for reducing optical beat interference
6,137,611	Suppression of coherent rayleigh noise in bidirectional communication systems
6,137,939	Method and apparatus for reducing temperature-related spectrum shifts in optical devices
6,141,141	Single sideband modulators
6,144,471	Optical transmission system
6,144,472	Upgrading a power-splitting passive optical network using optical filtering
6,147,784	Simultaneous wavelength-division multiplexing and broadcast transmission system
6,147,786	Hybrid analog/digital WDM access network with mini-digital optical node
6,148,006	Communication system architecture, exchange having a plurality of broadband modems and method of supporting broadband operation on a one to one basis
6,151,144	Wavelength division multiplexing for unbundling downstream fiber-to-the-home
6,151,150	Method and apparatus for level decision and optical receiver using same
6,154,211	Three-dimensional, virtual reality space display processing apparatus, a three dimensional virtual reality space display processing method, and an information providing medium
6,160,810	ATM based VDSL communication system having meta signaling for switching a subscriber between different data service providers
6,160,815	Band setting apparatus for suppressing cell delay variation
6,160,990	Cable network system with ingress noise suppressing function
6,161,011	Hybrid fiber coax communications systems
6,163,637	Chirped waveguide grating router as a splitter/router
6,167,070	Optical semiconductor device and method of fabricating the same
6,169,619	Apparatus and method for reception of optical signal
6,181,210	Low offset and low glitch energy charge pump for PLL-based timing recovery systems
6,181,849	Interleaved wavelengths multi/demultiplexer with multiple-input-ports and multiple-output-ports for wavelength add/drop WDM systems
6,181,856	Method and apparatus for aligning optical waveguide arrays
6,185,222	Asymmetric switch architecture for use in a network switch node
6,185,352	Optical fiber ribbon fan-out cables
6,188,397	Set-top electronics and network interface unit arrangement
6,195,355	Packet-Transmission control method and packet-transmission control apparatus
6,198,558	Architecture repartitioning to simplify outside-plant component of fiber-based access system
6,198,745	ATM based VDSL communication system for providing video and data alarm services
6,200,503	Graded index polymer optical fibers and process for manufacture thereof
6,201,622	Optical network
6,205,267	Optical switch
6,212,196	Multiple access communication system and method for multiple access communication
6,215,930	Remote-splitter fiber optic cable
6,219,165	Burst-mode laser techniques
6,219,470	Wavelength division multiplexing transmitter and receiver module
6,224,269	Connection means for optical fibres
6,229,634	Burst mode optical receiver and repeater
6,229,788	Method and apparatus for traffic shaping in a broadband fiber-based access system
6,229,830	Burst-mode lase techniques

Patent	Title
6,229,890	Network interface device with automatic connector closure
6,229,933	Component for cross-connecting optofibres
6,233,261	Optical communications system
6,239,887	Method to determine a switching moment and a line terminator, a control network unit and a network unit realizing such a method and a tree-like optical network including such a line terminator, such a control network unit or such a network unit
6,240,114	Multi-quantum well lasers with selectively doped barriers
6,240,337	Flywheel reserve power for outside plant of a communication network
6,246,282	First stage amplifier circuit
6,249,628	Fiber optic cable units
6,253,003	Optical coupling method and optical coupling device
6,256,308	Multi-service circuit for telecommunications
6,256,321	Information communication network system, central information communication control device and information communication device used in the system, information sending method, and modulation method
6,262,997	Synchronization in digital communications networks
6,269,137	Method and apparatus for fast burst mode data recovery
6,269,212	Method for performing fixing inside a container for optical connection components
6,271,947	Simultaneous wavelength-division multiplexing and broadcast transmission system
6,282,189	Unified access platform for simultaneously delivering voice and cell-based services
6,282,345	Device for coupling waveguides to one another
6,288,610	Method and apparatus for correcting signals, apparatus for compensating for distortion, apparatus for preparing distortion compensating data, and transmitter
6,288,806	Optical subscriber network system and fault supervising method for optical subscriber network system
6,288,809	Optical subscriber network system
6,292,292	Rare earth polymers, optical amplifiers and optical fibers
6,292,651	Communication system with multicarrier transport distribution network between a head end terminal and remote units
6,295,401	Optical fiber ribbon cables
6,301,420	Multicore optical fibre
6,301,674	Power control method, power control system and computer program product for supplying power to a plurality of electric apparatuses connected to a power line
6,304,350	Temperature compensated multi-channel, wavelength-division-multiplexed passive optical network
6,307,869	System and method for phase recovery in a synchronous communication system
6,313,932	Multiplexed transmission of optical signals
6,314,228	Optical waveguide component and a method of producing the same
6,317,234	Communications network
6,322,375	Network interface device with circuit board architecture
6,326,852	Low offset and low glitch energy charge pump for PLL-based timing recovery systems
6,327,400	Protection scheme for single fiber bidirectional passive optical point-to-multipoint network architectures
6,334,219	Channel selection for a hybrid fiber coax network
6,335,814	Optical transmission system and optical transmitter and optical receiver used therefor
6,337,887	Burst receiving circuit and control method thereof
6,339,487	Bi-directional optical transmission system
6,339,664	Wavelength division multiplexing
6,341,039	Flexible membrane for tunable fabry-perot filter

Patent	Title
6,344,919	Methods and systems for producing linear polarization states of light at the end of a length of optical fiber
6,346,956	Three-dimensional virtual reality space display processing apparatus, a three-dimensional virtual reality space display processing method, and an information providing medium
6,347,096	Method for structuring of digital data which can be transferred in both directions on a passive optical network (PON) in a PON TDMA system
6,348,986	Wireless fiber-coupled telecommunication systems based on atmospheric transmission of laser signals
6,351,581	Optical add-drop multiplexer having an interferometer structure
6,351,582	Passive optical network arrangement
6,356,674	Electrically controllable grating, and optical elements having an electrically controllable grating
6,359,884	Modular scalable packet scheduler with rate based shaping and virtual port scheduler
6,359,941	System and method for improved reference threshold setting in a burst mode digital data receiver
6,361,330	Mounting opto-electric modules on circuit boards
6,363,192	Composite cable units
6,365,072	Polymer optical fibers and process for manufacturing thereof
6,366,372	Burst mode wavelength manager
6,370,303	Optical fiber cable with support member for indoor and outdoor use
6,373,604	Optical MUX/DEMUX
6,373,632	Tunable Fabry-Perot filter
6,381,045	Method and apparatus for bidirectional communication over a single optical fiber
6,381,047	Passive optical network using a fabry-perot laser as a multiwavelength source
6,383,815	Devices and methods for measurements of barrier properties of coating arrays
6,383,829	Optical semiconductor device and method of fabricating the same
6,385,366	Fiber to the home office (FTTHO) architecture employing multiple wavelength bands as an overlay in an existing hybrid fiber coax (HFC) transmission system
6,396,573	System and method for optically testing broadcasting systems
6,396,575	Test and measurement system for detecting and monitoring faults and losses in passive optical networks (PONs)
6,405,240	Data transfer method
6,411,410	Wavelength-division multiplexing in passive optical networks
6,411,642	Techniques for fabricating and packaging multi-wavelength semiconductor laser array devices (chips) and their applications in system architectures
6,414,768	Optical communication system
6,415,085	Sub-miniature optical fiber cables, and apparatuses and methods for making the sub-miniature optical fiber cables
6,418,558	Hybrid fiber/coax video and telephony communication
6,420,928	AC coupled pre-amplifier for burst signal
6,421,150	Architecture repartitioning to simplify outside-plant component of fiber-based access system
6,424,656	Method to assign upstream timeslots to a network terminal and medium access controller for performing such a method
6,427,035	Method and apparatus for deploying fiber optic cable to subscriber
6,427,042	Optical fibre ducting system
6,434,154	TDM/TDMA distribution network
6,434,296	Optical multiplexer/demultiplexer with three waveguides
6,437,777	Three-dimensional virtual reality space display processing apparatus, a three-dimensional virtual reality space display processing method, and an information providing medium
6,438,132	Virtual port scheduler

Patent	Title
6,441,655	Frequency division/multiplication with jitter minimization
6,449,413	Radiation-curable composition for optical fiber matrix material
6,455,607	Peelable bonded ribbon matrix material; optical fiber bonded ribbon arrays containing same; and process for preparing said optical fiber bonded ribbon arrays
6,456,657	Frequency division multiplexed transmission of sub-band signals
6,456,767	Optical waveguide transmitter-receiver module
6,459,521	Electroabsorption modulator integrated distributed feedback laser transmitter
6,460,182	Optical communication system for transmitting RF signals downstream and bidirectional telephony signals which also include RF control signals upstream
6,462,325	Circuit for detecting the shutoff of an optical output
6,463,075	Time multiplexing method, and related arrangements to be used in a central station and network terminals of a communications network
6,466,342	Optical transmission system and method using an optical carrier drop/add transceiver
6,466,708	Optical module and manufacturing method thereof
6,470,032	System and method for synchronizing telecom-related clocks in ethernet-based passive optical access network
6,470,118	Optical module
6,473,427	ATM based VDSL communication system having meta signaling for switching a subscriber between different data service providers
6,477,174	Polling response selection using request monitoring in a network switch apparatus
6,483,831	Asynchronous transfer mode switch
6,483,903	Splitterless ethernet DSL on subscriber loops
6,483,977	Fiber management frame having movable work platform
6,483,978	Compact optical amplifier module
6,487,263	Decoding of a biphase modulated bitstream and relative self-synchronizing frequency divider with noninteger ratio
6,490,065	Optical transmission system
6,493,140	Polarization splitter and combiner and optical devices using the same
6,493,335	Method and system for providing low-cost high-speed data services
6,493,491	Optical drop cable for aerial installation
6,493,874	Set-top electronics and network interface unit arrangement
6,496,479	Network resource reservation control method and apparatus, receiving terminal, sending terminal, and relay apparatus
6,496,525	Laser driver and optical transceiver
6,496,639	Method and apparatus for upgrading an optical fiber communication system
6,496,641	Fiber optic interface device
6,498,667	Method and system for packet transmission over passive optical network
6,498,883	Optical fiber ribbon with pigmented matrix material and processes for making same
6,504,636	Optical communication system
6,515,751	Mechanically resonant nanostructures
6,515,791	Active reflection and anti-reflection optical switch
6,516,015	Laser driver and optical transceiver
6,519,255	Universal optical network unit for use in narrowband and broadband access networks
6,522,804	Connectorized outside fiber optic drop
6,523,178	Video transmission system
6,525,855	Telecommunications system simultaneously receiving and modulating an optical signal
6,525,858	Optical receiver and optical network system using thereof
6,525,880	Integrated tunable fabry-perot filter and method of making same
6,527,454	Optical module for receiving and transmitting light signal in optical communication

Patent	Title
6,530,087	Cable network system with ingress noise suppressing function
6,532,324	Optical multiplexer/demultiplexer with three waveguides
6,534,997	Apparatus and a method for locating a fault of a transmission line
6,535,715	Hybrid/fiber coax video and telephony communication system with poly-phase filtering
6,538,781	Multimedia distribution system using fiber optic lines
6,538,805	Codopant polymers for efficient optical amplification
6,539,147	Connectorized inside fiber optic drop
6,542,266	System and method for providing broadband data service
6,542,267	Light ramp 2000 fiber optic local access architecture
6,542,463	Method and arrangement for controlling accesses of network terminal units to predetermined resources of a packet-oriented communication network
6,542,652	Method and apparatus for deploying fiber optic cable to a subscriber
6,542,670	Wavelength demultiplexer
6,546,014	Method and system for dynamic bandwidth allocation in an optical access network
6,546,557	Method and system for enhancing digital video transmission to a set-top box
6,549,571	Circuitry and method for duty measurement
6,552,366	Optical transmitting and receiving device and the manufacturing method
6,552,832	Telecommunications system including transmultiplexer installed between digital switch and optical signal transmission fiber
6,556,640	Digital PLL circuit and signal regeneration method
6,556,745	Wavelength selective reflective/transmissive optical coupler and method
6,559,993	Optical router for a light-based communication network
6,560,394	Fiber management frame for closure
6,563,613	Optical subscriber network, and delay measurement method
6,563,990	Self-supporting cables and an apparatus and methods for making the same
6,567,197	Optical ring network architecture
6,567,579	Multi-channel, multi-mode redundant optical local loop having a bus topology
6,567,753	Devices and methods for simultaneous measurement of transmission of vapors through a plurality of sheet materials
6,570,563	Method and system for three-dimensional virtual reality space sharing and for information transmission
6,570,692	Communication network based on the atmospheric transmission of light
6,570,886	Time slot management method and a main station and substation realizing such a method
6,577,414	Subcarrier modulation fiber-to-the-home/curb (FTTH/C) access system providing broadband communications
6,577,422	Long reach delivery of broadcast services using broadband optical sources and pre-compensation dispersion
6,579,739	Optical transmitting and receiving device and the manufacturing method
6,587,267	Beam directing device
6,587,476	Ethernet frame encapsulation over VDSL using HDLC
6,591,052	Excessive length treatment and cartridge for optical fibers used in electric equipment
6,592,272	Burst mode transmission over multiple optical wavelengths
6,594,298	Multi-wavelength semiconductor laser array and method for fabricating the same
6,597,482	Multiplexing/demultiplexing apparatus for wavelength division multiplexed system and wavelength division multiplexed passive optical subscriber networks using the same apparatus
6,597,491	Micromechanical optical switch
6,602,427	Micromachined optical mechanical modulator based transmitter/receiver module
6,603,770	Apparatus and method for accessing a network

Patent	Title
6,603,895	Direct driving type optical fiber switch
6,606,430	Passive optical network with analog distribution
6,606,442	Optical waveguide component and a method of producing the same
6,608,721	Optical tapped delay line
6,608,834	System for encapsulating Ethernet frames over very high speed digital subscriber lines
6,611,366	Micromechanical optical switch
6,611,372	Erbium and ytterbium co-doped phosphate glass optical fiber amplifiers using short active fiber length
6,611,928	Homo-code continuity proof testing device
6,614,759	ONU function processing apparatus in ATM-PON system
6,614,950	Fiber bragg grating-based optical CDMA encoder/decoder
6,614,964	Optical communication apparatus
6,614,980	Connectorized outside fiber optic drop
6,616,344	Interconnection system for optical networks
6,616,348	Method and optical communication network for bidirectional protection protocols
6,621,975	Distribution terminal for network access point
6,625,375	Fiber optic interface device
6,633,541	Ascending transmission speed controlling method and communication system in ATM-PON system
6,636,527	Optical line termination in ATM-based PON
6,639,702	Optical module for access networks to wide band communication systems and relevant production method
6,640,025	Optical apparatus for optical communication terminal and optical communication system
6,643,052	Apparatus comprising a micro-mechanical optical modulator
6,643,290	Method for controlling accesses to resources of a communication network
6,647,210	Delay adjustment unit and method, optical network unit, and communication system
6,650,818	Rare earth doped optical waveguide and laser with optimal bending curves
6,650,839	Method and apparatus for optical media access protection in a passive optical network
6,650,840	Method for identifying faults in a branched optical network
6,650,841	Optical subscriber line terminal unit and a state transition control method
6,654,157	Micromechanical optical switch
6,654,536	Fiber management frame having connector platform
6,656,528	Method of making specular infrared mirrors for use in optical devices
6,658,009	Band allocation method and transmission system for transmitting variable-length packets
6,665,315	Transmission apparatus automatically acquiring identifying information and independently measuring propagation delay
6,668,127	Connectorized inside fiber optic drop
6,671,074	Optical receiver for burst transmission system
6,671,465	Apparatus and methods for improving linearity and noise performance of an optical source
6,674,785	Vertical-cavity, surface-emission type laser diode and fabrication process thereof
6,674,966	Re-configurable fibre wireless network
6,674,967	Fiber-to-the-home (FTTH) optical receiver having gain control and a remote enable
6,674,968	Passive thermal stabilization for an optical mux/demux
6,678,442	Fiber optic connector for a segmented FTTH optical network
6,680,940	System for transporting ethernet frames over very high speed digital subscriber lines
6,681,083	Power splitter for optical networks
H2,075	Restorable architectures for fiber-based broadband local access networks
RE35138	Achromatic overclad fiber optic coupler

Patent	Title
RE36,471	Passive optical communication network with broadband upgrade

Table A-4.2: Number of Fiber-to-the-Home -related Patents per Patent Holder

Assignee	Patents
Lucent Technologies, Inc.	90
British Telecommunications	67
Alcatel	39
Fujitsu Limited	33
Nortel Networks Corporation	26
AT&T Bell Laboratories	24
NEC Corporation	22
AT&T Corp.	21
Siemens Aktiengesellschaft	15
Borden Chemicals, Inc.	13
Bell Atlantic Network Services, Inc.	12
Corning Incorporated	12
Sony Corporation	10
Telefonaktiebolaget LM Ericsson	10
ADC Telecommunications, Inc.	9
Bellsouth Intellectual Property Management Corporation	9
Inventor	9
Kabushiki Kaisha Toshiba	8
Marconi Communications Limited	8
Matsushita Electric Industrial Co., Ltd.	8
U.S. Philips Corporation	8
Koninklijke PTT Nederland N.V.	7
Minnesota Mining and Manufacturing Company	7
General Instrument Corporation	6
Oki Electric Industry Co., Ltd.	6
Quantum Bridge Communications, Inc.	6
Samsung Electronics Co., Ltd.	6
Agere Systems Optoelectronics Guardian Corp.	5
France Telecom	5
Koninklijke KPN N.V.	5
3 Com Corporation	4
Dominion Lasercom, Inc.	4
GPT Limited	4
Photon-X, Inc.	4
Qwest Communications International Inc.	4
Siecor Corporation	4
Sumitomo Electric Industries, Ltd.	4
The Whitaker Corporation	4
Axsun Technologies, Inc.	3
Broadcom Corporation	3
Cheetah Omni, LLC	3
Com 21, Inc.	3
Electronics and Telecommunications Research Institute	3
General Electric Company	3
Hughes Aircraft Company	3
Italtel Societa Italiana Telecomunicazioni, S.p.A.	3

Assignee	Patents
Mitsubishi Denki Kabushiki Kaisha	3
Nippon Telegraph and Telephone Corporation	3
Nokia Telecommunications Oy	3
Pirelli Cavi e Sistemi S.p.A.	3
Scientific-Atlanta, Inc.	3
Alloptic, Inc.	2
Avaya Technology Corp.	2
Bell Communications Research, Inc.	2
BICC Public Limited Company	2
Cisco Technology, Inc.	2
CSELT - Centro Studi E Laboratori Telecomunicazioni S.P.A.	2
Motorola, Inc.	2
NGK Insulators, Ltd.	2
Powerdsine, Ltd.	2
Raynet Corporation	2
Telcordia Technologies, Inc.	2
U S West, Inc.	2
ACS Industries, Inc.	1
AMP Incorporated	1
Aralight, Inc.	1
Bell Canada	1
Board of Trustees of the Leland Stanford Junior Universty	1
British Technology Group InterCorporate Licensing Limited	1
Broadband Technologies, Inc.	1
BTG International Limited	1
Canon Kabushiki Kaisha	1
Ciena Corporation	1
Cornell Research Foundation Inc.	1
Daimler-Benz Aerospace Airbus GmbH	1
Dalsa Semiconductor Inc.	1
E. I. Du Pont de Nemours and Company	1
ECI Telecom Ltd.	1
Essex Corporation	1
Finisar Corporation	1
Fitel U.S.A. Corp.	1
Fondazione Ugo Bordoni	1
Fujikura Ltd.	1
GTE Laboratories Incorporated	1
Hewlett-Packard Company	1
Hitachi, Ltd.	1
Intel Corporation	1
JDS Uniphase Inc.	1
Jedai Broadband Networks Inc.	1
Korea Advanced Institute of Science and Technology	1
KTH, LLC	1
Litton Systems, Inc.	1
MediaOne Group, Inc.	1

Assignee	Patents
Microsoft Corporation	1
Minolta Co., Ltd.	1
Mitsubishi Gas Chemical Company, Inc.	1
MK Industries, Inc.	1
National Science Council	1
New Focus, Inc.	1
Next Level Communications, L.L.P.	1
Nippon Hoso Kyokai	1
Oplink Communications, Inc.	1
Optical Biopsy Technologies, Inc.	1
Optical Zonu Corporation	1
Orckit Communications, LTD	1
Pangrac and Associates Development, Inc.	1
Paradyne Corporation	1
Physical Optics Corporation	1
Picolight, Inc.	1
Quantum Devices, Inc.	1
Read-Rite Corporation	1
Reliance Comm/Tec Corporation	1
Rice University	1
Ricoh Company, Ltd.	1
Sharp Kabushiki Kaisha	1
STMicroelectronics S.r.l.	1
Swales Aerospace, Inc.	1
Telesector Resources Group, Inc.	1
The Arizona Board of Regents on behalf of the University of Arizona	1
The Perkin-Elmer Corporation	1
The Secretary of State for Defence in Her Britannic Majesty's Government of	1
Toshiba Machine Co., Ltd.	1
Unitrode Corporation	1
University of Maryland Baltimore County	1
University of Massachusettes	1
W. L. Gore & Associates, Inc.	1

Table A-4.3: Number of Fiber-to-the-Home -Related Patents Per Patent Class

Patents	Class Name and Number
253	398 Optical Communications
182	385 Optical Waveguides
147	370 Multiplex Communications
48	359 Optical: Systems And Elements
45	725 Interactive Video Distribution Systems
44	372 Coherent Light Generators
44	375 Pulse Or Digital Communications
27	379 Telephonic Communications
16	327 Miscellaneous Active Electrical Nonlinear Devices, Circuits, And Systems
14	356 Optics: Measuring And Testing
14	380 Cryptography
12	330 Amplifiers
12	709 Electrical Computers And Digital Processing Systems: Multicomputer Data Transferring Or Plural Processor Synchronization
12	714 Error Detection/Correction And Fault Detection/Recovery
11	250 Radiant Energy
11	455 Telecommunications
11	522 Synthetic Resins Or Natural Rubbers -- Part Of The Class 520 Series
9	713 Electrical Computers And Digital Processing Systems: Support
8	257 Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)
8	427 Coating Processes
7	340 Communications: Electrical
7	345 Computer Graphics Processing, Operator Interface Processing, And Selective Visual Display Systems
7	428 Stock Material Or Miscellaneous Articles
6	65 Glass Manufacturing
5	348 Television
4	264 Plastic And Nonmetallic Article Shaping Or Treating: Processes
4	361 Electricity: Electrical Systems And Devices
4	438 Semiconductor Device Manufacturing: Process
4	439 Electrical Connectors
3	252 Compositions
3	307 Electrical Transmission Or Interconnection Systems
3	331 Oscillators
3	363 Electric Power Conversion Systems
3	501 Compositions: Ceramic
3	528 Synthetic Resins Or Natural Rubbers -- Part Of The Class 520 Series
3	700 Data Processing: Generic Control Systems Or Specific Applications
2	174 Electricity: Conductors And Insulators
2	216 Etching A Substrate: Processes
2	254 Implements Or Apparatus For Applying Pushing Or Pulling Force
2	323 Electricity: Power Supply Or Regulation Systems
2	329 Demodulators
2	341 Coded Data Generation Or Conversion
2	422 Chemical Apparatus And Process Disinfecting, Deodorizing, Preserving, Or Sterilizing

Patents	Class Name and Number
2	707 Data Processing: Database And File Management Or Data Structures
1	1 Misclassified
1	29 Metal Working
1	57 Textiles: Spinning, Twisting, And Twining
1	148 Metal Treatment
1	156 Adhesive Bonding And Miscellaneous Chemical Manufacture
1	204 Chemistry: Electrical And Wave Energy
1	209 Classifying, Separating, And Assorting Solids
1	244 Aeronautics
1	310 Electrical Generator Or Motor Structure
1	320 Electricity: Battery Or Capacitor Charging Or Discharging
1	324 Electricity: Measuring And Testing
1	332 Modulators
1	333 Wave Transmission Lines And Networks
1	337 Electricity: Electrothermally Or Thermally Actuated Switches
1	342 Communications: Directive Radio Wave Systems And Devices (e.g., Radar, Radio Navigation)
1	349 Liquid Crystal Cells, Elements And Systems
1	377 Electrical Pulse Counters, Pulse Dividers, Or Shift Registers: Circuits And Systems
1	382 Image Analysis
1	405 Hydraulic And Earth Engineering
1	425 Plastic Article Or Earthenware Shaping Or Treating: Apparatus
1	430 Radiation Imagery Chemistry: Process, Composition, Or Product Thereof
1	436 Chemistry: Analytical And Immunological Testing
1	526 Synthetic Resins Or Natural Rubbers -- Part Of The Class 520 Series
1	701 Data Processing: Vehicles, Navigation, And Relative Location
1	702 Data Processing: Measuring, Calibrating, Or Testing
1	710 Electrical Computers And Digital Data Processing Systems: Input/Output
1	715 Data Processing: Presentation Processing Of Document
1	717 Data Processing: Software Development, Installation, And Management

Table A-4.4: Fabry-Perot Laser Diode Patents

Patent	Title
4,622,671	Multicavity optical device
4,734,380	Multicavity optical device held together by metallic film
4,873,690	Optical switch
5,073,983	Optical communication system with reduced distortion
5,128,800	Gain switchable optical fiber amplifier
5,222,089	Optical signal source for overcoming distortion generated by an optical amplifier
5,231,611	Wavelength multiplexed fiber optics resonant ring hydrophone array
5,317,588	Ridge waveguide distributed-feedback laser diode with a depressed-index cladding layer
5,351,317	Interferometric tunable optical filter
5,369,523	Optical amplifier and laser
5,386,490	Automated workstation for the manufacture of optical fiber couplers
5,418,802	Frequency tunable waveguide extended cavity laser
5,440,669	Photorefractive systems and methods
5,453,873	Optical amplifier and laser
5,459,799	Tunable optical filter
5,463,705	Optical waveguide isolation
5,541,947	Selectively triggered, high contrast laser
5,602,475	Laser pumped magnetometer
5,668,826	Electro-optical device comprising a controlled laser diode
5,684,611	Photorefractive systems and methods
5,691,989	Wavelength stabilized laser sources using feedback from volume holograms
5,768,460	Low skew optical fiber ribbons
5,845,030	Semiconductor laser module and optical fiber amplifier
5,946,128	Grating assisted acousto-optic tunable filter and method
6,058,131	Wavelength stabilization of laser source using fiber Bragg grating feedback
6,072,616	Apparatus and methods for improving linearity and noise performance of an optical source
6,108,355	Continuously-tunable external cavity laser
6,141,361	Wavelength selective filter
6,157,757	Polymer fiber optical transmission system
6,186,673	Package for optical semiconductor module
6,188,705	Fiber grating coupled light source capable of tunable, single frequency operation
6,212,151	Optical switch with coarse and fine deflectors
6,246,657	Fiber bundle switch
6,270,262	Optical interconnect module
6,274,879	Process and device for the quantitative detection of a given gas
6,282,215	Continuously-tunable external cavity laser
6,298,027	Low-birefringence optical fiber for use in an optical data storage system
6,324,319	Spliced optical fiber coupler
6,343,088	Semiconductor laser module
6,366,380	Optical transceiver EMI detuning device
6,381,047	Passive optical network using a fabry-perot laser as a multiwavelength source
6,396,115	Detector layer for an optics module
6,404,533	Optical amplitude modulator
6,404,727	Electromagnetic rotary actuator
6,456,381	Apparatus for and method of using optical interference of light propagating through an optical fiber loop

Patent	Title
6,459,844	Tunable fiber optic filter
6,483,635	Apparatus for light amplification
6,526,071	Tunable laser transmitter with internal wavelength grid generators
6,529,464	Low-birefringence optical fiber for use in an optical data storage system
6,587,190	System and method for measuring chromatic dispersion in optical fiber
6,587,421	Refractive index matching means coupled to an optical fiber for eliminating spurious light
6,587,530	Method and apparatus for signal integrity verification
6,600,760	Method and apparatus for tuning a laser
6,608,854	Method, device, and system for waveform shaping of signal light
6,661,377	Phased array antenna using gain switched multimode fabry-perot laser diode and high-dispersion-fiber
6,665,321	Tunable laser operation with locally commensurate condition
6,671,465	Apparatus and methods for improving linearity and noise performance of an optical source
6,683,902	Semiconductor laser module

Table A-4.5: Number of Fabry-Perot Laser Diode Patents Per Patent Holder

Assignee	Patents
Seagate Technology LLC	5
Accuwave Corporation	3
AT&T Bell Laboratories	3
British Telecommunications public limited company	3
International Business Machines Corporation	3
Iolon, Inc.	3
Lucent Technologies Inc.	3
New Focus, Inc.	3
E-Tek Dynamics, Inc.	2
Eastman Kodak Company	2
Intel Corporation	2
Kwangju Institute of Science & Technology	2
Telefonaktiebolaget LM Ericsson	2
The Furukawa Electric Co., Ltd.	2
AT&T Corp.	1
British Technology Group Limited	1
Cirrex Corp.	1
Cisco Technology, Inc	1
Drager Medizintechnik GmbH	1
Fujikura Ltd.	1
Fujitsu Limited	1
General Instrument Corporation	1
Harris Corporation	1
JDS Uniphase Corporation	1
Matsushita Electric Industrial Co., Ltd.	1
Motorola, Inc.	1
Siecor Corporation	1
Sumitomo Electric Industries, Ltd.	1
Tesa Brown & Sharpe SA	1
Texas Instruments Incorporated	1
The Charles Stark Draper Laboratory, Inc.	1
The Regents of the University of Michigan	1
The United States of America as represented by the Administrator of the	1
The United States of America as represented by the Secretary of Commerce	1

Table A-4.6: Number of Fabry-Perot Laser Diode Patents Per Patent Class

Patents	Class Name and Number
24	372 Coherent Light Generators
16	385 Optical Waveguides
14	359 Optical: Systems And Elements
6	369 Dynamic Information Storage Or Retrieval
5	356 Optics: Measuring And Testing
5	398 Optical Communications
4	250 Radiant Energy
2	257 Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)
1	324 Electricity: Measuring And Testing
1	342 Communications: Directive Radio Wave Systems And Devices (e.g., Radar, Radio Navigation)
1	361 Electricity: Electrical Systems And Devices
1	367 Communications, Electrical: Acoustic Wave Systems And Devices
1	375 Pulse Or Digital Communications
1	438 Semiconductor Device Manufacturing: Process

Appendix 5: Model Settings

5.1 Introduction

This Appendix contains the complete text of the model including all of the default settings. The section titles match individual runs described in the text, and any changes from the model defaults are documented. The full listing of model equations is in Section 15 of this Appendix. For ease of duplication, the base case of the model is available for download from: http://web.mit.edu/sly/www/dist. That directory contains two files: broadbanddemand.mdl and broadbanddemand.vmf. The file broadbanddemand.mdl is a text file of all of the equations and parameters for the model created in a program called Vensim from Ventana Systems. The file broadbanddemand.vmf is a Vensim binary file that can be viewed with the Vensim Model Reader which is available as a free download from http://www.vensim.com.

5.2 Video

```
average cable monthly fee = 80
```

5.3 Fiberinc

```
rate of change in fiber fraction = .10
```

5.4 Video+fiberinc

```
rate of change in fiber fraction = .10
average cable monthly fee = 80
```

5.5 50take

```
static take rate = .50
```

5.6 Nomuni

```
total suburban towns = 6000
initial telco towns with FTTH = 39
total muni towns = 0
initial muni towns with FTTH = 0
```

5.7 Mandate

```
mandate switch = 1
churn switch = 1
```

5.8 Slowdep

```
mandate switch = 1
churn switch = 1
mandated completion time = 120
```

5.9 Slowdep20

```
mandate switch = 1
churn switch = 1
mandated completion time = 240
```

5.10 Discard

```
mandate switch = 1
churn switch = 1
discard switch = 1
```

5.11 Lowchurn+discard

```
mandate switch = 1
churn switch = 1
churn rate = .10
discard switch = 1
```

5.12 Cost of money

```
cost of money switch = 1
```

5.13 TELRIC

```
telric switch = 1
```

5.14 TELRIC50

```
telric switch = 1
% telric = .50
```

5.15 Base

```
"% active" = 0.5
     Units: dmnl

"% cancellations" = 0.0025 / 12
     Units: dmnl

"% computer owning households" = INTEG( computer growth rate , 0.51)
     Units: dmnl

"% computer owning non-dialup households" = "% computer owning
households" - "% dialup subscribing households"
     Units: dmnl

"% dialup subscribing households" = 0.412
     Units: dmnl

"% former customers"[broadband type] = zidz ( former
customers[broadband type] , total potential customers[broadband type]
)
     Units: dmnl

"% FTTH" = households with FTTH available / households with broadband
available * ( 1 - mandate switch ) + mandate switch * ( mandate
households with FTTH available/ mandate households with broadband
available )
     Units: dmnl

"% new ordering"[broadband type] = zidz ( new ordering[broadband type]
, total purchasing customers[broadband type] )
     Units: fraction

"% new potential customers"[broadband type] = zidz ( potential
customers[broadband type] , total potential customers[broadband type]
)
     Units: dmnl
```

"% PON" = 0.5
Units: dmnl

"% repurchasing"[broadband type] = zidz (repurchasing[broadband type] , total purchasing customers[broadband type])
Units: fraction

"% telric" = 0.15
Units: dmnl

active CO electronics cost[population] = 45280, 45280, 40500
Units: dollars/town

"active cost of splicing & enclosures"[population] = 1.211e+006, 1.224e+006, 455700
Units: dollars/town

active fiber infrastructure cost[population] = cost of active fiber loop plant[population] + drop loop cost[population]
Units: dollars/town

active fiber management cost[population] = 33900, 33900, 24860
Units: dollars/town

active infrastructure cost[population] = "CO non-construction active cost"[population] + outside plant active cost[population]
Units: dollars/town

"active non-telco deployment cost"[population] = cumulative effect of input cost reduction* ("active non-telco electronics cost"[population] + "active non-telco non-elec costs"[population])
Units: dollars/town

"active non-telco electronics cost"[population] = ((active CO electronics cost[population] + cost of RT electronics[population] * CMU switch) * take rate assumption adjustment[population]) / (CMU adjustment[population] * (1 - CMU switch + CMU switch / CMU adjustment[population])) + ((1 - CMU switch) * rt per user price * assumed number of households[population] * connection per household)
Units: dollars/town

"active non-telco non-elec costs"[population] = ("RT non-electronics cost"[population] + "active cost of splicing & enclosures"[population] + active fiber infrastructure cost[population] + active fiber management cost[population]) / (CMU adjustment[population] * (1 - CMU switch + CMU switch / CMU adjustment[population]))
Units: dollars/town

active xcvr price = xcvr standardization switch * xcvr price[standardized] + (1 - xcvr standardization switch) * xcvr price[active]
Units: $/unit

actual EBITDA = static price - total recurring
Units: $/(month*household)

annual loan rate = 0.04
Units: dmnl

assimilated customers[broadband type] = INTEG(assimilation rate[broadband type] - cancellation rate[broadband type] + prior customer product arrival[broadband type] - price adjustment on current customers[broadband type] , initial assimilated customers[broadband type])
Units: households

assimilation rate[broadband type] = new buyers[broadband type] / time to assimilate
Units: households/month

assumed deployment cost[provider type,population] = (telco CO costs[population] + "telco non-electronics plant passive cost"[provider type,population]) * cumulative effect of input cost reduction
Units: dollars/town

assumed number of households[population] = model households[population] * model take rate
Units: households/town

Attractiveness to Munis[broadband type] = Effect Of Affordability On Muni Attractiveness[broadband type] * EffectOfPerformanceOnMuniAttractiveness[broadband type] * effect of muni success on muni attractiveness[broadband type] * effect of other success on muni attractiveness[broadband type]
Units: dmnl

"available broadband non-traditional funds" = "max available non-traditional funding" * novelty effect on funding
Units: dollars

average cable monthly fee = 42
Units: $/(month*household)

average CPE per customer = 1
Units: units/household

average deployment cost[population] = ("active non-telco deployment cost"[population] + "passive non-telco deployment cost"[population]) / 2
Units: dollars/town

average DSL cost per user[population] = 1400, 1800, 3000
Units: $/household

average funding per town = (CostOfOtherBroadBand + cost to provide FTTH service) / 2
Units: dollars/town

"backbone/transport" = 6
Units: $/(month*household)

bad debt = 1.24
Units: $/(month*household)

BBAttractiveness = EffectOfAffordabilityOnBroadBandAttractiveness * EffectOfBBPerformanceOnAttractiveness
Units: dmnl

broadband households[broadband type] = assimilated customers[broadband type] + new buyers[broadband type]
Units: households

broadband price ratio = static price / dialup price
Units: dmnl

broadband type : FTTH,other

BroadBandAffordability = perceived average funding per town / CostOfOtherBroadBand
Units: fraction

calculated breakeven monthly fee[provider type,population] = (assumed deployment cost[provider type,population] / npv adjustment[provider type]) / (assumed number of households[population] * payment period)
Units: $/(month*household)

calculated competition breakeven monthly fee[provider type,population] = (assumed deployment cost[provider type,population] / npv adjustment[provider type]) / ((assumed number of households[population] * payment period) / 2)
Units: $/(month*household)

calculated dialup contribution to market[broadband type] = price effect on dialup subscribers* "% dialup subscribing households" * calculated households with broadband available[broadband type]
Units: households

calculated households with broadband available[FTTH] = mandate switch * mandate households with FTTH available+ (1 - mandate switch) * households with FTTH available
calculated households with broadband available[other] = mandate switch * "mandate households with pre-existing broadband available" + (1 - mandate switch) * households with other broadband available
    Units: households

"calculated non-Internet contribution to market"[broadband type] = "% computer owning non-dialup households" * "price effect on computer owning non-dialup households" * calculated households with broadband available[broadband type]
    Units: households

calculated potential market[broadband type] = calculated dialup contribution to market[broadband type] + "calculated non-Internet contribution to market"[broadband type]
    Units: households

cancellation rate[broadband type] = assimilated customers[broadband type] * "% cancellations" / time to cancel
    Units: households/month

census households[population] = 18000, 9000, 1000
    Units: households/town

change in fiber fraction = min ("fraction pre-existing fiber" * rate of change in fiber fraction , max fiber fraction - "fraction pre-existing fiber") / time to change fiber
    Units: dmnl/month

change in perceived ratio of towns funded = (ratio of towns funded - perceived ratio of towns funded) / time to perceive trends
    Units: 1/month

change in perceived take rate = (take rate - perceived take rate) / time to perceive take rate
    Units: 1/month

churn = 0.35
    Units: dmnl

churn switch = 0
    Units: dmnl

churn time = 12
    Units: months

CMU adjustment[population] = 1, 2, 9
    Units: dmnl

CMU model adjusted households[population] = 18000, 18000, 9000
Units: households/town

CMU model final households[population] = 25030, 25130, 9122
Units: households/town

CMU model subscribers[population] = 17520, 17590, 6386
Units: households/town

CMU model take rate[population] = CMU model subscribers[population] / CMU model final households[population]
Units: dmnl

CMU switch = 0
Units: dmnl

CO construction cost[population] = 440000, 440000, 215000
Units: dollars/town

"CO non-construction active cost"[population] = active fiber management cost[population] + active CO electronics cost[population]
Units: dollars/town

"CO non-construction passive cost"[population] = passive CO electronics cost[population] + passive fiber management cost[population]
Units: dollars/town

CO port deployment rate = "% PON" * new CPE deployment * PON ratio - CO port redeployment rate + CO replacement
Units: units/month

CO port failure rate = total deployed CO ports / CO time to fail
Units: units/month

CO port per user price = total CO port price * PON ratio
Units: $/unit

CO port production rate = CO port deployment rate
Units: units/month

CO port redeployment rate = min (new CPE deployment * PON ratio * "% PON" , removed CO ports / time to redeploy)
Units: units/month

CO port removal due to cancellation = min (total deployed CO ports / time to cancel, "% PON" * CPE removal due to cancellation * PON ratio)
Units: units/month

CO replacement = CO port failure rate
Units: units/month

```
CO time to fail = 120
      Units: months

community type : rlec,muni,telco

completing FTTH muni deployment = FTTH muni deployment in process /
time to deploy FTTH
      Units: towns/month

completing FTTH rlec deployment = max ( 0, FTTH rlec deployment in
process / time to deploy FTTH )
      Units: towns/month

completing FTTH telco deployment = FTTH telco deployment in process /
time to deploy FTTH
      Units: towns/month

completing other broadband muni deployment = other broadband muni
deployment in process / time to deploy other broadband
      Units: towns/month

completing other broadband rlec deployment = max ( 0, other broadband
rlec deployment in process / time to deploy other broadband )
      Units: towns/month

completing other broadband telco deployment = other broadband telco
deployment in process / time to deploy other broadband
      Units: towns/month

computer growth rate = min ( desired penetration growth rate * "%
computer owning households" , max penetration - "% computer owning
households" ) / time to change rate
      Units: dmnl/month

computer households = "% computer owning households" * total
households
      Units: households

"computer non-dialup households" = "% computer owning non-dialup
households" * total households
      Units: households

connection per household = 1
      Units: units/household

contacts of noncust with newcust[broadband type] = contacts with new
customers * PotCust concentration[broadband type]
      Units: contacts/month
```

contacts of noncust with old cust[broadband type] = contacts with old customers * PotCust concentration[broadband type]
Units: contacts/month

contacts with new customers = (SUM (new buyers[broadband type!]) + SUM (new customers with ordered products[broadband type!])) * sociability
Units: contacts/month

contacts with old customers = SUM (old customers[broadband type!]) * sociability
Units: contacts/month

content = 2
Units: $/(month*household)

cost of active fiber loop plant[population] = 2.072e+007, 2.828e+007, 1.019e+007
Units: dollars/town

cost of money switch = 0
Units: dmnl

cost of OFAP[population] = 823300, 828000, 307150
Units: dollars/town

cost of passive CO electronics per customer[population] = passive CO electronics cost[population] / CMU model subscribers[population]
Units: $/household

cost of passive fiber loop plant[population] = 2.075e+007, 2.834e+007, 1.027e+007
Units: dollars/town

cost of RT[population] = 7.353e+006, 7.427e+006, 2.772e+006
Units: dollars/town

cost of RT electronics[population] = 3.753e+006, 3.77e+006, 1.377e+006
Units: dollars/town

cost of RT electronics per customer[population] = cost of RT electronics[population] / CMU model subscribers[population]
Units: $/household

cost to provide FTTH service = average deployment cost[rural]
Units: dollars/town

CostOfOtherBroadBand = assumed number of households[rural] * average DSL cost per user[rural]
Units: dollars/town

CPE cumulative production = INTEG(CPE production rate , initial deployed CPE)
Units: units

CPE deployment rate = (new CPE deployment - CPE redeployment rate) + replacement CPE
Units: units/month

CPE failure rate = total deployed CPE / time to fail
Units: units/month

CPE production rate = CPE deployment rate
Units: units/month

CPE redeployment rate = min (new CPE deployment , removed CPE / time to redeploy) * (1 - discard switch)
Units: units/month

CPE removal due to cancellation = min (total deployed CPE / time to cancel , total FTTH equipment cancellations * average CPE per customer)
Units: units/month

CPE revenue = 300
Units: $/unit

cumulative effect of input cost reduction = reduction rate ^ (Time / reduction period)
Units: dmnl

cumulative revenue = INTEG(revenue , 0)
Units: dollars

customer base[broadband type] = assimilated customers[broadband type] + new buyers[broadband type]
Units: households

"customer care/billing" = 5
Units: $/(month*household)

deployment rate[cpe] = CPE deployment rate
deployment rate[rt] = remote terminal port deployment rate
deployment rate[co port] = CO port deployment rate
Units: units/month

desired additional potential customers[broadband type] = max (0, market differential[broadband type])
Units: households

desired fraction of DSL deployments = 0.05
Units: dmnl

desired payback period = 60
Units: dmnl

desired penetration growth rate = 0.067
Units: dmnl

desired removal of potential customers[broadband type] = abs (min (0, market differential[broadband type]))
Units: households

device : cpe,rt,co port

dialup price = 20
Units: $/(month*household)

dialup subscribing households = "% dialup subscribing households" * total households
Units: households

discard switch = 0
Units: dmnl

drop loop cost[population] = 2.484e+006, 3.929e+006, 5.641e+006
Units: dollars/town

EBITDA difference = actual EBITDA - necessary EBITDA
Units: $/(month*household)

Economies of scale effect on price[device] = (effective deployment rate[device] / nominal production[device]) ^ (LN (1 - economies of scale fraction[device]) / LN (2))
Units: dmnl

economies of scale fraction[device] = 0.05, 0.05, 0.05
Units: dmnl

Effect Of Affordability On Muni Atractiveness f ([(0,0)-(2,2)],(0,0),(0.430588,0.0640569),(0.611621,0.22807),(0.782875,0.45614),(0.917431,0.763158),(1,1),(1.03976,1.07895),(1.10092,1.18421),(1.20489,1.32456),(1.35168,1.54386),(1.43119,1.66667),(1.5107,1.73684),(1.66361,1.88596),(1.85933,1.9386),(2,2))
Units: dmnl

Effect Of Affordability On Muni Attractiveness[broadband type] = Effect Of Affordability On Muni Atractiveness f (Muni Relative Affordability[broadband type])
Units: dmnl

Effect of exposure on conversions f ([(0,0)-(100,1)],(0,0),(10.3976,0.118421),(20.7951,0.25),(32.1101,0.333333),(44.0367,0.403509),(56.5749,0.460526),(72.1713,0.486842),(100,0.5))
Units: dmnl

effect of fraction of connected towns on available funding f ([(0,0)-(1,1)],(0,1),(0.0733945,1),(0.131498,1),(0.152905,1),(0.235474,1),(0.336391,1),(0.437309,0.982456),(0.565749,0.960526),(0.64526,0.925439),(0.703364,0.885965),(0.724771,0.868421),(0.755352,0.820175),(0.798165,0.754386),(0.844037,0.671053),(0.88685,0.570175),(0.926606,0.421053),(0.954128,0.315789),(0.963303,0.254386),(0.990826,0.0350877),(1,0))
Units: dmnl

Effect of lowest price on dialup households f ([(0,0)-(4,1)],(0,0.99),(0.5,0.92),(1,0.8),(1.5,0.58),(1.75,0.51),(2,0.45),(2.5,0.33),(3,0.18),(3.5,0.06),(4,0))
Units: dmnl

"Effect of lowest price on non-dialup households f" ([(0,0)-(4,1)],(0,0.96),(0.5,0.92),(1,0.76),(1.5,0.6),(1.75,0.48),(2,0.4),(2.5,0.25),(3,0.11),(3.5,0.04),(4,0))
Units: dmnl

effect of muni success on muni attractiveness[FTTH] = zidz (number of muni towns with FTTH , (number of muni towns with FTTH + number of muni towns with other broadband))
effect of muni success on muni attractiveness[other] = zidz (number of muni towns with other broadband , (number of muni towns with FTTH + number of muni towns with other broadband))
Units: dmnl

effect of other success on muni attractiveness[FTTH] = zidz (towns with FTTH , (towns with FTTH + towns with other broadband))
effect of other success on muni attractiveness[other] = zidz (towns with other broadband , (towns with FTTH + towns with other broadband))
Units: dmnl

Effect of price on current customers f ([(0,0)-(4,1)],(0,0.01),(0.5,0.08),(1,0.14),(1.5,0.21),(1.75,0.25),(2,0.3),(2.5,0.44),(3,0.7),(3.5,0.9),(4,1))
Units: dmnl

Effect of price on fomer customers f ([(0,0)-(4,1)],(0,0.99),(0.5,0.92),(1,0.8),(1.5,0.58),(1.75,0.51),(2,0.45),(2.5,0.33),(3,0.18),(3.5,0.06),(4,0))
Units: dmnl

effective deployment rate[device] = max (deployment rate[device] , nominal production[device])
Units: units/month

effective xcvr deployment rate[xcvr type] = max (xcvr nominal production[xcvr type] , xcvr deployment rate[xcvr type])
Units: units/month

```
EffectOfAffordabilityOnAtractiveness f ( [(0,0)-(2,2)],(0,0),
(0.430588,0.0640569),(0.611621,0.22807),(0.782875,0.45614),(0.917431,
0.763158),(1,1),(1.03976,1.07895),(1.10092,1.18421),(1.20489,1.32456),
(1.35168,1.54386),(1.43119,1.66667),(1.5107,1.73684),(1.66361,1.88596)
,(1.85933,1.9386),(2,2) )
     Units: dmnl

EffectOfAffordabilityOnBroadBandAttractiveness =
EffectOfAffordabilityOnAtractiveness f ( BroadBandAffordability )
     Units: dmnl

EffectOfAffordabilityOnFiberAttractiveness =
EffectOfAffordabilityOnAtractiveness f ( FiberAffordability )
     Units: dmnl

EffectOfBBPerformanceOnAttractiveness = 1
     Units: dmnl

EffectOfFiberPerformanceOnAttractiveness = 2
     Units: dmnl

EffectOfPerformanceOnMuniAttractiveness[broadband type] = 2, 1
     Units: dmnl

failure rate = CPE failure rate + remote terminal port failure rate
     Units: units/month

FiberAffordability = perceived average funding per town / cost to
provide FTTH service
     Units: fraction

FiberAttractiveness = EffectOfAffordabilityOnFiberAttractiveness *
EffectOfFiberPerformanceOnAttractiveness
     Units: dmnl

FINAL TIME = 360
     Units: month

fixed xcvr price[xcvr type] = 40, 20, 30
     Units: $/unit

former customers[broadband type] = INTEG( cancellation rate[broadband
type] - repurchasing[broadband type] + prior customer
cancellations[broadband type] + price adjustment on current
customers[broadband type] , 0)
     Units: households

fraction FTTH that go forward without funding = 0.01
     Units: dmnl
```

fraction of connected muni towns = zidz (number of muni towns with broadband , (number of muni towns with broadband + number of muni towns without broadband))
Units: dmnl

fraction of connected rlec towns = number of rlec towns with broadband / (number of rlec towns with broadband + number of rlec towns without broadband)
Units: dmnl

fraction of connected telco towns = number of telco towns with broadband / (number of telco towns with broadband + number of telco towns without broadband)
Units: dmnl

fraction of FTTH applicants = IF THEN ELSE (total funding applicants = 0, 0, potential FTTH rlec towns / total funding applicants)
Units: dmnl

Fraction of Muni Towns[broadband type] = zidz (Attractiveness to Munis[broadband type] , Total Muni Attractiveness)
Units: fraction

fraction of other broadband applicants = IF THEN ELSE (total funding applicants = 0, 0, potential other broadband rlec towns / total funding applicants)
Units: dmnl

fraction of revenue to marketing = 0.05
Units: dmnl

fraction of telco DSL capable towns = 0.25
Units: dmnl

fraction of towns with broadband = towns with broadband / (towns with broadband + towns without broadband)
Units: dmnl

fraction other broadband that go forward without funding = 0.05
Units: dmnl

"fraction pre-existing fiber" = INTEG(change in fiber fraction , "initial fraction pre-existing fiber")
Units: dmnl

FractionOfTownsChoosingFiber = zidz (FiberAttractiveness , TotalRuralAttractiveness)
Units: fraction

FractionOfTownsChoosingOtherBroadband = zidz (BBAttractiveness , TotalRuralAttractiveness)
Units: fraction

```
FTTH muni deployment in process = INTEG( muni towns deploying FTTH -
completing FTTH muni deployment , 0)
      Units: towns

FTTH rlec deployment in process = INTEG( rlec towns deploying FTTH -
completing FTTH rlec deployment , 0)
      Units: towns

FTTH telco deployment in process = INTEG( telco towns deploying FTTH -
completing FTTH telco deployment , 0)
      Units: towns

FTTH towns funded = fraction of FTTH applicants * total possible
number of funded towns
      Units: towns

house truckroll = 125
      Units: $/household

households with broadband available = households with FTTH available +
households with other broadband available
      Units: households

households with FTTH available = muni households with FTTH available +
rlec households with FTTH available + telco households with FTTH
available
      Units: households

households with other broadband available = muni households with other
broadband available + rlec households with other broadband available +
telco households with other broadband available
      Units: households

industry yearly capex = 1.5e+010
      Units: dollars

initial assimilated customers[broadband type] = 325, 1.71116e+006
      Units: households

initial assumed take rate = 0.3
      Units: dmnl

initial deployed CO ports = initial deployed CPE * "% PON" * PON ratio
      Units: units

initial deployed CPE = ( initial assimilated customers[FTTH] + initial
new buyers[FTTH] ) * average CPE per customer
      Units: units
```

initial deployed remote terminal ports = "% active" * initial deployed CPE
Units: units

"initial fraction pre-existing fiber" = 0.123
Units: dmnl

initial FTTH rlec towns = 111
Units: towns

initial muni towns with FTTH = 12
Units: towns

initial muni towns with other broadband = percent munis with existing service * model muni towns
Units: towns

initial new buyers[broadband type] = 1667, 1.05297e+006
Units: households

initial other broadband rlec towns = percent rlec towns with existing service * model rlec towns
Units: towns

initial potential muni towns = model muni towns - initial muni towns with FTTH - initial muni towns with other broadband
Units: towns

initial potential rlec towns = model rlec towns - initial FTTH rlec towns - initial other broadband rlec towns
Units: towns

initial potential telco towns = model suburban towns - initial telco towns with other broadband - initial telco towns with FTTH
Units: towns

initial telco towns with FTTH = 27
Units: towns

initial telco towns with other broadband = percent telco towns with existing service * model suburban towns
Units: towns

INITIAL TIME = 0
Units: month

initial unit nominal price[device] = 300, 7550, 12100
Units: $/unit

initial xcvr deployment[standardized] = initial deployed CPE + initial deployed remote terminal ports
initial xcvr deployment[active] = initial deployed remote terminal ports + initial deployed CPE * "% active"
initial xcvr deployment[passive] = initial deployed CPE * "% PON"
Units: units

initial xcvr price[xcvr type] = 150, 80, 150
Units: $/unit

intial potential DSL telco towns = fraction of telco DSL capable towns * initial potential telco towns
Units: towns

maintenance marketing = 0.5
Units: $/(month*household)

mandate average community population = ("mandate rural have-nots" * model households[rural] + "mandate suburban have-nots" * model households[suburban]) / ("mandate rural have-nots" + "mandate suburban have-nots")
Units: households/town

mandate deployed communities = INTEG(mandate deploying communities , mandate initial FTTH communities)
Units: towns

mandate deploying communities = min (necessary deployment rate , mandate potential communities / mandate deployment time)
Units: towns/month

mandate deployment time = 1
Units: month

mandate households with broadband available = mandate households with FTTH available + "mandate households with pre-existing broadband available"
Units: households

mandate households with FTTH available = mandate average community population * mandate deployed communities
Units: households

"mandate households with pre-existing broadband available" = (initial telco towns with other broadband) * model households[suburban] + initial other broadband rlec towns * model households[rural] + telco urban towns * model households[urban]
Units: households

mandate initial FTTH communities = 20
Units: towns

mandate initial potential communities = "mandate rural have-nots" + "mandate suburban have-nots" - mandate initial FTTH communities
Units: towns

mandate potential communities = INTEG(- mandate deploying communities , mandate initial potential communities)
Units: towns

"mandate rural have-nots" = initial potential rlec towns
Units: towns

"mandate suburban have-nots" = initial potential muni towns + initial potential telco towns
Units: towns

mandate switch = 0
Units: dmnl

mandate towns with other broadband = initial other broadband rlec towns + initial telco towns with other broadband + telco urban towns
Units: towns

mandated completion time = 36
Units: months

market differential[broadband type] = calculated potential market[broadband type] - total market population[broadband type]
Units: households

marketing conversions[broadband type] = (Effect of exposure on conversions f (marketing exposure[broadband type])) * potential customers[broadband type] / time for marketing to take effect
Units: households/month

marketing expenditure = fraction of revenue to marketing * revenue
Units: $/month

marketing exposure[broadband type] = zidz (total marketing expenditure , potential customers[broadband type])
Units: $/(month*household)

"marketing/help desk" = 50
Units: $/household

"max available non-traditional funding" = 2.157e+009
Units: dollars

max fiber fraction = 1
Units: dmnl

max penetration = 0.85
Units: dmnl

max telco builds = industry yearly capex / assumed deployment cost[RBOC,suburban]
Units: towns

model households[population] = CMU model adjusted households[population] * CMU switch + (1 - CMU switch) * census households[population]
Units: households/town

model muni towns = (total muni towns / CMU adjustment[suburban]) * CMU switch + (1 - CMU switch) * total muni towns
Units: towns

model rlec towns = (total rlec towns / CMU adjustment[rural]) * CMU switch + total rlec towns * (1 - CMU switch)
Units: towns

model suburban towns = (total suburban towns / CMU adjustment[suburban]) * CMU switch + total suburban towns * (1 - CMU switch)
Units: towns

model take rate = take rate switch * perceived take rate + (1 - take rate switch) * static take rate
Units: dmnl

monthly WACC[provider type] = (WACC[provider type] * (1 - cost of money switch) + annual loan rate * cost of money switch) / 12
Units: dmnl

muni 20 year bond rate = 0.045
Units: dmnl

muni breakeven monthly rate[population] = (average deployment cost[population] / muni npv adjustment) / assumed number of households[population]
Units: $/(month*household)

muni cost to provide DSL service = assumed number of households[suburban] * average DSL cost per user[suburban]
Units: dollars/town

muni cost to provide FTTH service = average deployment cost[suburban]
Units: dollars/town

muni deployment pressure = fraction of connected muni towns * muni left behind effect
Units: dmnl

muni deployment rate = muni deployment pressure * Potential broadband muni towns
Units: towns

muni desired payback time = 240
Units: dmnl

muni households with FTTH available = model households[suburban] * number of muni towns with FTTH
Units: households

muni households with other broadband available = model households[suburban] * number of muni towns with other broadband
Units: households

muni left behind effect = towns with broadband / (towns with broadband + towns without broadband)
Units: dmnl

muni monthly rate = muni 20 year bond rate / 12
Units: dmnl

muni npv adjustment = (1 - (1 / (1 + muni monthly rate)) ^ muni desired payback time) / muni monthly rate * muni payment period
Units: month

muni payment period = 1
Units: month

Muni Relative Affordability[FTTH] = muni cost to provide FTTH service / muni cost to provide DSL service
Muni Relative Affordability[other] = muni cost to provide DSL service / muni cost to provide FTTH service
Units: fraction

muni towns deploying broadband = muni deployment rate / time to decide
Units: towns/month

muni towns deploying FTTH = potential FTTH muni towns / time to begin deployment
Units: towns/month

muni towns deploying other broadband = potential other broadband muni towns / time to begin deployment
Units: towns/month

muni towns selecting FTTH = Fraction of Muni Towns[FTTH] * muni towns deploying broadband
Units: towns/month

muni towns selecting other broadband = muni towns deploying broadband * Fraction of Muni Towns[other]
    Units: towns/month

necessary deployment rate = mandate initial potential communities / mandated completion time
    Units: towns/month

necessary EBITDA = total acquisition cost * churn / churn time
    Units: $/(month*household)

neighborhood truckroll = 42
    Units: $/household

network operations = 3.63
    Units: $/(month*household)

new buyers[broadband type] = INTEG(new product arrival[broadband type] - assimilation rate[broadband type] , initial new buyers[broadband type])
    Units: households

new CPE deployment = (new product arrival[FTTH] + prior customer product arrival[FTTH]) * average CPE per customer
    Units: units/month

new customer cancellations[broadband type] = "% cancellations" * new customers with ordered products[broadband type] / time to cancel
    Units: households/month

new customers with ordered products[broadband type] = INTEG(- new customer cancellations[broadband type] - new product arrival[broadband type] + new ordering[broadband type] , 0)
    Units: households

new fruitfulness = 0.005
    Units: households/contact

new ordering[broadband type] = min (potential customers[broadband type] / time to adopt , total wom conversions[broadband type] + marketing conversions[broadband type])
    Units: households/month

new product arrival[broadband type] = new customers with ordered products[broadband type] / static delivery delay
    Units: households/month

new wom Conversions[broadband type] = contacts of noncust with newcust[broadband type] * new fruitfulness
    Units: households/month

nominal production[device] = 100, 100, 100
Units: units/month

novelty effect on funding = effect of fraction of connected towns on available funding f (fraction of connected rlec towns)
Units: dmnl

npv adjustment[provider type] = (1 - (1 / (1 + monthly WACC[provider type])) ^ desired payback period) / monthly WACC[provider type]
Units: dmnl

number of muni towns with broadband = number of muni towns with FTTH + number of muni towns with other broadband
Units: towns

number of muni towns with FTTH = INTEG(completing FTTH muni deployment , initial muni towns with FTTH)
Units: towns

number of muni towns with other broadband = INTEG(completing other broadband muni deployment , initial muni towns with other broadband)
Units: towns

number of muni towns without broadband = potential FTTH muni towns + potential other broadband muni towns + Potential broadband muni towns
Units: towns

number of rlec towns with broadband = number of rlec towns with FTTH + number of rlec towns with other broadband
Units: towns

number of rlec towns with FTTH = INTEG(completing FTTH rlec deployment , initial FTTH rlec towns)
Units: towns

number of rlec towns with other broadband = INTEG(completing other broadband rlec deployment , initial other broadband rlec towns)
Units: towns

number of rlec towns without broadband = potential FTTH rlec towns + potential other broadband rlec towns + Potential broadband rural lec towns
Units: towns

number of telco towns with broadband = number of telco towns with FTTH + number of telco towns with other broadband
Units: towns

number of telco towns with FTTH = INTEG(completing FTTH telco deployment , initial telco towns with FTTH)
Units: towns

number of telco towns with other broadband = INTEG(completing other broadband telco deployment , initial telco towns with other broadband)
    Units: towns

number of telco towns without broadband = potential FTTH telco towns + potential other broadband telco towns + Potential broadband telco towns
    Units: towns

old customers[broadband type] = assimilated customers[broadband type] + prior customers with ordered products[broadband type]
    Units: households

old fruitfulness = 0.001
    Units: households/contact

old wom Conversions[broadband type] = contacts of noncust with old cust[broadband type] * old fruitfulness
    Units: households/month

other broadband muni deployment in process = INTEG(muni towns deploying other broadband - completing other broadband muni deployment , 0)
    Units: towns

other broadband rlec deployment in process = INTEG(rlec towns deploying other broadband - completing other broadband rlec deployment , 0)
    Units: towns

other broadband telco deployment in process = INTEG(telco towns deploying other broadband - completing other broadband telco deployment , 0)
    Units: towns

Other broadband towns funded = fraction of other broadband applicants * total possible number of funded towns
    Units: towns
other recurring cost = 5
    Units: $/(month*household)

outside plant active cost[population] = "outside plant non-fiber active cost"[population] + active fiber infrastructure cost[population]
    Units: dollars/town

"outside plant non-fiber active cost"[population] = "active cost of splicing & enclosures"[population] + cost of RT[population]
    Units: dollars/town

"outside plant non-fiber passive cost"[population] = cost of OFAP[population] + "passive cost of splicing & enclosures"[population]
Units: dollars/town

outside plant passive cost[population] = "outside plant non-fiber passive cost"[population] + passive fiber infrastructure cost[population]
Units: dollars/town

passive CO electronics cost[population] = 1.981e+006, 1.9945e+006, 757800
Units: dollars/town

"passive cost of splicing & enclosures"[population] = 1.273e+006, 1.286e+006 , 477000
Units: dollars/town

passive fiber infrastructure cost[population] = cost of passive fiber loop plant[population] + drop loop cost[population]
Units: dollars/town

passive fiber management cost[population] = 60300, 61800, 23400
Units: dollars/town

passive infrastructure cost[population] = "CO non-construction passive cost"[population] + outside plant passive cost[population]
Units: dollars/town

"passive non-telco deployment cost"[population] = cumulative effect of input cost reduction * (((outside plant passive cost[population] + passive fiber management cost[population] + passive CO electronics cost[population] * CMU switch * take rate assumption adjustment[population]) / (CMU adjustment[population] * (1 - CMU switch + CMU switch / CMU adjustment[population]))) + ((1 - CMU switch) * CO port per user price * assumed number of households[population] * connection per household))
Units: dollars/town

passive xcvr price = xcvr standardization switch * xcvr price[standardized] + (1 - xcvr standardization switch) * xcvr price[passive]
Units: $/unit

payment period = 1
Units: month

perceived average funding per town = average funding per town * perceived ratio of towns funded
Units: dollars/town

perceived ratio of towns funded = INTEG(change in perceived ratio of towns funded , 1)
Units: dmnl

perceived take rate = INTEG(change in perceived take rate , initial assumed take rate)
Units: dmnl

percent munis with existing service = 0.85
Units: dmnl

percent rlec towns with existing service = 0.41
Units: dmnl

percent telco towns with existing service = 0.72
Units: dmnl

PON ratio = 1 / 32
Units: dmnl

population : urban,suburban,rural

PotCust concentration[broadband type] = potential customers[broadband type] / total households
Units: dmnl

Potential broadband muni towns = INTEG(- muni towns deploying broadband , initial potential muni towns)
Units: towns

Potential broadband rural lec towns = INTEG(- rlec towns deploying broadband , initial potential rlec towns)
Units: towns

Potential broadband telco towns = INTEG(- telco towns deploying broadband , initial potential telco towns)
Units: towns

potential customers[broadband type] = INTEG(- potential customers removed[broadband type] + potential customers added[broadband type] - new ordering[broadband type] + new customer cancellations[broadband type] , 0)
Units: households

potential customers added[broadband type] = desired additional potential customers[broadband type] / time to adjust
Units: households/month

potential customers removed[broadband type] = min (potential customers[broadband type] , desired removal of potential customers[broadband type]) / time to adjust
Units: households/month

potential DSL telco towns = INTEG(- telco towns selecting DSL , fraction of telco DSL capable towns * initial potential telco towns)
Units: towns

potential FTTH muni towns = INTEG(muni towns selecting FTTH - muni towns deploying FTTH , 0)
Units: towns

potential FTTH rlec towns = INTEG(rlec towns selecting FTTH - rlec towns deploying FTTH , 0)
Units: towns

potential FTTH telco towns = INTEG(telco towns selecting FTTH - telco towns deploying FTTH , 0)
Units: towns

potential other broadband muni towns = INTEG(muni towns selecting other broadband - muni towns deploying other broadband , 0)
Units: towns

potential other broadband rlec towns = INTEG(rlec towns selecting other broadband - rlec towns deploying other broadband , 0)
Units: towns

potential other broadband telco towns = INTEG(telco towns selecting DSL - telco towns deploying other broadband , 0)
Units: towns

price adjustment on current customers[broadband type] = ((1 - churn switch) * Effect of price on current customers f (broadband price ratio) + churn switch * churn) * assimilated customers[broadband type] / time to adjust
Units: households/month

"price effect on computer owning non-dialup households" = "Effect of lowest price on non-dialup households f" (broadband price ratio)
Units: dmnl

price effect on dialup subscribers = Effect of lowest price on dialup households f (broadband price ratio)
Units: dmnl

prior customer cancellations[broadband type] = "% cancellations" * prior customers with ordered products[broadband type] / time to cancel
Units: households/month

prior customer product arrival[broadband type] = prior customers with ordered products[broadband type] / static delivery delay
Units: households/month

prior customers with ordered products[broadband type] = INTEG(repurchasing[broadband type] - prior customer cancellations[broadband type] - prior customer product arrival[broadband type] , 0)
Units: households

provider type : RBOC,CLEC

rate of change in fiber fraction = 0.054
Units: dmnl

ratio of towns funded = IF THEN ELSE (total funding applicants = 0, perceived ratio of towns funded , min (1, total possible number of funded towns / total funding applicants))
Units: dmnl

reduction period = 12
Units: months

reduction rate = 0.95
Units: dmnl

remote terminal port deployment rate = "% active" * new CPE deployment + remote terminal replacement - remote terminal port redeployment rate
Units: units/month

remote terminal port failure rate = total deployed remote terminal ports / time to fail
Units: units/month

remote terminal port production rate = remote terminal port deployment rate
Units: units/month

remote terminal port redeployment rate = min (new CPE deployment * "% active" , removed remote terminal ports / time to redeploy)
Units: units/month

remote terminal removal due to cancellation = min (total deployed remote terminal ports / time to cancel , "% active" * CPE removal due to cancellation)
Units: units/month

remote terminal replacement = remote terminal port failure rate
Units: units/month

removed CO ports = INTEG(CO port removal due to cancellation - CO port redeployment rate , 0)
Units: units

removed CPE = INTEG(CPE removal due to cancellation - CPE redeployment rate , 0)
Units: units

removed remote terminal ports = INTEG(remote terminal removal due to cancellation - remote terminal port redeployment rate , 0)
Units: units

replacement CPE = CPE failure rate
Units: units/month

repurchasing[broadband type] = Effect of price on fomer customers f (broadband price ratio) * former customers[broadband type] / repurchasing time
Units: households/month

repurchasing time = 1
Units: month

revenue = static price * total broadband households
Units: $/month

rlec households with FTTH available = model households[rural] * number of rlec towns with FTTH
Units: households

rlec households with other broadband available = model households[rural] * number of rlec towns with other broadband
Units: households

rlec towns deploying broadband = rural deployment rate / time to decide
Units: towns/month

rlec towns deploying FTTH = min (potential FTTH rlec towns / time to receive funding notice , FTTH towns funded / time to receive funding notice + ((potential FTTH rlec towns / time to receive funding notice) - FTTH towns funded / time to receive funding notice) * fraction FTTH that go forward without funding)
Units: towns/month

rlec towns deploying other broadband = min (potential other broadband rlec towns / time to receive funding notice , Other broadband towns funded / time to receive funding notice + ((potential other broadband rlec towns / time to receive funding notice) - Other broadband towns funded / time to receive funding notice) * fraction other broadband that go forward without funding)
Units: towns/month

rlec towns selecting FTTH = FractionOfTownsChoosingFiber * rlec towns deploying broadband
Units: towns/month

rlec towns selecting other broadband = rlec towns deploying broadband * FractionOfTownsChoosingOtherBroadband
Units: towns/month

"RT non-electronics cost"[population] = cost of RT[population] - cost of RT electronics[population]
Units: dollars/town

rt per user price = active xcvr price + RT ratio * unit price no xcvr[rt]
Units: $/unit

RT ratio = 1 / 48
Units: dmnl

rural deployment pressure = fraction of connected rlec towns * rural left behind effect
Units: dmnl

rural deployment rate = Potential broadband rural lec towns * rural deployment pressure
Units: towns

rural left behind effect = towns with broadband / (towns with broadband + towns without broadband)
Units: dmnl

SAVEPER = TIME STEP
Units: month [0,?]

sociability = 250
Units: contacts/(month*household)

standardized xcvr deployment rate = CPE deployment rate + remote terminal port deployment rate
Units: units/month

static delivery delay = 1
Units: month

static marketing expenditure = 3e+007
Units: $/month

static price = 40
Units: $/(month*household)

static take rate = 0.3
Units: dmnl

take rate = SUM (customer base[broadband type!]) / households with broadband available
Units: dmnl

take rate assumption adjustment[population] = model take rate / CMU
model take rate[population]
Units: dmnl

take rate switch = 0
Units: dmnl

tech support = 9.5
Units: $/(month*household)

telco build switch = IF THEN ELSE (((1 - telric switch) *
calculated breakeven monthly fee[RBOC,suburban] + telric switch *
telric breakeven monthly fee[suburban]) <= average cable monthly fee
, 1, 0)
Units: dmnl

telco CO costs[population] = passive CO electronics cost[population] *
CMU switch * (take rate assumption adjustment[population]) / (CMU
adjustment[population] * (1 - CMU switch + CMU switch / CMU
adjustment[population])) + (1 - CMU switch) * CO port per user
price * assumed number of households[population] * connection per
household
Units: dollars/town

telco households with FTTH available = model households[suburban] *
number of telco towns with FTTH
Units: households

telco households with other broadband available = model
households[suburban] * number of telco towns with other broadband +
model households[urban] * telco urban towns
Units: households

"telco non-electronics plant passive cost"[RBOC,population] = ((1 -
"fraction pre-existing fiber") * passive fiber infrastructure
cost[population] + "outside plant non-fiber passive cost"[population]
+ passive fiber management cost[population]) / (CMU
adjustment[population] * (1 - CMU switch + CMU switch / CMU
adjustment[population]))
"telco non-electronics plant passive cost"[CLEC,population] = (
passive fiber infrastructure cost[population] + "outside plant non-
fiber passive cost"[population] + passive fiber management
cost[population]) / (CMU adjustment[population] * (1 - CMU switch +
CMU switch / CMU adjustment[population]))
Units: dollars/town

telco towns deploying broadband = telco towns selecting FTTH + telco
towns selecting DSL
Units: towns/month

telco towns deploying FTTH = potential FTTH telco towns / time to plan
Units: towns/month

telco towns deploying other broadband = potential other broadband telco towns / time to plan
Units: towns/month

telco towns selecting DSL = (1 - telco build switch) * min (desired fraction of DSL deployments * potential DSL telco towns , potential DSL telco towns) / time to decide
Units: towns/month

telco towns selecting FTTH = telco build switch * min (max telco builds , Potential broadband telco towns) / time to decide
Units: towns/month

telco urban towns = 1000
Units: towns

telric breakeven monthly fee[population] = (assumed deployment cost[RBOC,population] / (npv adjustment[RBOC] * payment period) - telric price * "% telric" * assumed number of households[population]) / (assumed number of households[population] - "% telric" * assumed number of households[population])
Units: $/(month*household)

telric price = 0.65 * average cable monthly fee
Units: $/(month*household)

telric switch = 0
Units: dmnl

time for marketing to take effect = 3
Units: month

TIME STEP = 0.0625
Units: month [0,?]

time to adjust = 12
Units: months

time to adopt = 1
Units: month

time to assimilate = 6
Units: month

time to begin deployment = 6
Units: months

time to cancel = 1
Units: month

time to change fiber = 12
Units: months

time to change rate = 12
Units: months

time to decide = 12
Units: months

time to deploy FTTH = 6
Units: months

time to deploy other broadband = 2
Units: months

time to fail = 60
Units: months

time to perceive take rate = 3
Units: month

time to perceive trends = 12
Units: months

time to plan = 12
Units: months

time to receive funding notice = 12
Units: months

time to redeploy = 1
Units: month

total acquisition cost = (total passive CPE price * cumulative effect of input cost reduction - CPE revenue) * connection per household + house truckroll + neighborhood truckroll + "marketing/help desk"
Units: $/household

total active CO cost[population] = active CO electronics cost[population] + active fiber management cost[population] + CO construction cost[population]
Units: dollars/town

total active CPE price = active xcvr price + unit price no xcvr[cpe]
Units: $/unit

total active per user price = total active CPE price + rt per user price
Units: $/unit

total broadband households = SUM (new buyers[broadband type!]) + SUM (assimilated customers[broadband type!])
Units: households

total CO port price = unit price no xcvr[co port]
Units: $/unit

total cumulative CO production = INTEG(CO port production rate , initial deployed CO ports)
Units: units

total cumulative remote terminal port production = INTEG(remote terminal port production rate , initial deployed remote terminal ports)
Units: units

total cumulative xcvr production[xcvr type] = INTEG(total xcvr production rate[xcvr type] , initial xcvr deployment[xcvr type])
Units: units

total customers[broadband type] = new buyers[broadband type] + old customers[broadband type]
Units: households

total deployed CO ports = INTEG(CO port deployment rate - CO port failure rate - CO port removal due to cancellation + CO port redeployment rate , initial deployed CO ports)
Units: units

total deployed CPE = INTEG(CPE deployment rate - CPE failure rate - CPE removal due to cancellation + CPE redeployment rate , initial deployed CPE)
Units: units

total deployed remote terminal ports = INTEG(remote terminal port deployment rate - remote terminal port failure rate - remote terminal removal due to cancellation + remote terminal port redeployment rate , initial deployed remote terminal ports)
Units: units

total FTTH equipment cancellations = price adjustment on current customers[FTTH] + cancellation rate[FTTH]
Units: households/month

total funding applicants = potential FTTH rlec towns + potential other broadband rlec towns
Units: towns

total households = 8.85e+007
Units: households

total market population[broadband type] = old customers[broadband type] + new buyers[broadband type] + former customers[broadband type] + new customers with ordered products[broadband type] + potential customers[broadband type]
Units: households

total marketing expenditure = static marketing expenditure
Units: $/month

Total Muni Attractiveness = SUM (Attractiveness to Munis[broadband type!])
Units: dmnl

total muni towns = 529
Units: towns

total passive CO cost[population] = CO construction cost[population] + passive CO electronics cost[population] + passive fiber management cost[population]
Units: dollars/town

total passive CPE price = passive xcvr price + unit price no xcvr[cpe]
Units: $/unit

total passive per user price = total passive CPE price + CO port per user price
Units: $/unit

total possible number of funded towns = zidz ("available broadband non-traditional funds" , average funding per town)
Units: towns

total potential customers[broadband type] = former customers[broadband type] + potential customers[broadband type]
Units: households

total purchasing customers[broadband type] = new ordering[broadband type] + repurchasing[broadband type]
Units: households/month

total recurring = "backbone/transport" + bad debt + content + "customer care/billing" + maintenance marketing + network operations + other recurring cost + tech support
Units: $/(month*household)

total rlec towns = 18000
Units: towns

total standarized deployed xcvrs = INTEG(standardized xcvr deployment rate - failure rate , initial xcvr deployment[standardized])
Units: units

total suburban towns = 5500
Units: towns

total towns = towns with broadband + towns without broadband
Units: towns

total wom conversions[broadband type] = new wom Conversions[broadband type] + old wom Conversions[broadband type]
Units: households/month

total xcvr production rate[xcvr type] = xcvr deployment rate[xcvr type]
Units: units/month

TotalRuralAttractiveness = BBAttractiveness + FiberAttractiveness
Units: dmnl

towns with broadband = towns with FTTH + towns with other broadband
Units: towns

towns with FTTH = number of muni towns with FTTH + number of rlec towns with FTTH + number of telco towns with FTTH
Units: towns

towns with other broadband = number of muni towns with other broadband + number of rlec towns with other broadband + number of telco towns with other broadband + telco urban towns
Units: towns

towns without broadband = number of muni towns without broadband + number of rlec towns without broadband + number of telco towns without broadband
Units: towns

unit price no xcvr[device] = initial unit nominal price[device] * Economies of scale effect on price[device]
Units: $/unit

WACC[provider type] = 0.0859, 0.14
Units: dmnl

xcvr deployment rate[standardized] = standardized xcvr deployment rate
xcvr deployment rate[active] = remote terminal port deployment rate + CPE deployment rate * "% active"
xcvr deployment rate[passive] = CPE deployment rate * "% PON"
Units: units/month

xcvr Economies of scale effect on fixed costs[xcvr type] = (effective xcvr deployment rate[xcvr type] / xcvr nominal production[xcvr type]) ^ (LN (1 - xcvr economies of scale fraction[xcvr type]) / LN (2))
Units: dmnl

```
xcvr economies of scale fraction[xcvr type] = 0.25, 0.3, 0.2
     Units: dmnl

xcvr nominal production[xcvr type] = 2000, 2000, 2000
     Units: units/month

xcvr price[xcvr type] = initial xcvr price[xcvr type] * xcvr Economies
of scale effect on fixed costs[xcvr type] + fixed xcvr price[xcvr
type]
     Units: $/unit

xcvr standardization switch = 0
     Units: dmnl

xcvr type : standardized,active,passive

Years = TIME BASE ( 0, 0.0833333)
     Units: Years [0,0.0833333]
```

Bibliography

Advanced Television Systems Committee. (2004). Digital television standard (A/53), revision C. Retrieved January 15, 2005, from http://www.atsc.org/standards.html

Ainscough, D. (2003). *The realities of tiered broadband service*. Boston: The Yankee Group.

American Public Power Association. (2004a). Community broadband: separating fact from fiction. Retrieved February 15, 2005, from http://www.appanet.org/legislative/index.cfm?ItemNumber=9964

American Public Power Association. (2004b). State barriers to community broadband services. Retrieved March 8, 2005, from http://www.appanet.org/legislative/index.cfm?ItemNumber=9998

Bergen, R. S., Jr. (1986). Economic analysis of fiber versus alternative media. *IEEE Journal on Selected Areas in Communications*(4), 1523-1526.

Borin, E. (2004). Satellite service battles lag. Retrieved January, 15, 2005, from http://www.wired.com/news/wireless/0,1382,64937,00.html

Brealey, R. A., & Myers, S. C. (2003). *Principles of corporate finance* (Seventh ed.). Boston: McGraw-Hill Irwin.

broadbandreports.com. (2004). Central office finder. Retrieved August 19, 2004, from http://www.dslreports.com/coinfo

Cable Television Laboratories Inc. (2003). Data-over-cable service interface specifications DOCSIS 1.1: Radio frequency interface specification. Retrieved July 7, 2004, from http://www.cablemodem.com/downloads/specs/SP-RFIv1.1-I10-030730.pdf

Cable Television Laboratories Inc. (2004). Data-over-cable service interface specifications DOCSIS 2.0: Radio frequency interface specification. Retrieved July 7, 2004, from http://www.cablemodem.com/downloads/specs/SP-RFIv2.0-I05-040407.pdf

Credit Suisse First Boston Equity Research. (2003). *The broadband battle*: Credit Suisse First Boston.

D'Agostino, B. (2004). Fiber project paused; no November vote. *Palo Alto Weekly*.

Eilenberger, G. (1988). Optical solutions for the access network. *Alcatel Telecommunications Review*(3), 225-231.

Esty, S. A. (1987). *"Fiber to the home" activity in the United States of America.* Paper presented at the IEEE/IEICE Global Telecommunications Conference.

Federal Communications Commission. (1999). Action by the commission, September 15, 1999: Third Report and Order and Fourth Further Notice of Proposed Rulemaking in CC Docket 96-98 (FCC 99-238): FCC.

Federal Communications Commission. (2000). Deployment of advanced telecommunications capacity: Second report. Retrieved November 6, 2002, from http://www.fcc.gov/Bureaus/Common_Carrier/News_Releases/2000/nrcc0040.html

Federal Communications Commission. (2002). Deployment of advanced telecommunications capability to all Americans in a reasonable and timely fashion, CC docket no. 98-146: Third report. Retrieved November 6, 2002, from http://ftp.fcc.gov/Bureaus/Common_Carrier/News_Releases/2002/nrcc0201.html

Federal Communications Commission. (2003a). Action by the commission, February 20, 2003: Report and order on remand and further notice of proposed rulemaking in CC docket 01-338, 96-98, and 98-147, triennial review order (FCC 03-36): FCC.

Federal Communications Commission. (2003b). Automated reporting management information system (ARMIS). Retrieved February 8, 2005, from http://www.fcc.gov/wcb/armis/
Federal Communications Commission. (2003c). Review of the Commission's rules regarding the pricing of unbundled network elements and the resale of service by incumbent local exchange carriers: WC docket no. 03-173. Retrieved March 15, 2005, from http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-224A1.pdf
Federal Communications Commission. (2004a). Availability of advanced telecommunications capability in the United States: Fourth report to Congress. Retrieved February 15, 2005, from http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-208A1.pdf
Federal Communications Commission. (2004b). High-speed services for Internet access: Status as of June 30, 2004. Retrieved December 26, 2004, from http://www.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/IAD/hspd1204.pdf
Federal Communications Commission. (2004c). In the matter of unbundled access to network elements, review of the section 251 unbundling obligations of incumbent local exchange carriers: WC Docket 04-313, CC Docket 01-338,Order on remand adopted December 15, 2004 (FCC 04-29): FCC.
Grant County Public Utility District. (2004). The Zipp network. Retrieved March 23, 2005, from http://www.gcpud.org/zipp/zipnet.htm
Gregg, B. J. (2005). A survey of unbundled network element prices in the United States. Retrieved January 3, 2005, from http://www.nrri.ohio-state.edu/documents/Intro02-05.pdf
Hassett, K. A., & Kotlikoff, L. J. (2002). The role of competition in stimulating telecom investment. Retrieved May 6, 2005, from http://econ.bu.edu/kotlikoff/modelpap10-5-02.pdf
Ibbotson Associates. (2004). *Stocks, bonds, bills, and inflation 2004 yearbook*. Chicago: R. G. Ibbotson Associates.
International Engineering Consortium. Very-high-data-rate digital subscriber line (VDSL). Retrieved July 7, 2004, from http://www.iec.org/online/tutorials/vdsl/
Keto, A. (2004). Everyone should have access to broadband, Bush says. Retrieved April 3, 2004, from http://online.wsj.com/article/0,SB108032728080366544,00.html
Knuth, D. (1998). *Sorting and searching* (Vol. 3). Reading, MA: Addison-Wesley.
Kraushaar, J. M. (1999). Fiber deployment update end of year 1998. Retrieved January 6, 2003, from http://www.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/Fiber/fiber98.pdf
Light Reading Inc. (2005). Light reading index. Retrieved May 6, 2005, from http://www.lightreading.com/lrindex.asp
Marchiori, R. P. (2005). Rural utilities service, USDA, notice of funds availability. Retrieved March 26, 2005, from http://a257.g.akamaitech.net/7/257/2422/01jan20051800/edocket.access.gpo.gov/2005/05-4241.htm
MarketWatch. (2005). DJ US fixed line telecommunications index. Retrieved May 6, 2005, 2005, from http://www.marketwatch.com/tools/industry/indchart.asp?bcind=fts&bcind_sid=171540
Merit Network Inc. (1995, April 1995). The NSFNET backbone project, 1987-1995. Retrieved February 5, 2005, from ftp://nic.merit.edu/nsfnet/final.report

National Research Council Committee on Broadband Last Mile Technology. (2002). *Broadband: Bringing home the bits*. Washington, D.C.: National Academy Press.
National Telecommunications and Information Administration. (2004). A nation online: Entering the broadband age. Retrieved February 6, 2005, from http://www.ntia.doc.gov/reports/anol/index.html
Neuman, W. R., McKnight, L., & Solomon, R. J. M. P., 1997. (1997). *The Gordian Knot: Political gridlock on the information highway.* Boston: MIT Press.
Newburger, E. C. (2001). Home computers and Internet use in the United States: August 2000. Retrieved February 7, 2005, from http://www.census.gov/prod/2001pubs/p23-207.pdf
Nixon v. Missouri Municipal League, 541 US 125 (2004).
North American Numbering Plan Association. (2004). Central office code assignment records. Retrieved June 3, 2004, from http://www.nanpa.com/reports/reports_cocodes_assign.html
Osorio Urzua, C. A. (2004). *Bits of power: the involvement of municipal electric utilities in broadband service.* Massachusetts Institute of Technology, Cambridge.
Rowbotham, T. R. (1989). Plans for a British trial of fibre to the home. *British Telecommunications Engineering, 8*(2), 78-82.
Shumate, P. W., Jr. (1989, February). Optical fibers reach into homes. *IEEE Spectrum,* 43-47.
Sirbu, M., & Reed, D. (1988). *An optimal investment strategy model for fiber to the home.* Paper presented at the International Symposium on Subscriber Loops and Services, ISSLS 88.
Stok, M. (2003). Text:Soundex. from http://search.cpan.org/dist/Text-Soundex
The Baller Herbst Law Group. (2005). Proposed state barriers to public entry. Retrieved March 8, 2005, from http://www.baller.com/pdfs/proposed_barriers_3-7-05.pdf
U.S. Bureau of the Census. (2000). Census 2000 gazetteer places. Retrieved April 24, 2003, from http://www.census.gov/geo/www/gazetteer/places2k.html
Veyres, C., & Mauro, J. J. (1988). *Fiber to the home: Biarritz (1984)…twelve cities (1988).* Paper presented at the IEEE International Conference on Communications: Digital Technology - Spanning the Universe, Washington, D.C.
Warren Communications News Inc. (2004). The television & cable factbook. Retrieved August 11, 2004, from http://www.warren-news.com/factbook.htm
Weldon, M. K., & Zane, F. (2003). The economics of fiber to the home revisited. *Bell Labs Technical Journal, 8*(1), 181-206.