Technological Analysis of Open Access

and Cable Television Systems

Prepared for the American Civil Liberties Union

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I. Executive Summary

There has been much controversy in recent years over the provision of Internet access by cable providers, and whether they should be required to offer subscribers "open access" to Internet Service Providers (ISPs) that compete with their own ISP. The debate has ranged from political to economic to technical issues. This Report concerns the technical side of the issue. The Report evaluates the capabilities of existing cable systems as well as existing models for the implementation of open access – an evaluation based on a four-part process of research and analysis with four components. Specifically, the Report:

- Examines the different models of cable architecture.
- Analyzes the capability of these architectures to provide open access on cable systems.
- Evaluates two cable systems – one that offers a limited form of access (Tacoma Click! in Tacoma, Washington) and one that does not (AT&T Broadband in Portland, Oregon).
- Summarizes interviews with officials at two ISPs who have been excluded from offering access on many cable systems.

On the basis of this analysis, this Report reaches the following conclusions:

1) There are no insurmountable technical bars to nondiscriminatory open access,[1] either now or in the long term.
2) Technically, nothing precludes cable operators from monitoring and manipulating customers' Internet use under the single-ISP standard or under the "rebranding" approach that many operators have adopted.
3) Neither of the cable systems studied features true open access. Even the system in Tacoma, which allows "rebranding" access to multiple ISPs, is not open access because it limits the ISPs' ability to offer different services and enables manipulation and monitoring of data.
4) Cable operators should adopt a recommended "public interest architecture" if the goal is to facilitate open access.

The Report was prepared by Columbia Telecommunications Corporation (CTC) for the American Civil Liberties Union.

[1] This report uses the term "open access" to refer to the ability of competing Internet Service Providers to offer services over cable systems, assuming both of the following essential technical requirements are met: (1) the technical architecture or its configuration enable ISPs to offer the services they wish without constraints imposed by the cable company for non-technical reasons; and (2) the technical architecture or its configuration precludes the cable company from manipulating or monitoring the content of the data transmissions sent and received by the ISPs' customers. Under this definition, simple access by multiple ISPs (as in the "rebranding" scenario favored by some cable operators) is not open access because the cable company controls the services the ISP can offer and is able to manipulate and monitor data.

1.1 The Controversy

Broadband cable services were introduced over cable in the mid-1990s, a few years before the commercial introduction of broadband over telephone and wireless technology.[2] Cable operators limited subscribers to a single Internet Service Provider, usually the operator's own ISP or affiliated ISPs[3]. With only one ISP available, cable broadband data networks therefore typically provide a single data network, operated solely by the cable television operator or its industry partners. In contrast, public switched telephone networks are "common carriers" who must connect consumers to any number of data network providers.

Cable currently leads both DSL and wireless broadband data services in number of subscribers. Cable broadband is more widely available to residential customers than are either DSL or wireless broadband.[4] As control over cable broadband access became concentrated in a few companies, concerns arose regarding diversity of content and technological innovation.[5] ISPs, competitive and incumbent phone companies, and public interest groups argued for "open access" by multiple ISPs to data networks over cable systems.

These proponents of open access argue as follows:

- The practice of excluding unaffiliated ISPs gives cable operators excessive control, not only over high-speed communications services, but also over the content available over those communications systems.

- The vertical architecture control that results from corporate unions such as that of AOL Time Warner (AOLTW) enables companies to prioritize affiliated content

[2] Broadband represents the second generation of home Internet access. Broadband subscribers can view video, participate in interactive multimedia games, communicate by video link, download music and images, and accomplish everything that other Internet users can, but with higher quality and shorter downloading time. Broadband is available by way of cable lines, telephone lines, and wireless. To offer broadband services, cable or telephone lines generally have to be upgraded or rebuilt. Broadband cable modem services are provided over a separate channel from those used for video services. Subscribers are equipped with a cable modem that provides the link between the cable system and the subscriber's computer. Broadband telephone services are generally provided over digital subscriber line (DSL) technology. Subscribers are equipped with a DSL modem or router and may receive the service over the same line as their telephone services, if the line is in adequate condition. Broadband wireless services are available to subscribers with a small antenna on their homes that links their computer to a large antenna in their metropolitan area.

[3] Affliliated ISPs include Road Runner (affiliated with Time Warner Cable), AT&T Worldnet (affiliated with AT&T Broadband), and Excite@Home (until its recent demise, affiliated with AT&T Broadband, Comcast, and Cox).

[4] "Federal Communications Commission Releases Data on High Speed Services for Internet Access." FCC News, http://www.fcc.gov/Bureaus/Common_Carrier/News_Releases/2001/nrcc0133.html.

[5] See, for example, "Creating Open Access to the Broadband Internet," Consumer Federation of America, December 1999; Lawrence Lessig, *Code and Other Laws of Cyberspace,* (New York, Basic Books, 1999).

(content they own or are paid to favor) and exclude or discriminate against unaffiliated content.

- Single-ISP cable systems also have the ability to create and enforce usage patterns that are not only unattractive to the consumer but that raise privacy and other public policy concerns. For example, the favored ISP and its distribution affiliates can remove or block material on customer web sites and can monitor transmissions such as site requests and Internet relay chat messaging. Customer privacy could be compromised by the resale or distribution of user information to advertisers.

- The problem is especially acute in broadband (as opposed to narrowband services such as telephone dial-up) because there currently does not exist any market restraint on these practices. The consumer does not have an alternative source of these services, other than in the unlikely event that comparable DSL or wireless broadband is available.

The debate over open access took place largely in the context of local government attempts to require open access of cable franchisees.[6] The cable operators opposed what they called "forced access" requirements. Many large operators are, however, contemplating or running trials of limited forms of multiple ISP access[7], usually of the "rebranding" model.

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[6] For example, the transfer of cable systems belonging to Tele-Communications, Inc. (TCI) to AT&T Broadband (AT&T) led the City of Portland, Oregon, to require AT&T to open its systems to competing ISPs as a condition of transfer of the local franchise. AT&T argued that the local government had no authority to impose the requirement and that Internet access policies should be driven by market forces rather than government regulations. ("AT&T Wins Case to Keep Rivals Off Networks" Corey Grice, *CNET News.com*, http://news.cnet.com/news/0-1004-200-2130173.html?tag=st.ne.1002.thed.ni.) A federal district court upheld Portland's open access regulations, but the decision was later overturned on AT&T's appeal to the Ninth Circuit Court of Appeals.

[7] In December 2000, Time Warner and AOL agreed to provide some form of access to other ISPs as a condition imposed by the FCC and Federal Trade Commission (FTC) for approval of their merger. The conditions arose from monopoly concerns relating to the combined industry strengths of AOL's Internet presence and Time Warner's cable and media systems. The conditions were also motivated by concerns to maintain competition and interoperability between AOLTW and other companies on the Internet. Under the agreement, AOLTW is required to offer at least one independent ISP service on each Time Warner Cable (TWC, the cable division of AOLTW) system before AOL service can be offered over that system. Within 90 days of offering AOL on a TWC system, AOLTW must sign deals with at least two other non-affiliated ISPs. AOLTW also must meet the following requirements: 1) may not unfairly favor its own Internet services when customers seek ISP service information; 2) must allow each ISP to control the content of the subscriber's first screen; 3) may not require an ISP to include any content; 4) may not force cable modem users to reach the ISP of their choice though affiliated ISPs (AOL or RoadRunner); 5) must permit the ISP to have direct billing arrangements with subscribers; and 6) may not sign any contracts that prevent ISPs from disclosing terms of their agreement to the FCC. ("Conditioned Approval of AOL-Time Warner Merger," http://www.fcc.gov/transaction/aol-tw-decision.html.)

1.2 The Current State of Open Access and Broadband Competition

As of this writing, only one ISP is available on most cable systems that offer cable modem service. In those circumstances where multiple ISPs are available, and the cable operator announces it has implemented "open access," it is often referring to a limited form of access (often referred to as "branding" or "rebranding"—see Section III below) in which the operator decides which ISPs are granted access to the system.[8] Consumer choice is limited to those providers that have agreements with the cable operator. Further, the operators usually retain significant control over what services the ISPs can provide consumers, and the ISPs generally are limited to rebranding the connection to the Internet backbone that is selected and set up by the operators.

Cable competition exists in only a few markets, despite legal and regulatory attempts in the 1990's to foster competition and despite the efforts of "overbuilders"[9] such as RCN and Wide Open West, most of whom have curtailed or stopped construction of competitive cable networks because of economic circumstances.

The limited broadband competition that exists is "facilities-based" among cable, wireless, and DSL services, rather than among competing providers over the same medium. As a result, some dissatisfied cable customers may be able to switch to a competing medium, such as DSL (in those areas where competing media are available), but almost none have the option of selecting a competing cable modem service.[10]

This model is certainly simple from a technical standpoint, but begs the question of competition. Most wireless networking technologies currently lag behind cable and DSL in terms of reliability, capacity and speed, and may be technically infeasible where terrain or foliage prevent deployment. In addition, DSL is more limited in bandwidth than cable modem service and requires proximity to a telephone central office. In the current market, cable modems are dominant for residential use and DSL is used more commonly by small to medium businesses.[11]

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[8] In the case of the AOLTW systems, the consent decree partially determines which ISPs have access. (Ibid.)

[9] The term overbuilder refers to companies that build plant to offer services in areas already served by an incumbent company that previously has held a monopoly.

[10] Tacoma, Washington is one of the few areas where facilities-based cable competition is available. In the late 1990s, the Click! Network was formed by Tacoma's electrical utility to offer competitive cable and wholesale Internet services as a competitor to the incumbent cable operator, AT&T Broadband. Click! is an "overbuilder." The background, technology, and services of the Click! Network are described in detail in Appendix A.

[11] "Broadband Today," http://ftp.fcc.gov/Bureaus/Cable/Reports/broadban.pdf; "DSL vs. Cable Modems: The Future of High-Speed Internet Access 2000 – 2005," http://www.insight-corp.com; "Give Peace a Chance," Patricia Fusco, *ISP-Planet*, http://www.isp-planet.com/politics/give_peace_a_ chance.html.

1.3 Conclusions

CTC's analysis of cable architecture and its potential to offer open access yields three conclusions:

Conclusion No. 1: There are no technical barriers to true open access

Despite the claims of some cable operators, there is virtually no technical bar to allowing competing ISPs to offer services over cable systems, so long as a cable operator is willing or forced to cooperate in providing access. CTC found no technical reason why the cable systems we studied in Portland and Tacoma cannot offer either a separate-channel or a policy-based router plan (described in detail in Section III below), and know of no reason why such models should not be possible on other cable systems.

The most common cable system architecture, hybrid-fiber coaxial (HFC), is capable of offering advanced, interactive services in an open access environment. The operator does not need to construct or upgrade cable plant, although some additional repair and maintenance may be necessary. Each of the technical barriers to open access has been overcome by equipment manufacturers or, in the case of Canada, by the regulatory body responsible for cable.

There are several models for offering access to multiple ISPs over cable, but not all of them amount to true open access. The few cable operators who already offer access to multiple ISPs typically do so by "rebranding." Under this model, the cable operator sells services to ISPs on a wholesale basis, and the ISPs resell the services at retail under their own brands to consumers. Rebranding, however, does not increase the diversity of choices open to consumers, because the cable operator can control what the ISPs offer with respect to the speed, content, and other aspect of the Internet connection. Absent policy or contractual limitations, the cable operator is free to manipulate and control the Internet content of its competitor's customers just as it does with its own customers. From a technical standpoint, rebranding is not "open" access at all but is merely the provision of an identical Internet connection by multiple ISPs.

There are other ways of providing open access that do create real choice for consumers, however. One is the "separate-channel" solution, which allows ISPs to share capacity by using separate channels in the same way as competing television programmers. Operators have successfully used this approach to separate business customers or Institutional Networks from residential cable modem customers. It is relatively simple to adapt this model to open access. The separate-channel approach is limited by the availability of capacity for separate channels -- most cable systems can accommodate only a few ISPs on separate channels. It is, however, a viable way to enable competing ISPs to offer a range of services. Most significantly, it precludes the cable operator from controlling other ISPs' speed, quality, and flow of content from the Internet.

Another viable technical model for open access is "policy-based routing" (PBR). PBR allows customers to reach their ISP through a cable network by way of a policy-based router, which routes Internet traffic from the user to the appropriate ISP based on the user's source Internet Protocol (IP) address. Like the rebranding model, PBR allows the cable operator to control the speed, content, and other aspects of the Internet connection. However, it potentially allows users the most freedom in ISP choice and can enable the ISP to have more control over the product it provides to a customer, if the cable operator is constrained in its control over the Internet connection. As of this writing, this model has not been used by any major cable operator to implement open access in a large-scale implementation, although the technology for implementation is currently available.

PBR has received extensive criticism because it makes possible the kind of practices by cable companies to which the proponents of open access object.[12] PBR is capable of enabling the implementation of open access, but, even in an "open" environment, can be set up to allow the cable company control over content, private information, and the other areas of concern raised by open access proponents.

It is true that PBR can be used either to facilitate or to defeat the purposes of open access, depending on how it is implemented. Which ends PBR serves in a given implementation is not a technical matter—it is a matter of the contractual relationships entered into by the cable operator and other ISPs to whom it grants access – and of the public policies under which those contracts are established. From a technical standpoint, PBR is a viable model for providing consumer choice over cable broadband.

Conclusion No. 2: Technically, rebranding is not open access because it does not preclude cable operators from manipulating and monitoring data transmissions over their networks

When a cable broadband service offers a closed, single-ISP configuation – or its equivalent, multiple ISPs under a rebranding model – the operator has the technical ability to manipulate data transmissions in numerous ways, many of which its customers will not be aware. These include:

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[12] See, for example, "The Internet Under Siege," Lawrence Lessig, *Foreign Policy,* November/December 2001:

> Cable companies have deployed technologies to enable them to engage in a form of discrimination in the service they provide. Cisco, for example, developed "policy-based routers" that enable cable companies to choose which content flows quickly and which flows slowly. With these, and other technologies, cable companies will be in a position to exercise power over the content and applications that operate on their networks.
>
> This control has already begun in the United States. ISPs running cable services have exercised their power to ban certain kinds of applications (specifically, those that enable peer-to-peer service). They have blocked particular content (advertising from competitors, for example) when that content was not consistent with their business model. The model for these providers is the model of cable television generally—controlling access and content to the cable providers' end.

(referring to "Controlling Your Network – A Must For Cable Operators," Cisco Systems, 1999).

- Controlling the speed and reliability of the connection to the Internet.

- Blocking certain types of usage such as virtual private networks (VPN), which can bridge a user to an office or corporate network; the usage of the cable modem by multiple computers attached to a user's home network; and Internet-based voice services.

- Forcing customers to access the Internet over a certain home page selected by the operator for financial or political reasons.

- Blocking access to the Internet under certain circumstances and forcing the user to used closed "on-line" services.

- Requiring customers to purchase an upgraded service package to be able to use restricted or high-bandwidth services such as telecommuting, video-conferencing, or imaging.

- Limiting, slowing, or blocking the use of upstream capacity – in effect blocking the use of the Internet as a peer-to-peer service (enabling video-conferencing or other symmetrical high-bandwidth, real-time, two-way applications).

- Slowing or blocking access to certain sites on the Internet, such as those without financial arrangements with the cable company's ISP, or those with content considered objectionable for political or competitive reasons; and speeding transmission to affiliated sites.

- Maintaining records of the content of Internet sites visited by customers and addresses to which customers send e-mail.

All of these forms of data manipulation are technically possible in circumstances where operators offer rebranding, and rebranding therefore is not technically open access, even if it does enable competing ISPs to offer services. For example, in the Takoma Click! Network, multiple ISPs have access to the network, but they are limited by Click! as to what services they can provide. From a technical standpoint, this form of "access" is only marginally more "open" than that offered by AT&T Broadband in Portland, where only one ISP is available as of this writing. Both the Takoma and Portland systems are discussed in detail below.

Conclusion No. 3: Recommendation for a Public Interest Architecture

A study of available cable architectures and models for the provision of open access leads us to recommend the adoption of a "Public Interest Architecture" for cable systems. This "Public Interest Architecture" is based on the principle of maximizing consumer choice, ISP competition, and local community access to technology. This architecture represents the next generation of network construction, which offers the cable and ISP industries the most capable, flexible systems possible utilizing current technology. These public interest principles thus harmonize with many industry interests, and merit significant consideration as future rounds of construction and upgrades are undertaken.

The elements of that architecture include:

- In the short term, taking advantage of routine upgrades and rebuilds to facilitate open access by taking steps such as upgrading equipment and expanding the space available in facilities for the co-location of other ISPs' equipment.

- Enabling open access so that customers have access to a diversity of providers even when facilities-based competition is absent.

- The long-term installation of extensive fiber optics, either fiber-to-the-curb or fiber-to-the-home.

- Standardizing cable company and consumer equipment in order to speed deployment and allow for multiple, competing providers and thus customer choice in the purchase of hardware such as set-top boxes.

1.4 Explanation of Report Format

Section II of this Report briefly describes the three major categories of cable systems in order to assess the capability of each category to offer open access and to compare the categories with regard to issues such as design architecture, use of advanced technology, bandwidth capacity, overall reliability, and scalability.

Section III describes and compares the various model architectures for single and multiple ISP cable modem service and enumerates their relative advantages and drawbacks.

Section IV summarizes CTC's discussions with two ISPs in order to ascertain the interests and plans of some ISPs with respect to open access, as well as to ascertain the experience of ISPs in trying to obtain access to cable systems.

Finally, **Section V** provides technical recommendations for future cable system development, in light of the public interest principles underlying such matters as open access, and community access to technology. Specifically, "public interest upgrades" are recommended to facilitate open access on existing cable systems in the short-term, and the "Public Interest Architecture" is recommended for the next generation of network construction to facilitate the public interest in the long-term.

II. Introduction to Three Types of Cable Systems

The cable television industry includes three primary types of cable systems:

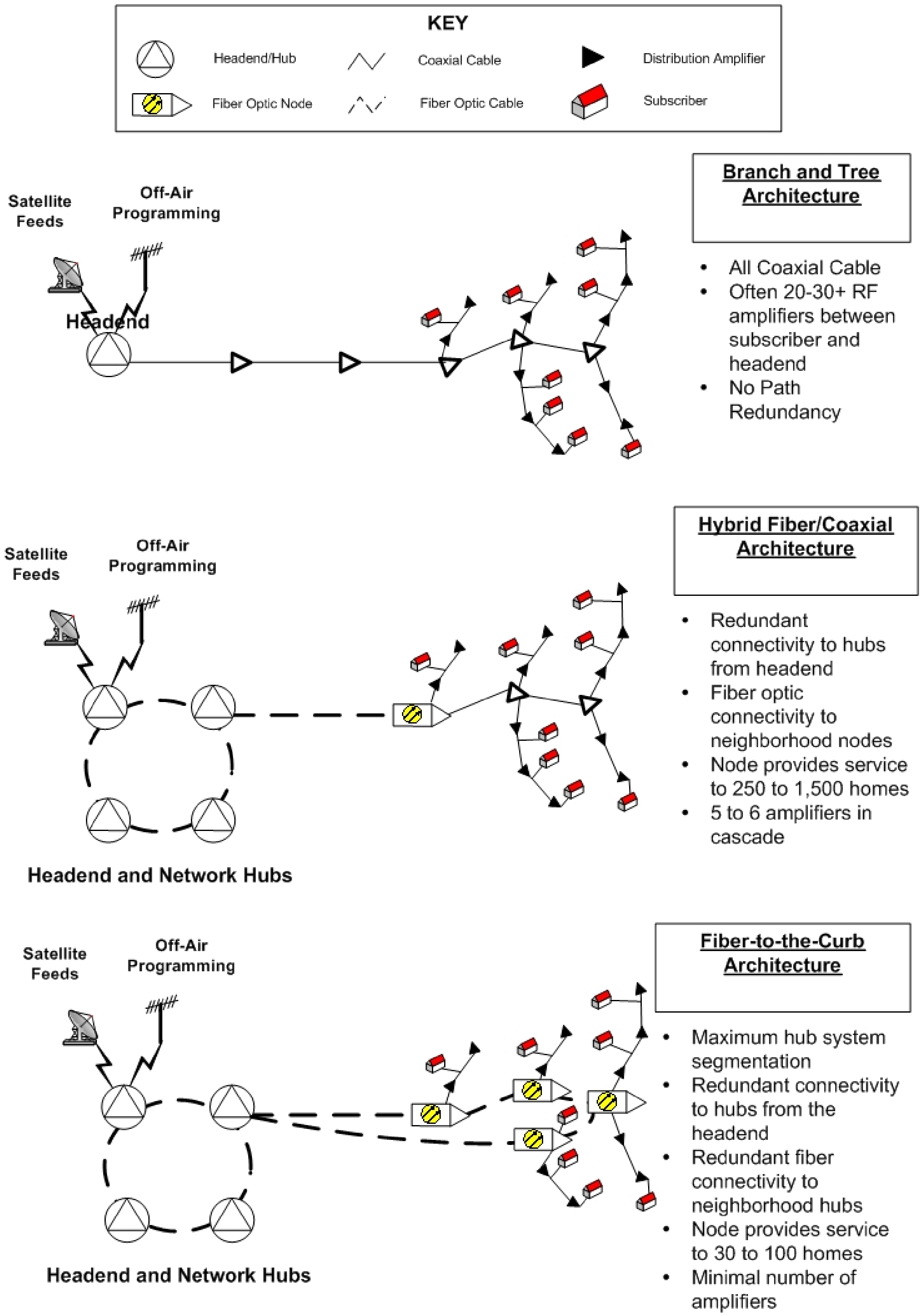
- "Branch and Tree" architecture offering one-way transmission only;
- "Hybrid Fiber/Coaxial" (HFC) two-way capable systems integrating fiber optic and coaxial cable; and
- "Fiber-to-the-Curb" (FTTC) enhanced two-way systems with increased reliability, capacity, and scalability.

All three categories include a central facility known as the "headend," which serves as the central location for all technical operations. The headend receives and processes the various programming signals and then sends these transmissions to the subscribers over the cable plant. The headend building contains video modulators, network administration equipment, and the equipment used for signal receiving, processing, and transmitting, such as satellite and off-air antennas. In some systems, some of the functionality of the headend is distributed to "hubs" that deploy the headend equipment closer to the subscriber.

Generally, the remainder of the cable system can be referred to as "cable plant," which includes all coaxial and/or fiber optic lines over which signals are sent, amplifiers and nodes to boost and distribute the signal, and power supplies to run and maintain the system.

Detailed technical information regarding all three system categories, including illustrative graphics, is included in Appendices C-E. A summary comparison of all three categories is included in Appendix F.

Figure 1: Summary Diagram of Three Categories of Cable Architecture



2.1 Branch and Tree Legacy Architecture

"Branch and tree" coaxial cable topology refers to the architecture of cable systems that have typically not been upgraded since 1995. These systems are also known as "legacy" systems because their architecture dates from the earliest days of cable in the 1950s and 1960s.[13]

Branch and tree systems utilize dated technology that reflects the origin of cable television as a one-way entertainment medium with no status monitoring systems or architectural redundancy. Early cable television systems started as centralized antennas on hills that received over-the-air television signals and transmitted them by cable to homes that could not receive over-the-air signals. In later years, cable systems added additional signals to their offerings by receiving programming over satellite dishes. In this way, cable became a transmission medium for superstations, national news, sports, and movies channels as well as for the original local broadcast stations. Cable was able to offer more programming alternatives and better quality than over-the-air television.

The dated architecture of branch and tree systems precludes two-way and other advanced services. All-coaxial systems cannot offer two-way services other than rudimentary pay-per-view and telemetry. Two-way operation is precluded by the large amount of system noise in the upstream direction and by the lack of fiber optics and, therefore, of significant capacity. A branch and tree system is based on one trunk. This is in contrast to more recent architectures described below, in which the system is segmented (essentially, multiple trunks are created by construction of neighborhood fiber optic nodes that translate and boost the signal) to enable each node to reuse channels and thereby multiply capacity for cable modem users.

A detailed discussion of branch and tree technology is presented in Appendix C.

2.2 Hybrid Fiber/Coaxial Architecture

Since the mid-1990s, most American cable networks have incorporated fiber optic technology. These systems use fiber optic cable to link the headend to neighborhood coaxial cable in an architecture called Hybrid Fiber/Coaxial (HFC). In the neighborhoods, the traditional coaxial cable distribution remains, but with upgrades to enable two-way operation.

Generally, the evolution of cable networks from the branch and tree configuration to modern HFC networks has entailed construction of fiber optics from the headend to intermediate "hubs" and then eventually to "nodes" in each neighborhood. The nodes contain active devices that convert the fiber optic signals to RF signals for delivery over existing coaxial cable. This architecture has enabled the provision of two-way services

[13] After the most recent round of system upgrades in the late 1990s and early 2000s, most urban and suburban systems have been upgraded to HFC. Branch and Tree systems are found primarily in rural and less populated areas.

and has greatly increased the reliability and quality of the signals offered over the cable system.

The technical architecture and operations of HFC systems, including illustrative diagrams, is detailed in Appendix D, which also includes an extensive discussion of the workings of cable modem networks on HFC systems.

2.2.1 Advantages of HFC Architecture

The use of fiber optic cable in HFC systems provides a significant number of advantages over all-coaxial branch and tree systems. These improvements include:

- Fiber backbone with greater capacity than coaxial trunk cables;
- Ability to segment neighborhoods based on nodes, increasing available capacity for each subscriber;
- Reduction in active components, decreasing noise;
- Higher reliability and more cost effective maintenance; and
- Fiber replacing much of the coaxial cables plant, reducing susceptibility to unwanted electromagnetic interference.

All of these improvements make it possible for HFC systems to offer high-speed Internet service with several times the speed of conventional phone line services. In practice, properly operating cable modem networks operate about three times as fast as telephone services in the upstream direction and up to twenty-six times as fast in the downstream direction.[14] HFC capitalizes on the fact that the cable pipe is the largest bandwidth communications pipe into most residences and that cable architecture can be modified in a cost-effective manner to deliver packet-based data networking to customers. Unlike telephone dial-up Internet users, the customers on a cable modem network are on a large local area network, as if they were in the same office building or campus as the cable company. This is a great advantage for delivering fast download speeds to customers. Video-on-demand, subscription video-on-demand, and telephone services can also be offered over HFC networks.

HFC systems also offer significant reliability, as well as the capability to monitor problems and outages, so that customer complaints are not the sole form of status monitoring, as they are in branch and tree systems. As the Internet becomes a more critical part of economic and emergency infrastructure, that reliability becomes crucial. Customers rely on the telephone infrastructure for critical services and will increasingly demand the same reliability from cable modem infrastructure for Internet and telephone services.

Significantly, HFC systems are capable of offering open access, as is discussed in Section III below. AT&T is currently offering ISP choice on a trial basis on its HFC system in

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[14] AT&T Broadband Welcome Letter, http://help.broadband.att.com/faqprintable.jsp?name=downstream_rate_management.

Boulder, Colorado. AT&T is reportedly planning to offer multiple ISPs statewide in Massachusetts in 2002.[15]

2.2.2 Limitations of HFC architecture

The shared HFC architecture also creates limitations for the network. For example, security concerns necessitate that packets on the network be encrypted or scrambled to protect the information of subscribers sharing a segment. The architecture also does not offer a ready-made solution to offer a range of service levels to different customers. Finally, the network architecture makes it more difficult to separate the provider of the physical architecture from the provider of the Internet connection and Internet services, relative to a physical architecture where each user has a dedicated physical connection from a home or business to the ISP's routers. All of these challenges have solutions that are being tested and implemented in the cable industry.

Another limitation of the HFC architecture is that extensive additional fiber construction and terminal equipment are required to scale HFC systems for significantly greater bandwidth per customer. There exists a hard capacity limit per node area. The limitation is imposed by the need for data services to go through HFC-based router equipment in the cable headend. In all existing and planned cable modem systems, the hardware limits each network segment to 40 or less Mbps downstream capacity. In order to increase the capacity available to a subscriber, the cable operator must segment its system to progressively smaller node areas. Even at maximum segmentation, HFC will have a hard limit of 40 Mbps per user. This is in contrast to fiber optic technologies, that transport hundreds of thousands of Mbps, and that can be easily scaled to higher speed as technology advances by changing the equipment at the ends of the fiber and leaving the cable plant itself unchanged.

HFC-based equipment is also more specialized than equipment for fiber optic communications and is thus manufactured by fewer companies. This affords the cable operator less flexibility than an ISP using telephone or carrier facilities.

2.2.3 Analysis of a Typical HFC System: Portland, Oregon

CTC visited and analyzed a large metropolitan system that is technologically typical of HFC cable architectures around the United States and examined its capabilities from the point of view of open access. To this end, CTC studied the AT&T Broadband cable system in Portland, Oregon.

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[15] "A Tale of Two Trials," Leslie Ellis, *Communications & Engineering Design*, May 2001, http://cedmagazine.com/ced/2001/0501/05d/htm; "Massachusetts Coalition for Consumer Choice and Competition on the Internet and AT&T Agree on Plan for Consumer Choice of ISPs in Massachusetts," AT&T News Release, http://www.att.com/press/item/0,1354,3037,00.html, June 27, 2001. Although the industry is reluctant to disclose technical information, these systems are almost certainly offering rebranding.

No form of access by multiple ISPs has been offered over this system. However, CTC found no technical reason why that system cannot offer either a separate-channel or a policy-based router plan (discussed in Section III), provided that AT&T deploys the necessary equipment and works in cooperation with ISPs.

Although AT&T refused to meet with CTC, CTC obtained extensive information regarding the system from David C. Olson, director of the local cable regulatory body that oversees the Portland system.[16] Olson reported that Portland customers have significant problems with AT&T, particularly poor response time for telephone calls, and that the City had fined AT&T $180,000 as of the end of 2000 for not answering the telephone in accordance with FCC and City standards.

Detailed information on the Portland AT&T system is presented in Appendix B.

2.3 Fiber-to-the-Curb Architecture

The third category of systems, known as fiber-to-the-curb (FTTC), continues the trend of deploying fiber deep into the network. As nodes are segmented into smaller areas, the number of users on a node decreases and available bandwidth and system redundancy increase. In a variation of FTTC architecture, "fiber-to-the-home" (FTTH) systems deploy fiber all the way into residences. As of the current writing, there exist only a few FTTC systems in the United States, and the cable industry has not announced plans to upgrade most systems to this level.

Appendix E details a network infrastructure that combines the physical architecture of existing FTTC systems, which has been deployed in a few communities, with an advanced headend and hub concept that incorporates existing, tried technologies, although it has not yet been deployed. This architecture represents the next generation of cable network construction because of its flexibility in providing either cable-based or fiber-based services, its capability to directly connect multiple service providers to subscribers, its operational robustness, and its almost unlimited capacity per subscriber. For these same reasons, this architecture serves as the basis for the model public interest architecture described in Section VI below.

The advantages of FTTC include the following:

- Fiber optic cable costs approximately the same per-mile as coaxial cable.

- FTTC systems can provide more advanced high-speed interactive services than do HFC systems. An FTTC system can simultaneously offer interactive television, video-on-demand, and higher capacity data and Internet access. The deployment of fiber optics deep into neighborhoods enables the provider to offer all of the

[16] CTC wishes to acknowledge and thank Mr. Olson for his efforts to obtain information for this Report. CTC's analysis of the Portland AT&T system would have been impossible without Mr. Olson's assistance.

applications possible in HFC systems, and to operate with increased reliability and redundancy.

- Reliability is increased by replacement of active electronic components and coaxial cables by temperature-and RF-resistant fiber optic networks. In addition, the subscribers are able to connect via a range of services, including 10/100/1000 Mbps Ethernet, ATM, and dedicated fiber optics known as "dark fiber."

- Scalability is high with FTTC because of the high density of fibers and coverage of nodes. The system can be upgraded, in its entirety or by neighborhood, to a fully fiber-optic passive optical network (PON) by: 1) constructing fiber to users' homes, and 2) installing multiplexers at node locations (see Appendix E). Migration of FTTC to PON would also increase system scalability with almost unlimited capacity available to each home.

- Once constructed, FTTC architecture more economically facilitates the construction of fiber directly to those subscribers who request additional bandwidth, such as businesses and residents who run home businesses, telecommute, or are early adopters of new technology. With the ability to connect individual users with dedicated fiber optics, capacity is almost unlimited.

- This model thus addresses many of the limitations of HFC technology, and should be of interest to new cable operators and operators constructing networks in new developments, campuses, and apartment buildings. An FTTC system is likely to be the optimal choice when building a new network.

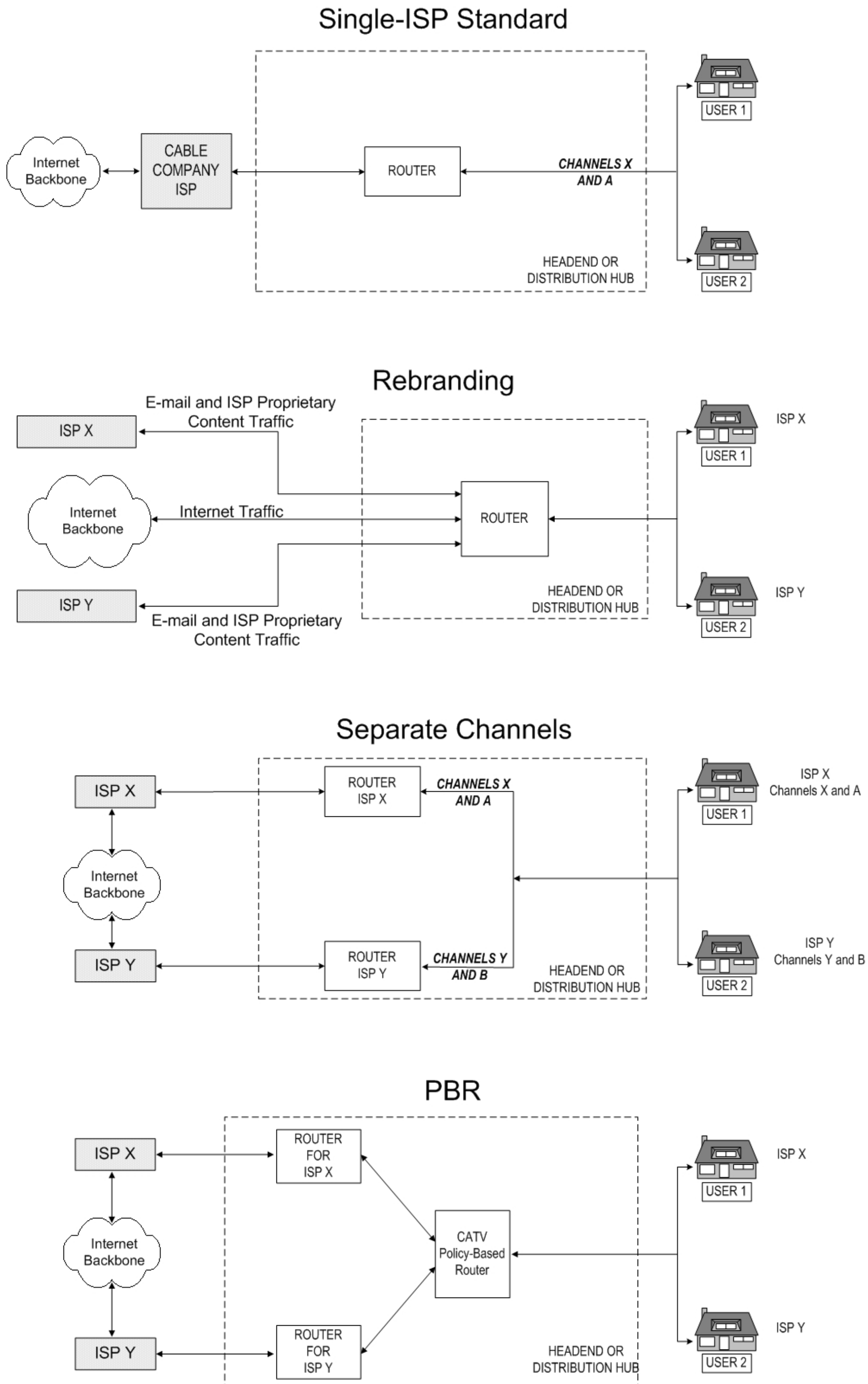
III. Potential Architectures for Access by Multiple ISPs

There are several different models for opening cable systems to multiple ISPs. They include:

- Resale and rebranding of wholesale services purchased by ISPs from the cable operator—this is the model proposed and favored by many of the large cable operators;
- Use of separate channels by separate ISPs; and
- Policy-based routing.

All of these models can be implemented on the HFC architecture that is used by most systems (including the AT&T Broadband system in Portland), as well as on an FTTC architecture. These three multiple-ISP models, along with the single-ISP model that is used by most cable systems today, are diagrammed in Figure 2 and discussed below.

Figure 2: Summary Diagram of Four Models for Cable Modem Service



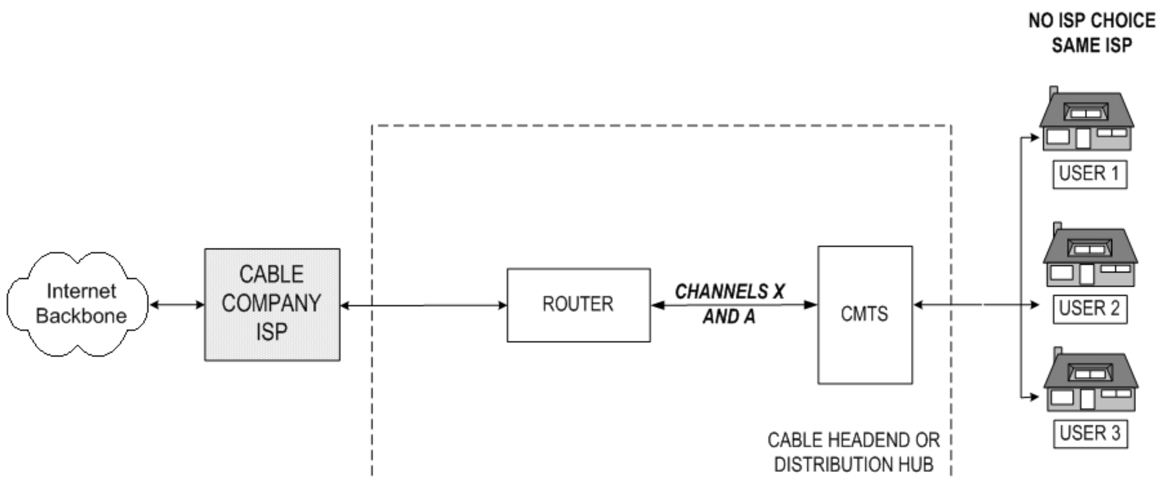
3.1 The Single-ISP "Closed" Standard

As of this writing, a single-ISP "closed" model is dominant on those cable systems that offer cable modem service, including the AT&T system in Portland. Under this model, only one ISP offers service over the cable modem system. Usually, that ISP is affiliated with or owned by the cable operator.

3.1.1 Technical Description of Single-ISP Standard

The single-ISP model is diagrammed in Figure 3, and described below.

Figure 3: The Single-ISP Standard for Cable Modem Service



Internet transmissions, which are sent in a form called "packets," normally follow the following path through a cable modem system: first, the customer's cable modem sends the packets over the cable system to a device, usually located in the headend, called a cable modem termination system (CMTS).[17] The CMTS then forwards the packets on to a router, which is also usually located in the headend.

Generally, the router identifies the destination address of an Internet packet and directs it accordingly: to the Internet or to servers for mail, proprietary content, news groups, and chat.[18] Various local servers may also connect to the router at the headend for caching of frequently-viewed web sites.

[17] The CMTS sets the power level of the transmissions and assigns the cable modem one or more time slots for upstream transmission. Upstream data is arranged into slots, where each modem "speaks" during its assigned time slots. All downstream data is sent out in one shared stream, with each modem reading only authorized information addressed to it. "DOCSIS Cable Modem Technology." David Fellow and Doug Jones, *IEEE Magazine*, March 2001. Business or high-end customers may receive more time slots or higher priority.

[18] In a multiple-ISP scenario such as PBR or rebranding, the router would direct the packets to the appropriate ISP.

Packets in the reverse direction follow the opposite path: from the Internet or ISP servers to the router, on to the CMTS, and then over the distribution system of the cable network to the user's home or business, where a cable modem enables the user's computer to receive and read the transmission.

Single-ISP systems often utilize a basic technology known as "destination based routing." Under this technology, the router directs the packet based on the destination address of the packet.[19] Destination based routing is made possible by the identifying numbers carried by every data packet that travels over the Internet. Under a protocol called Transmission Control Protocol/Internetworking Protocol (TCP/IP), packets are distinguished by numbers that identify, among other things:

- Their content-type (the "TCP" part of the number, also known as the "port," identifies the type of application originating the packet, such as mail, web-content, voice, video, etc.) and

- Their address (the "IP" part -- IP addresses are like street addresses or telephone numbers for each computer and other device on the Internet. All Internet packets contain headers with a source and destination IP address).

A destination-based router recognizes the IP address of the packet and then directs it accordingly.

Appendix D contains further description of the workings of a cable modem network, including the dominant standard for cable modems, known as Data Over Cable Service Interface Specification (DOCSIS).

3.1.2 The Single-ISP Standard Gives Operators Control Over Content, Usage, and Private Information

In a closed single-ISP situation, the operator has the technical ability (and, in the absence of genuine facilities-based competition, the freedom) to manipulate data transmissions in numerous ways, of which many customers will not be aware. These include:

- Controlling speed and reliability of the connection to the Internet.

- Blocking certain types of usage such as:
    - virtual private networks (VPN), which can bridge a user to an office or corporate network.
    - usage of the cable modem by multiple computers attached to a user's home network.

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[19] In contrast, "policy-based routing" (PBR) enables the router to recognize the packet based on other factors such as data path, including source address (source-based routing); content, such as e-mail text or digital media; Quality of Service; or the application associated with the data. ("Open Access: From Taboo to Take-off," David Iler, *Communications & Engineering Design*, April 2001, http://www.cedmagazine.com/ced/2001/0401/id3.htm.) PBR is described in detail below.

    - servers at user premises (used, for example, to host a personal web site or mail).
    - voice-over-IP over IP (VoIP), Internet-based voice services.

- Forcing customers to access the Internet over a certain home page selected by the operator for financial or political reasons (the user would not have the choice of selecting the home page to which their browser would open; rather, the browser would be programmed to open to the operator's selection each time the user used the Internet—this can be facilitated if the operator requires use of proprietary or customized software).

- Blocking access to the Internet under certain circumstances and forcing the user to use closed "on-line" services (also facilitated by requiring specific client software).

- Requiring customers to purchase an upgraded service package to be able to use restricted or high-bandwidth services such as telecommuting, video-conferencing, or imaging.

- Influencing and shaping customers' use of the Internet. The operator's economic interests lie in matching the user's usage to the technical capabilities and limitations of the cable modem system, such as limited "upstream" capacity (bandwidth from the user to the Internet)—therefore, the ISP may deliberately work to change users' preferences and expectations of network services. By limiting, slowing, or blocking the use of upstream capacity, the operator can turn the Internet into a web-browsing and downloading product for its customers, rather than a peer-to-peer service (enabling video-conferencing or other symmetrical high-bandwidth, real-time, two-way applications).

There is another way in which operators have control over content in a single-ISP scenario. The router's recognition of a destination address enables the operator to control data transmissions, without the knowledge of its customers, in order to further its own interests. For example, it may:

- Slow or block access to certain sites on the Internet, such as those without financial arrangements with the cable company's ISP, or those with content considered objectionable for political or competitive reasons.

- Speed transmission to an affiliated site (or a site that has paid the operator for the privilege of special treatment).

- Maintain records of the content of Internet sites visited by customers and addresses to which customers send e-mail.

3.1.3 Adapting the Single-ISP Standard for Multiple ISPs

The primary technical challenges associated with open access arise from modifying a system that was originally designed for one shared network operated by one company. Cable modems give users access to the Internet over modems arranged on a shared local area network (LAN) topology, in many ways similar to that by which computers share an office network.[20] The shared network topology creates technical difficulties in developing a platform in which multiple ISPs have equal footing, rather than the current situation, in which operators are accustomed to having sole access to their closed platforms. For example, an open access environment requires adaptation of such areas as backbone connectivity, offering of domain name services (DNS), bandwidth provisioning, customer service, and billing.

Nonetheless, these technical issues have been resolved such that the models described below are all viable, based on:

- Work done by equipment makers and vendors who implement these systems;
- Published reports of the work of the Canadian regulatory body overseeing the mandatory implementation of open access in Canada;[21] and
- Widespread industry experience with implementation of some of these models for analogous purposes.

3.2 Rebranding and Resale of Wholesale Services

Under this scenario, the competing ISPs contract with the cable operator to purchase wholesale services and resell them to consumers. Technically, and even practically, this model does not differ from the single-ISP standard. The drawbacks of this model therefore mirror many of the concerns involved with a single vendor system. The cable operator still handles the backbone connections, DNS, and routing. This allows the operator to control how content is handled on the network.

3.2.1 Technical Description of Rebranding

The rebranding model is employed in the Tacoma Click! network (described in detail in Appendix A), where three ISPs host services through dedicated T1 connections to the Click! headend. Initial managed access trials by Time Warner Cable are also closely related to this solution,[22] although TWC is also reported to be experimenting with the

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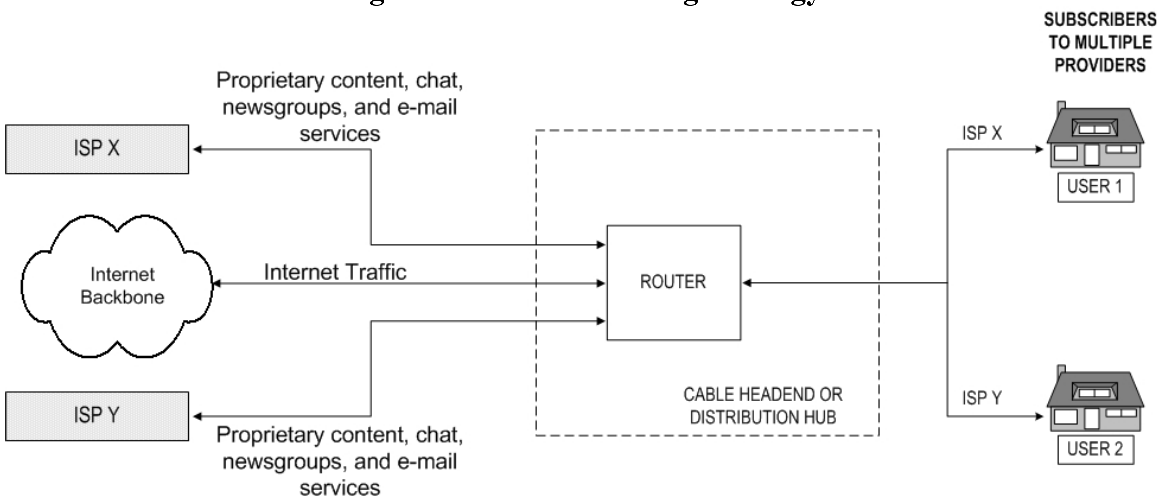
[20] "Overview of Cable Modem Technology and Services," *Cable Datacom News*, http://www.cabledatacomnews.com/cmic/cmic1.html.

[21] See http://www.crtc.gc.ca/eng/publications.htm.

[22] "Special Report: Part II: Open Access – How to Provide a Full Menu of Choices," Natalia Feduschak, *Communications Technology*, May 2001, http://www.cabletoday.com/ct2/archives/0501/122_openaccess.htm.

policy-based routing model discussed below.[23] The rebranding solution is illustrated in Figure 4.

Figure 4: The Rebranding Strategy



In this model, all users connect through the cable operator headend and equipment systems. Provisioning and signup are performed by the ISPs, who also handle all customer installation and service and serve as the point of contact for the subscriber. Although the cable operator handles the outdoor cable plant and actual connections to the Internet, these processes are invisible to customers, who interact only with their ISP.

All headend CMTS equipment is the responsibility of the cable operator, as are all routing and bandwidth management. Customer Internet traffic goes through the headend, directly to the Internet backbone.

In the Tacoma Click! Network (see Appendix A), ISPs connect to the headend to manage billing and to provide services such as e-mail, newsgroups, and hosting of customer Web sites. Customer service and subscriber installations are handled by the ISPs, who pay the cable operator for the opportunity to offer Internet service under their brand over the cable backbone.

3.2.2 Rebranding Duplicates the Problems of the Single-ISP Standard

Even though alternative ISPs are allowed access to the cable system, they are unable to offer any backbone Internet connection other than that provided to them for resale by the cable operator. They therefore must offer Internet access with the same restrictions and control over content that the cable operator offers through its own ISP. The end result of this rebranding scenario is that multiple ISPs offer the same Internet connection and restricted services as a single ISP in the single-ISP standard discussed above.

[23] Discussion between Andrew Afflerbach, CTC Principal Engineer, and Greg Collins, Earthlink Director of Network Engineering and Operations, November 6, 2001.

At best, competing ISPs who are allowed onto the system can bill and "own" their customers and offer their own mail, news, and chat services, because these applications can be differentiated between ISPs by login and password and different setups of browsers and client software. ISPs will presumably compete to deliver superior customer service, prices, and value-added services such as proprietary content, e-mail, and chat rooms, even though they do not have the option of competing to offer differentiated Internet connections.

3.2.3 Example of Rebranding: Tacoma, Washington

One example of a system that provides the rebranding form of open access is the Click! Network in Tacoma, Washington. Click! is a municipally run cable system that was "overbuilt" parallel to the existing cable infrastructure owned by AT&T, with which it competes. Click! customers contract with one of three ISPs. Click! installs the physical connection to the house and any internal wiring required. The user installs the modem or has the ISP install it. The ISP is responsible for the customer having the PC correctly configured and network interface card (NIC) installed. The ISP takes customer calls and is the point of contact with Click! in the event of a network problem. The ISP pays Click! a fee for using the network, and Click! pays for the Internet backbone connections.

The results of CTC's technical investigation of the Click! Network are described in Appendix A.

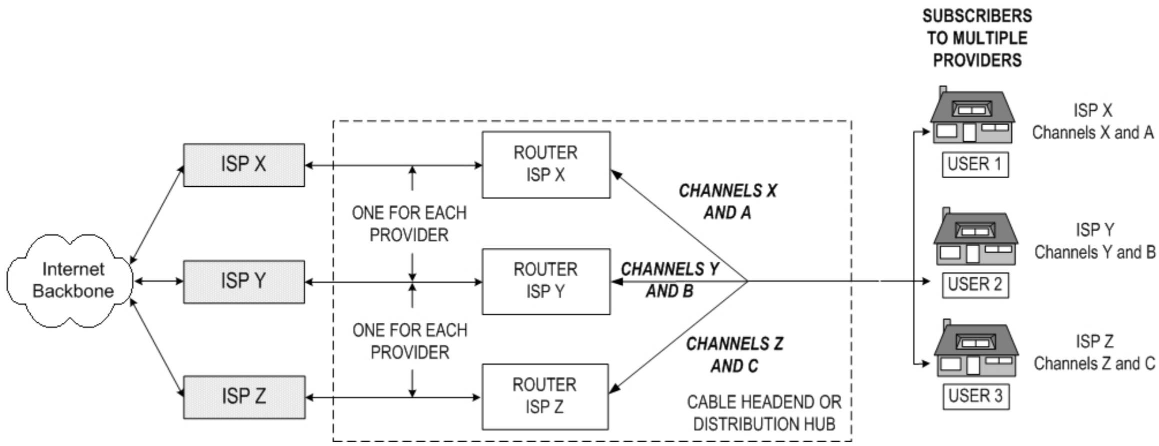
3.3 Operation of Separate Channels

A more "open" strategy for implementing a multiple-ISP network is for the various providers to operate their networks over separate channels of the cable system. This general approach has successfully been used by cable operators to separate business and Institutional Network uses from the residential cable modem network.

3.3.1 Technical Description of the Separate-Channel Strategy

The separate-channel solution is illustrated in Figure 5.

Figure 5: The Separate-Channel Strategy



Under the separate-channel scenario, the ISPs share portions of the cable system the same way that the system is currently shared among separate video channels, such as HBO or The Weather Channel. The cable operator assigns to each ISP channel capacity in both the upstream and downstream directions. The exact choice of channels and process of assignment is negotiated between the cable operator and the ISPs.

Under this scenario, the cable operator is responsible for maintaining the physical network and hosting each ISP's equipment at its headend or distribution hubs. At the cable headend, each ISP maintains its own CMTS, its own router, its own server (if desired), and its own connection to the Internet and outside networks.

Implementation in the home should not be a hindrance to implementation of this solution. Cable modems could be provided to subscribers in a number of different ways. One possibility is for each ISP to be responsible for installation of modems for its customers. The ISP could also enable its customers to install the modems themselves. This solution would be relatively easy to implement from the consumer side, as is demonstrated by the wide availability of DOCSIS modems for retail purchase. The competing ISPs could provide "starter packages" at retail outlets, much as ISPs currently give away starter software to sign up new users. Alternately, the ISP could contract with the cable operator to install and configure modems and to set the modem up to communicate with the correct CMTS.

3.3.2 The Separate-Channel Solution Solves Many of the Problems of the Single-ISP Standard and Rebranding

The separate-channels approach facilitates the goals of open access because it allows for a clear demarcation between the operator and the various ISPs in the following ways, among others:

- The operator cannot control or manipulate content or speed as it can under the rebranding approach because there is no need for routing of traffic between the cable operator's system and ISPs.
- Each ISP decides what type of cable modem, router, and CMTS it wants to use.
- Each ISP operates its own management, security, billing, and routing.
- ISPs operate their systems with relatively little need for regular interaction once the cable operator negotiates what channels it will offer, and the ISPs agree on ground rules for access to the equipment, operational signal levels, installation, and handling of service complaints.
- There is clear apportionment of capacity and traffic between users of different ISPs.

3.3.3 The Separate-Channel Approach Also Has Significant Disadvantages

There are disadvantages to the separate-channel approach, however, including:

- Difficulty in assigning channels. Channels may be scarce, particularly in the upstream direction. Some of these upstream channels will provide poorer performance and reliability than others because of interference from amateur radio, electronic appliances, and other devices.

- Lack of flexibility and inefficient use of bandwidth. With the separate channel solution, the cable modem system loses the flexibility to suddenly switch channels in the event of interference, because the channels have been split up among separate providers. The number of ISPs is limited by the number of channels on the system, and the use of bandwidth among a varying number of providers and data channels would be inefficient.

- Expense. Duplication of CMTS equipment at headends and hubs also adds to expenses, both of equipment and of additional rack and floor space to house the equipment.

3.4 Policy-Based Routing

A third multiple-ISP strategy is for the subscribers of various ISPs to share the same channel or channels, but have the customers' traffic routed to separate providers, in a scenario known as policy-based routing (PBR).

Under PBR, customers' data packets are "tagged," and routed according to those tags, or "policies." The router can recognize customers' traffic based on one or more of a number of factors, including:

- The source address of the data packet; and

- The content of the packet (for example, whether it contains e-mail, video, or a certain type of application).

Like destination-based routing (see Section 3.1 above) PBR is made possible by the identifying numbers carried by data packets on the Internet. Under TCP/IP, packets are distinguished by numbers that identify, among other things, their content or "port" (TCP) and their address (IP). A policy-based router recognizes these numbers, or policies, identifies the packets, and then treats them according to how the router has been configured.

The advantage of PBR is that it enables more efficient use of scarce spectrum on the cable system than does the separate-channel solution. It also permits the cable operator to use "frequency-agile" techniques to switch channels to avoid interference. The number of ISPs is limited only by the capacity of the policy-based router. ISPs can each provide their own cached or affiliated content.

3.4.1 PBR Enables Practices Contrary to the Goals of Open Access

However, PBR's recognition of content, source, and other characteristics enables the operator of the router to block protocols, limit available bandwidth, and block sites with much greater range and flexibility than does destination-based routing. In addition to all the types of control possible with destination-based routing, PBR gives the operator even greater control over data transmissions, such that it may:

- Speed transmission to or from an affiliated site (or a site that has paid the operator for the privilege of special treatment);
- Similarly, slow or block transmission to or from a non-affiliated or non-paying site;
- Slow or otherwise obstruct traffic of customers of competitor ISPs while favoring the traffic of its own or affiliated ISPs;
- Slow or block content that is competitive of the operator's other products. For example:
    - voice-over-IP over IP services that compete with the operator's telephone service.
    - video transmissions that compete with the operator's video-on-demand offerings over the cable system.
    - video-conferencing transmissions that compete with the operator's own video-conferencing offering.
    - transmissions from Internet sports sites that compete with the operator's pay-per-view offering of a major sports event.
- Block content on the basis of political, ideological, or any other objection to content; and
- Maintain records of the content of customers' transmissions; Internet sites visited by customers; and e-mail correspondents of customers.

3.4.2 PBR Can Also Be Used to Enable Open Access

Yet PBR can also be used to facilitate open access. With source-based routing, for example, the router uses both the source IP address (the originating user's address) and the destination address. In an open access application, the source address identifies a user's data to the system as being the responsibility of that user's ISP. This enables the router to determine the ISP through which the data is to be directed.

Under this scenario, users' computers are assigned IP addresses that identify them as customers of a particular ISP. The cable operator is responsible for transporting data between modems and the headend and then for routing signals, using a policy-based router, toward the appropriate provider as indicated by source IP address.

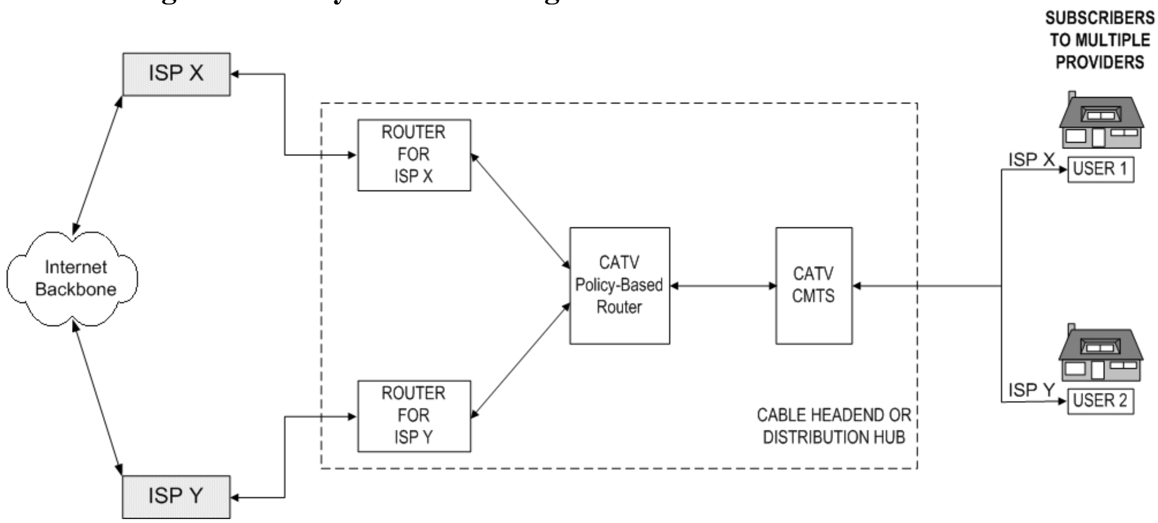
Significantly, configuring a policy-based router to enable open access does not preclude the operator from also configuring it to enable all the controversial practices described above. PBR enables both approaches simultaneously and there is no simple technical solution to preclude such a configuration. Absent contractual or public policy limitations on the uses of PBR, operators are technically free to use their routers to control content, information, and access to the Internet.

3.4.3 Technical Description of PBR

In a PBR open access scenario, all Internet access or use of online services by an ISP's subscriber would route to an ISP's router. ISPs could connect the cable system through a variety of methods. In one scenario, a provider could locate its own separate data switching and routing devices at the headend and connect directly to the ports of the cable operator router or switch.

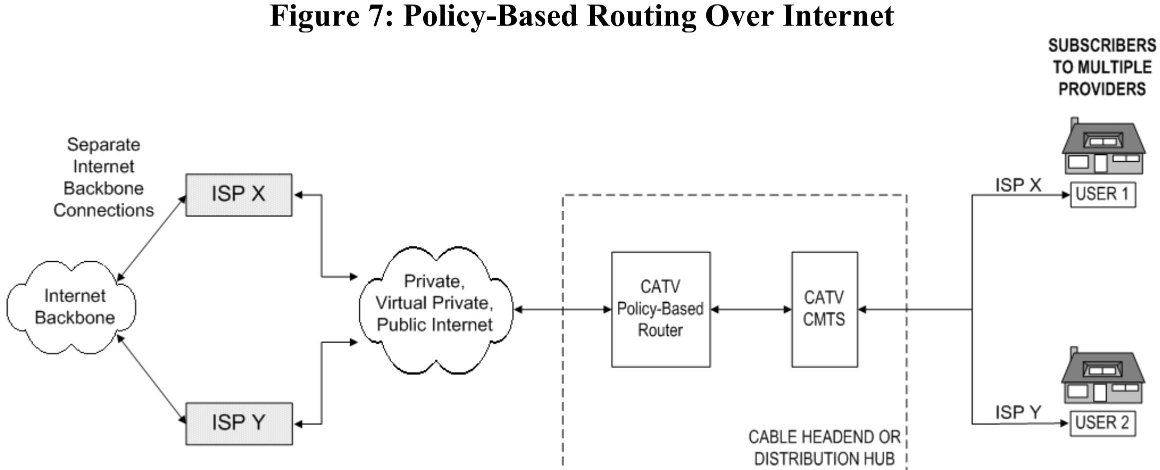
Having its own equipment at the headend would allow an ISP to have more control over its connection to the cable system and therefore over the content and service quality that its customers receive. In this scenario, the ISP could also locate servers at the premises, providing disk space, content, and caching services to users. This PBR model is diagrammed in Figure 6.

Figure 6: Policy-Based Routing with ISP Co-Location at Headend



Purchasing dedicated headend routers and constructing physical plant may not be feasible for some ISPs. Rather than directly connecting to headend equipment, ISPs could handle user traffic by setting up dedicated circuits, virtual private, or public network connections between the cable headend and ISP over the Internet. The cable operator's policy-based router would forward customer transmissions through the Internet to the ISP, which would keep its routers and servers at its own offices. This PBR model is diagrammed in Figure 7.

Figure 7: Policy-Based Routing Over Internet



3.4.4 Respective Roles of ISPs and Cable Operators in PBR

ISPs are responsible for DNS, backbone connections between the ISP and cable operator, hosting of their own affiliated content, site caching, providing a block of IP addresses for customers, and serving as point of contact with the customer for support and billing.

The cable operator is responsible for management of the network from the headend to the modem. This responsibility includes operating and maintaining the headend, hubs, and cable plant, authentication of users, and security of the data on the network between the user and the user's ISP.[24]

The cable operator bills an ISP either by customer or based on network usage and would potentially also charge ISPs for headend space or ports on a policy-based router. Setup of modem service will be accomplished by the cable operator and ISP.

Contrary to some expectations, under this approach consumers need not experience the difficulty and inconvenience generally associated with cable service calls. Rather, ISPs could, as with the separate-channel strategy, provide "starter packages" at retail outlets, which contain instructions and software for a user to add a cable modem to the provider's service on the cable system. However, there must also be coordination with the cable operator, so that the subscriber's cable drop is connected and the cable system recognizes the subscriber as an authorized user of the network and customer of the ISP. This can be accomplished through an automated provisioning process arranged between the ISP and cable operator or by requiring new users to contact the cable operator at the time of installation.

The ISP and cable operator must also coordinate the IP addresses the ISP provides to its subscribers. Any changes or expansion of the IP address block must also be coordinated.[25]

3.4.5 Service Provisioning

A multiple-ISP environment also requires addressing such issues as configuring the customers' computer and modem for service, customer support and troubleshooting, and billing customers. These activities generally involve interactions between different hardware and software systems both on an ISP-specific level and an overall system level.

Switching customers between ISPs can involve complex back-office operations. Ideally, transfers should be accomplished in a fashion that is as invisible to the user as possible. The less visible back-office interactions are, the easier it is for the users to exercise their options to select the ISP of their choice. This process involves developing an interface between the cable operator and ISPs in which the transfer of user identification data, service level, billing information, and IP allocation is accomplished seamlessly.[26] A number of companies are developing back-office applications for open access, including, for example, Alopa Networks.[27]

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[24] "Third Party Residential Internet Access: Point of Interconnect Network Design," Tekton Internet Associates, Inc., prepared for Canadian Cable Television Association, http://www.crtc.gc.ca/cisc/COMMITTE/G&H-docs/HSOD001.doc.
[25] Ibid.
[26] "Open Access Service Provisioning," Abraham Gutman, *Communications and Engineering Design*, May 2001, http://www.cedmagazine.com/ced/2001/0501/05g.htm.
[27] Alopa Networks Products & Services, MetaServ Platform, http://www.alopa.com/msplatform.html.

3.4.6 ISP Connections to the Network

The cable operator and ISP need to coordinate how their networks will connect and how they will scale as the networks grow and in the event that the ISP's percentage use of network capacity changes. Additional CMTS ports or port management schemes are needed to accommodate increases in the number of cable modem users. As the usage of the cable modem network increases, so will the need for PBR capacity and capacity between the cable system and the ISP. If an ISP locates its equipment in a cable operator facility, the footprint of that equipment may need to increase as that ISP adds new customers or services. This may become particularly challenging with several ISPs in the facility.

Connections between the ISPs and the cable network can also be facilitated at peering points located outside the headend, perhaps at an Internet network access point, "carrier hotel," or telephone central office. This would allow ISPs to host local content and management systems directly connected to the cable headend while avoiding costly headend installation and expansion. Distribution of provider hardware locations reduces the overall cost for the cable operator and allows the ISP to have easier control of and access to their own equipment, although at the cost of reducing the closeness and reliability of their connection to the cable system.[28]

3.4.7 Quality of Service

Cable systems may be noticeably slowed during peak usage hours by the volume of usage. Data traffic jams become more common as more users sign on. ISPs and cable operators need to agree on a target capacity available to each user, and the cable operator needs to be responsible for segmenting its network or taking other measures to increase capacity per user if the agreed target capacity cannot be met.[29]

When DOCSIS 1.1 becomes available[30], a cable modem customer will be able to receive minimum and maximum service level guarantees.[31] The ISP will need to coordinate with the cable company its service offering to each customer with the appropriate configuration of that user's services on the cable system. For example, a customer who purchases 512 kbps downstream and 128 kbps upstream data services and telephone-over-IP from an ISP will need the cable operator to configure its CMTS and the user's modem for that service. The cable operator will also need to make sure that its PBR has the bandwidth and quality of service it needs for all customers of all ISPs on the network.

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[28] "Third Party Residential Internet Access: Point of Interconnect Network Design," Tekton Internet Associates, Inc., prepared for Canadian Cable Television Association, http://www.crtc.gc.ca/cisc/COMMITTE/G&H-docs/HSOD001.doc.

[29] "The Cable Modem Traffic Jam," Walter Ciciora, *IEEE Spectrum Online*, http://www.spectrum.ieee.org/spectrum/jun01/features/cmode.html.

[30] DOCSIS, the standard for cable modems, is described in greater detail in Appendix C.

[31] "DOCSIS 1.1 Sounds All-Aboard SIGNAL." Craig Kuhl, *Communications & Engineering Design*, October 2001, http://www.cedmagazine.com/ced/2001/1001/id1.htm.

Finally, the ISP will need to ensure that its own backbone connection to the cable headend is adequate to support all of its users at the level they have subscribed. Specific services delivered to users upon request, such as video-on-demand and voice-over-IP, require immediate attention over the network for prompt and reliable programming transfer. The ISP must guarantee that its connection to voice and video providers have low latency.

3.4.8 Existing PBR Solutions: Juniper/Pacific Broadband

Juniper Networks manufactures high-end router equipment to provide open access solutions, including policy and source-based routing.[32] Juniper's routers forward data based on source and destination IP address, protocol number, source and destination port numbers, IP precedence value, other IP options, TCP flags, packet length, and incoming and outgoing logical or physical interface. These information fields can be read from the header of each data packet. These forwarding abilities allow the router to prioritize and direct data by users and their ISPs, as well as enabling the cable operator to apply service guarantees in its connection between the network and ISP.[33]

Juniper has implemented PBR, though it has not had the opportunity to do so for cable open access solutions, according to company representatives.[34]

Juniper is marketing a "simple, turnkey system for multiple ISP deployments"[35] with Pacific Broadband Communications (PBC).[36] This open access solution combines PBC's CMTS with Juniper's policy-based router. The combination extends Juniper's open access solution to the last mile of the network, according to company literature. The companies also maintain that the combined solution supports direction of multiple ISP traffic as well as multiple tier Quality of Service control for each ISP.[37]

3.4.9 Existing PBR Solutions: The Canadian Model

Various technology companies have devoted considerable design effort and development to the PBR solution, and complete designs for its implementation are being prepared by the Canadian Radio-Television and Telecommunications Commission (CRTC), the Canadian equivalent of the FCC.[38] The CRTC has formed a high-speed working group

[32] "Filter-based Forwarding – Technology Note," http://www.juniper.net/techcenter/notes/552003.html.
[33] Ibid.
[34] Telephone conversation between H. Augustin Cherng, CTC Staff Engineer, and Brad Ryan, Juniper Networks accounts manager, November 4, 2001.
[35] "Pacific Broadband Communications Introduces End-to-End MPLS Open Access Solution." http://www.pbc.com/news/press_11.28.01.html.
[36] PBC develops equipment to deliver standards-based data, telephony, and video over cable networks. Juniper announced its intention to acquire PBC in November 2001.
[37] "Pacific Broadband Communications Introduces End-to-End MPLS Open Access Solution." http://www.pbc.com/news/press_11.28.01.html.
[38] "Third Party Residential Internet Access: Point of Interconnect Network Design," Tekton Internet Associates, Inc., prepared for Canadian Cable Television Association, http://www.crtc.gc.ca/cisc/COMMITTE/G&H-docs/HSOD001.doc.

consisting of representatives of the CRTC, Canadian ISPs, and Canadian cable operators.[39]

The working group is developing a complete implementation plan for Third-Party Residential Internet Access (TPIA) using PBR. Many of its working documents are publicly available. Together, these documents outline a strategy for addressing the technical and business challenges of PBR, including routing of data, interface between ISP and cable operator, test procedures, customer billing, network management, response to end-user problems, tariff agreements for use of the cable networks, and procedures for adding, switching, and disconnecting subscribers.[40] Significantly, the Canadian cable industry is part of this working group and has participated in development of this plan.

[39] Specifically, the working group, which is known as CISC-HSWG, includes representatives of the Canadian Cable Television Association (CCTA), Canadian Association of Internet Service Providers (CAIP), AOL-Canada, Rogers, Shaw, and Videotron.

[40] A list of available documents can be found at http://www.crtc.gc.ca/cisc/eng/cisf3g8.htm and http://www.crtc.gc.ca/cisc/eng/CISF3G8G.HTM.

IV. ISP Perspectives

To understand how the cable industry has dealt with some ISPs, CTC held discussions with two ISPs: Earthlink, a nationally-known ISP currently offering service over cable systems in selected trial markets, and EasyStreet, an Oregon ISP not offering service on cable systems. Neither Earthlink nor EasyStreet is a cable operator partner or affiliate.

The interviews with the ISPs yielded three broad conclusions. The ISPs:

- Believe that cable operators tend to limit the number of ISPs on their networks and the services they can provide.
- Would like to use the cable system as a content-neutral "pipe" to the subscriber.
- Prefer the policy-based routing type of open-access over rebranding.

The ISPs believe that cable operators prefer to limit the number of ISPs on their networks and to limit the breadth of services these ISPs can offer on the networks. In their view, the cable companies take the most significant steps toward opening their networks when forced by regulation, as was the case when AOLTW was required to open TWC's networks as a condition of the merger.

The ISPs want to use the cable system as a "pipe" to the subscriber in a way that leaves them free to provide a wide range of services to subscribers, including video-on-demand, voice-over-IP, virtual private networks, and hosting of mail and Web content. Some cable companies have sought in negotiations with potential ISP partners to limit an ISP's ability to offer many of the above services over a cable system. The ISPs also believe that the most efficient delivery of advanced services calls for locating their routers and servers at cable NOCs or headends, which are currently proprietary facilities without co-location areas open to outside companies.

There are technological reasons for placing some limitations on the capabilities of the ISP or an ISP customer on a cable network. These include a desire not to overload the cable modem system beyond its capacity, particularly in the upstream direction, where bandwidth will be limited for the foreseeable future. These inherent limitations in cable modem capabilities may need to be addressed by the future upgrade of networks, for example, to the Public Interest Architecture proposed below.

However, it must be noted that many cable operators and ISPs affiliated with cable operators want to provide a wide range of advanced Internet services, and may wish to have the benefit of being the sole providers of video-on-demand or voice-over-IP on cable networks. In this scenario, the cable operator opens its network for multiple providers of "Internet browsing" services but is able to keep its network closed to unaffiliated providers of more advanced online services.

The ISPs with whom CTC engineers spoke prefer the PBR option to rebranding because PBR can be configured to allow them to offer differentiated services and Internet connections rather than limiting them to reselling the package provided by the operator.

4.1 Earthlink

CTC's engineer spoke with Greg Collins, Earthlink's Director of Network Engineering and Operations, on November 6, 2001, regarding open access and Earthlink's plans for broadband cable deployment.

4.1.1 Current Access to Cable Systems

Current broadband deployment by Earthlink is over DSL and over cable modems in select markets. Earthlink offers Internet service on Charter cable modem systems. However, that service is not branded as an Earthlink product; rather, Earthlink works as Charter's contractor.

Earthlink offers services on Time-Warner Cable systems. On these systems, TWC is in control of the connection from the cable system to the Internet and routes all Earthlink mail and proprietary content traffic to the ISP through the Internet. Earthlink customers connect to the Internet through the TWC's backbone connection just as TWC's cable modem customers do. Earthlink has no presence at the headend and there is no peering arrangement at intermediate Internet Point-Of-Presence (POP) or Network Access Points (NAP). The arrangement is similar to the rebranding arrangement on the Click! Network cable modem system (see Appendix A), except that the ISP is more limited in its ability to guarantee service level to its customers, because it does not provision a circuit directly to the headend for access by its customers to mail and proprietary content services.

An Earthlink customer on a TWC system contracts directly with Earthlink. TWC handles all aspects of physical installation.

4.1.2 Potential Access to Cable Systems

Under the consent decree imposed as a condition of the merger between AOL and Time Warner, TWC was required to support multiple ISPs. Earthlink had concluded an access agreement with TWC prior to the merger, and was specifically identified by the FTC as a required partner for AOLTW.[41] According to Collins, AOLTW planned to give access to multiple ISPs through multiple DHCP address pools, one of which would be reserved for Earthlink. A policy-based router would sit at the core of the network.

According to Collins, AOLTW now claims that it cannot technically implement PBR. Collins believes that the limitation is the inability of the Cisco 7000/7500 series routers used by AOLTW to perform PBR for a large number of customers. Equipment manufacturers such as Juniper Networks (see Section III above) believe that their equipment can make PBR open access possible on systems such as TWC's.

[41] "FTC Approves AOL/Time Warner Merger with Conditions," http://www.ftc.gov/opa/2000/12/aol.htm.

As of this writing, a PBR open access solution has not been implemented on any large American cable system. However, there is no technical reason why PBR cannot be implemented on an HFC system such as those owned by TWC, given the appropriate equipment and willingness on the part of AOLTW to configure it for open access.

In terms of facilities-based competition, Collins pointed out one advantage of cable over DSL. Cable enables an ISP or content provider to geographically isolate an area by headend service area, whereas this capability is much more limited with DSL, which can often only be isolated by local access transport area or state.

Earthlink has begun trials with AT&T Broadband, but at the time of the discussion with Collins, these plans were on hold because of uncertainty about the status of Excite@Home. Earthlink may also conduct trials with other cable companies, including Cox, Comcast, and Mediacom.

According to Collins, cable companies with whom Earthlink is negotiating potential access have attempted to limit the services Earthlink can provide over their systems. They have attempted to place limitations on services such as DVD-quality video; voice-over-IP; personal video recorder; turnkey home networking solutions; business and corporate data services; and video-on-demand and subscription video-on-demand services. These restrictions would effectively make cable operators and their affiliated ISPs the sole providers of advanced services over cable.

Cable operators are also seeking to bill competing ISPs for subscriber downloads that exceed certain levels, according to Collins. For example, AOLTW was seeking a limit of two or three GB per customer. Earthlink, in contrast, wanted limits of five GB upstream and 10 GB downstream. Collins believes that AOLTW was communicating that bandwidth was "available, but you had better not use it."

According to Collins, TWC attempted to restrict Earthlink from offering virtual private networking over TWC systems. However, these restrictions were eased because AOL wanted virtual private network capability, and the FTC/FCC decree required that AOL be subject to the same limitations as those that apply to competitive ISPs.

4.1.3 Earthlink's Vision of Open Access

According to Collins, Earthlink would ideally like to see an open access scenario with the following four characteristics:

- The cable operator would offer Earthlink access to high quality connections to subscribers without significant degradation problems.

- Earthlink would be able to install equipment at the headend or network operations center to deliver its desired product offerings. Earthlink is interested in handling caching and having content servers located as close to the network edge as possible.

- PBR would be the technical model used to provide open access.

- The cable companies would continue aggregating their headends to serve larger numbers of customers, reducing the burden on cable companies and ISPs for co-location of facilities.

Collins believes that the cable industry, if forced to implement some form of open access, will push as hard as possible for the rebranding model and will drag its feet in implementing PBR or any solution that involves installation of ISP infrastructure at the headend.

4.2 EasyStreet

A CTC engineer spoke with Rich Bader, President of EasyStreet, on November 26, 2001 regarding open access and EasyStreet's plans for broadband cable deployment. EasyStreet is a regional Oregon ISP with many customers in the Portland area. EasyStreet has 3,000 broadband subscribers and is one of the largest providers of broadband services in Oregon.

4.2.1 Current Access to Cable Systems

EasyStreet currently does not have access to any cable systems. EasyStreet offers broadband services over DSL connections provisioned by Verizon, Qwest, or Covad.

4.2.2 Potential Access to Cable Systems

According to Bader, EasyStreet is currently not investing much energy in attempting to secure access to the cable system because it has low expectations that AT&T would open its network to competing ISPs. According to Bader, to the extent AT&T is considering multiple ISP access, it is primarily seeking large partners rather than local ISPs like EasyStreet.

4.2.3 EasyStreet's Vision of Open Access

According to Bader, EasyStreet is interested in offering service over cable because cable has strong residential penetration. Cable passes more homes than DSL-ready telephone lines and Bader believes cable broadband would be a less expensive option for a customer already connected to cable service than offering service to that customer over DSL.

According to Bader, EasyStreet would ideally like to have open access to cable systems with the following four characteristics:

- Carriers would provide and maintain the physical and data link aspects of the system through telephone, cable, wireless, or other medium.

- The operator would be responsible for operation of the cable modem platform.

- Deployment would use standards-based protocols with clear lines of demarcation.

- Carriers would be allowed to compete in other aspects of the system in a nondiscriminatory manner.

Like Earthlink, EasyStreet is primarily interested in a PBR scenario under which the ISP has as much control of quality of service as possible. EasyStreet is not interested in merely reselling the cable operator's wholesale product. Bader stated that marketing and customer support are not sufficient incentives for EasyStreet to seek open access because he believes that there is not sufficient profit in those sectors.

V. Technical Recommendations

5.1 Short-Term Recommendations for Strategies By Which a Cable Company Can Enable Open Access

In the short term, there are some strategies that a cable operator can implement to develop a network more conducive to the public interest. These strategies generally require only small modifications to cable modem equipment already installed. They do not necessarily require construction of new cable plant or upgrades of outdoor plant. To some extent, the model of open access that the cable operator implements will determine the degree of challenge in implementing an open access network.

For example, in the rebranding model, the operator will have relatively minimal changes in equipment, but will need to coordinate with the ISPs their responsibilities for installing customers, connecting the ISPs with the cable modem network router, customer support, and billing. One approach to addressing these issues was used by Tacoma Click!, which developed a Request for Qualifications (Appendix A) for ISPs. Cable operators anticipating open access could develop such a document to enable potential partners to apply for carriage on the network and to serve as the basis for negotiations regarding how the ISP would be carried on the network.

As is discussed in Section III above, PBR or the separate-channel solution constitute preferable open access models for the public interest because they provide non-affiliated ISPs a greater role in delivering service to customers and more choice regarding the types of service to offer. To implement PBR open access, the cable operator and ISPs will need to do the same coordination as for the rebranding model. In addition, the cable operator will need to replace or upgrade router equipment in the headend, set aside space for the equipment ISPs will need to install in the headend or network operations center, and negotiate with ISPs details of how network addressing and routing will work.

5.1.1 Make Open Access Modifications During Upgrades and Conversions

Ideally, some of these modifications can be incorporated into a rebuild or upgrade plan so as to achieve economies of scale and minimize inconvenience. For example, when a system is upgraded to provide cable modem services, the headend is usually enhanced and new hub facilities are constructed.

5.1.2 Provide for Headend Co-Location

The primary issue is to ensure sufficient space in the headend for co-location by other ISPs and content providers. Some headends and network operations centers are already carrier-class facilities, with sufficient rack space for expansion. In metropolitan areas, cable operators typically have planned for expandability for the headend; therefore, rack space should not be an insurmountable problem, and can be leased to ISPs just as it is in Internet co-location facilities. Cable companies may wish to examine the models used in telephone central offices and Internet network access points for co-location. Some ISPs already lease fiber optics to unaffiliated service providers or competitive local exchange carriers and have co-location arrangements for these customers.

5.1.3 Upgrade Headend Router

The router that interconnects the cable operator and/or Internet backbone to the cable modem network must be capable of filter-based forwarding and be able to forward data packets based on the source address of the packet. The router must also have the capability to handle PBR for the volume of customers and ISPs who will be using the network. For a large metropolitan area headend, the cable operator may need to replace the existing router with a higher performance router. If the cable operator needs to replace a router when it reconnects its Excite@Home customers to an operator-affiliated ISP, it would be advisable for the operator to plan for PBR capability in the router.

5.1.4 Repair May Be Needed to Outdoor Cable Plant for Separate-Channel Solution

The cable plant does not need modifications to enable open access in the DOCSIS-compliant cable architecture currently deployed by most cable operators. Cable modems connect in a standardized manner in all DOCSIS cable modem systems. To implement PBR-based open access in a DOCSIS environment, the modifications required to the cable modem system take place at the system headend router, in the ISP network, and on the customer's computer or network router. (See Section III). None of these modifications involves changes in outdoor cable plant; any network that is capable of providing cable modem service from a single provider will not need outdoor plant modification to provide cable modem service from multiple ISPs.

In the event that total cable modem network usage increases as the new providers are added, the operator may need to increase network capacity by segmenting its network into smaller node service areas. This may require adding equipment inside node enclosures and additional ports at headends and hubs, but in the short-term is unlikely to require new cable plant or outdoor construction.

To implement the separate-channel solution, the cable operator may also need to make sure its upstream spectrum is clear over a wide enough range of channels to support multiple providers. Currently, many providers assign the cleanest part of their upstream spectrum to their cable modem services and do not track down sources of interference or noise in the rest of their upstream spectrum. In order to provide sufficient spectrum for multiple ISPs to carry services on separate channels, cable operators may need to fix loose connectors, replace damaged cables, replace damaged service drops, and filter noise entering the cable system from indoor wiring in subscriber residences.

5.2 Long-Term Recommendations: Public Interest Architecture

If open access is the goal, policy makers and cable operators should work toward the adoption of a Public Interest Architecture, a broadband infrastructure that addresses the engineering challenges of offering advanced services to consumers by anticipating future bandwidth needs, and by taking as a central principle the idea that networks grow and succeed when they are open to a broad range of service providers by technological design and by policy. A system utilizing this architecture would support such policy goals as broad consumer access at a range of prices; a variety of service offerings; user-friendly Internet access; and competition. Such a system would simultaneously serve the commercial interests of the relevant industries because it would support such potentially lucrative offerings as video-on-demand; interactive video; web-enhanced television; small business applications; and games/virtual reality.

The Public Interest Architecture proposed here consists of the following:

5.2.1 Construct Extensive Fiber Optics

Public policies should encourage the construction of fiber optics as deep into the system, and thus close to users, as possible. Where new housing developments are constructed, carriers and builders should take advantage of the fact that fiber optic construction costs are comparable to twisted-pair or coaxial construction costs, and complete fiber optic construction to individual apartments, office units, or homes if feasible.

5.2.2 Construct Survivable, Redundant Architecture

The operator should construct survivable physical architecture as far as possible into the network. Fiber optics should be constructed in a ring or a ring-within-ring architecture so that a cable break or failure of an individual component will not cut off services.

Network components should be deployed with sufficient standby electrical power so that the system can continue operation through an electrical failure until electricity is restored. This is particularly critical for network telephone service, alarms, and other lifeline emergency requirements.

5.2.3 Enable Access to Diversity of Providers

Ideally, customers should be able to obtain services from a diversity of facilities-based carriers offering voice, data, and video service over a variety of transmission media, including coaxial cable, fiber optics, or wireless signals.

There should also be diversity of service providers on individual facilities-based networks, particularly in the event that facilities-based competition is not available. This diversity enables user to choose among providers of similar services, even if they do not have choice among transmission media.

To facilitate this diversity, ISPs and potential application providers (such as IP telephony or video-on-demand providers) should have access to central offices, headends, and hub facilities of broadband networks to be able to deploy server content close to customers. This access should be nondiscriminatory and priced at market rates.

ISPs and application providers should be able to obtain access to necessary capacity on broadband networks, in a nondiscriminatory manner and at market prices, to provide services and applications with required quality of service.

5.2.4 Standardize Equipment

Standardization of user equipment, network server equipment, and switching equipment is necessary to speed deployment of new services and applications. Each item of consumer electronics should be available from multiple providers. Consumers can purchase necessary hardware in stores or online. For example, equipment such as cable modems, set top converters, game equipment, and interactive video equipment should be available from multiple equipment vendors in an electronics store or online. The equipment should be standardized so that the user can change geographic locations or service providers and still use the same equipment. To a great extent, this is already happening with DOCSIS-compliant cable modems. The trend needs to continue as Web-TV, interactive video, game equipment, and other technologies are deployed on the DOCSIS platform. As fiber moves to the curb or the home, cable operators and service providers ideally should make their fiber services available using standardized technologies such as Ethernet or SONET (or their successor technologies).

Appendix A: Click! Network, Tacoma, Washington

The Click! Network in Tacoma, Washington is an “overbuilt” cable system. Click! has affected the broadband competitive market in two ways.: first, it created facilities-based competition with the existing cable company for both cable and cable modem services; and second, it provides access to other ISPs on its network under the rebranding model.

A CTC engineer met with Click! staff in Tacoma, Washington on October 25, 2001 and toured Click! facilities. CTC obtained follow-up information in telephone discussions with Brian Wilson, who served as Communications Supervisor of Franchise and I-Net Management for the City of Tacoma and was responsible for the City’s oversight of Click! and AT&T Broadband during the first three years that Click! offered service.

I. Background

In the late 1990s, the Click! Network was formed by Tacoma’s electrical utility to offer competitive cable and wholesale Internet services as a competitor to the incumbent cable operator, AT&T Broadband. Click! is an “overbuilder,” a term that refers to companies that build plant to offer services in areas already served by an incumbent company that has generally had a monopoly until then.

Tacoma Power constructed Click! in 1998 as a communications system to provide the following services:

- Communications between Tacoma Power facilities, including substations and meters.
- Commercial broadband services.
- Cable television.
- Residential Internet.
- Residential power meter reading.

According to Diane Lachel, Click! Director of Government Relations, the concept of Click! originated when Steve Klein, Superintendent of Tacoma City Light (TCL), participated in discussions of telecommunications deregulation in 1992 in U.S. Congress. At the time, TCL was engaged in a process of strategic planning and reorganization. A five-year period of study led to a reorganization of TCL into a number of different departments for power generation, power transmission and distribution, power management, energy processes (inspection and conservation), and telecommunications. The telecommunications department became Click!

In 1996, Stanford Research Institute (SRI) was hired to assist TCL in developing a business plan for Click! based on the strengths and weaknesses of TCL. This research served as the basis for many of the business strategies adopted by Click!, including: 1) to provide cable television competition, 2) not to compete with existing local businesses other than the cable operator, and 3) an emphasis on customer service and network reliability. According to Lachel, there were significant problems with communications infrastructure in the City of Tacoma, including:

- Lack of availability of suitable telecommunications services to interconnect TCL substations to the energy control center.
- Twelve to 18-month wait periods for business telephone connections in downtown Tacoma.
- U.S. West's inability to connect some residents to telephone service and its provision of cellular telephones instead.
- The cable television had 36 channels, while neighboring communities had many more channels.
- The cable television service prompted many customer complaints, averaging four to five calls to the City per day.

According to Lachel, TCL had cash in reserve from sale of energy from its generation facilities and was required by its charter to reinvest the money in the City.

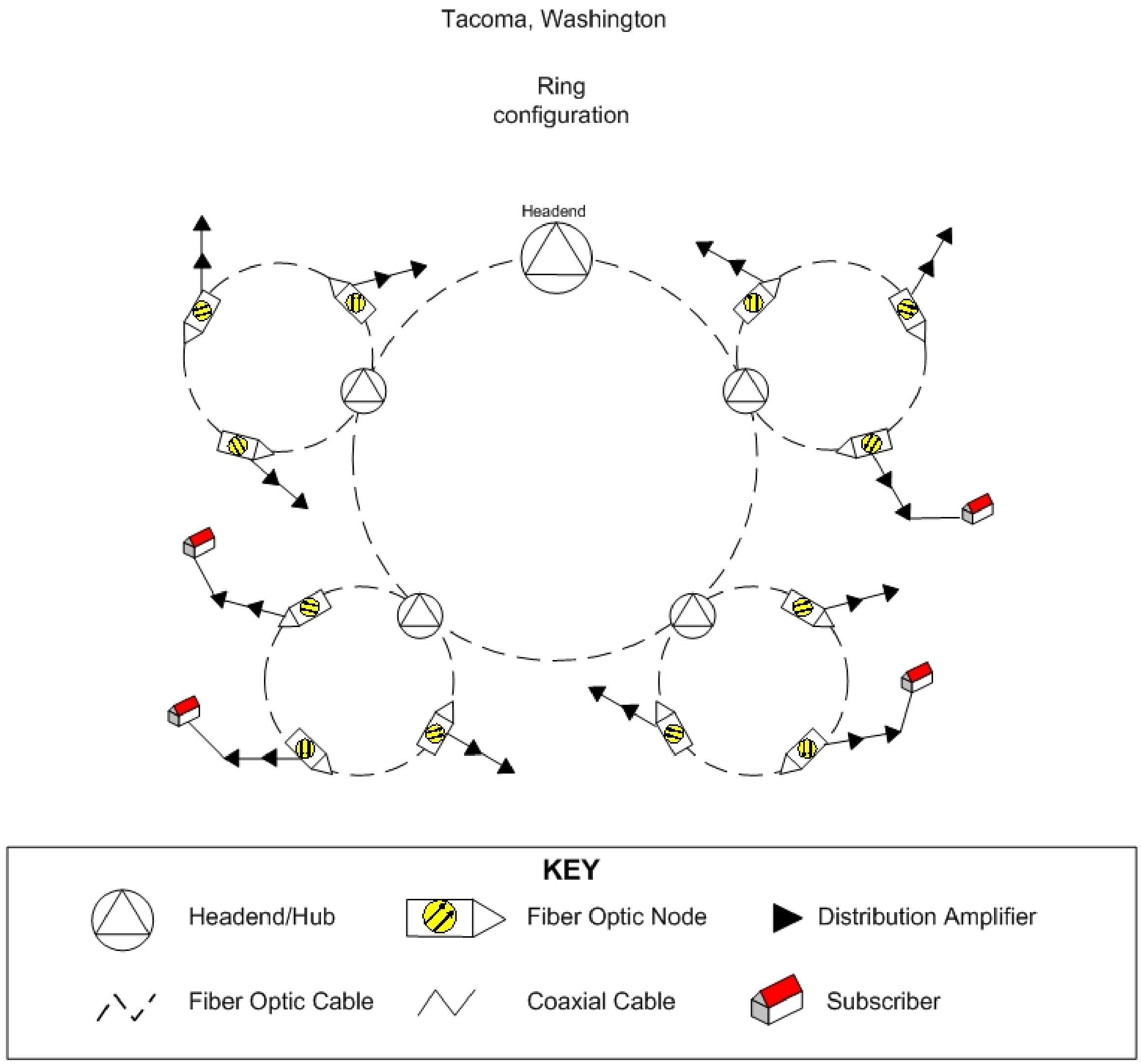
In 1997 TCL developed a more detailed business plan internally. According to TCL, the research for the plan included community focus groups.

II. Network Architecture

The Tacoma system was designed and built in the late-1990s as a utility grade network. It has backup power in the cable plant and a redundantly-routed fiber optic backbone ring (see Figure A-1). Network construction began in April 1997 and the first cable customer was connected in August 1998.

All fiber in Tacoma is structured in loops, including fiber to neighborhood nodes.

Figure A-1: Click! Network Architecture



The network architecture includes the following characteristics:

- Fiber optic backbone between headend and six backbone hubs located in Tacoma Power substations or former power substations in a figure-eight topology.
- 775 miles of cable plant.
- Service in City of Tacoma, backbone scalable to serve entire Tacoma Power service area.
- Survivable fiber optic rings (service loops) from hubs to nodes serving 1,000 to 1,200 homes.
- 96 to 144 fibers on each service loop.
- Design of nodes to enable splitting into four parts without construction of additional cable.
- Maximum amplifier cascade of four.

- 750 MHz capacity coaxial cable plant two-way activated.
- Electronic status monitoring of headend equipment, hubs, nodes, power supplies, and amplifiers.
- Eight hour battery backup and diesel generators at headend and hubs.
- Four hour standby battery backup in power supplies.
- Analog and digital satellite receivers at the headend.
- Scientific Atlanta Continuum modulators for analog channels.
- General Instruments C8U up-converters for digital channels.
- Video lineup originated from headend.
- Video sent from headend to hubs over RF amplitude modulated optical signals.
- SONET fiber optic transport backbone for data and voice.
- Motorola CFT2000 addressable analog set-top converters.
- Motorola DCT2000 digital set-top converters.
- Data network originated at hub sites and narrowcast to and from individual nodes.
- Emergency Alert System (EAS).
- Eighty-nine analog video channels.
- Ninety-one digital video channels.
- RG-6 quad-shielded drop cable.
- Five public, educational, and government (PEG) channels, with one additional channel pending, uplinked from downtown master control center to Click! over fiber optic feed.
- Video programming negotiated through contract through the National Cable Television Co-op.

A fiber optic data network for commercial customers and carriers began service in March 1999. The data and voice network operates over a Nortel SONET infrastructure around the backbone and service loop fiber. Backbone capacity is OC-48 (2.4 Gbps) with circuits available to users from fractional T1 to OC-48 in ring or point-to-point topology. Over 200 circuits are in use. Customers include competitive local exchange providers such as Advanced Telecommunications Group (ATG) and Electric Lightwave, Inc. (ELI). The majority of end-users of the infrastructure contract with CLECs or ISPs reselling services over the network.

III. Cable Modem Network

A cable-modem based data network for residential and small-business users in Tacoma operates over the cable television infrastructure. It began operation in September 1999. According to Lachel and Wilson, the Tacoma City council did not want Click! to cut into the revenues of local businesses, which became an important factor in the decision for Click! to provide its data network as a wholesale service. Three local ISPs contract directly with the customer. One additional ISP, OlyWaNet, is no longer marketing services on the network. ATG recently acquired OlyWaNet and, according to Lachel, Click! is not sure of the future status of OlyWaNet customers.

The Click! cable modem network has the following characteristics:

- DOCSIS 1.0 compliant cable modem termination system and modems.
- Two load-sharing fail-safe DS3 (two 45 Mbps) connections from network to Internet backbone.
- Single Class B IP subnet.
- Local cache stores recently requested content.
- Domain name services, DHCP server at network operations center.
- VPN services permitted, with some ISPs assisting customers in setting up VPNs across the network.
- Hosting of content by end-users prohibited.
- T1 connections to each ISP for value-added services including E-mail, Web-hosting, and customer care.
- Two levels of service: 1) dynamic IP with 128 kbps upstream and 1 Mbps downstream and 2) static IP addresses with 256 kbps upstream and 2 Mbps downstream.
- Traffic between cable modem users and the Internet travels through the Click! network and does not pass through the ISP, unless it is related to the value-added services from the ISP.

A customer contracts with one of three ISPs (currently Harbornet, Net Venture, and Advanced Stream). Click! installs the physical connection to the house and any internal wiring required. The user installs the modem or has the ISP install it. The ISP is responsible for the customer having the PC correctly configured and network interface card (NIC) installed. The ISP takes customer calls and is the point of contact with Click! in the event of a network problem. The ISP pays Click! a fee for using the network, and Click! pays for the Internet backbone connections.

ISPs join the network if they are approved through a request for qualifications (RFQ) process. The first RFQ was issued February 2000. Four providers joined the network. Since then, three have left and two others have joined the network. There is currently an open RFQ to join the network. The RFQ requires:

- An initial connection fee.
- Monthly usage charge.
- A dedicated T1 circuit to the Click! gateway.
- Ability to offer e-mail services.
- Customer service during some evening and weekend hours in addition to regular business days and hours.
- Non-discriminatory service.
- Ability to install and verify function of end-user equipment within 10 business days of request.
- Experience in responding to local market.

Click! staff estimated that their network can support up to six ISPs. According to Lachel, there are more than 3,000 Click! cable modem customers, and approximately 300 signed up with Click! following the temporary disconnection of cable modem service on AT&T Broadband.

Click! customers can also obtain cable-based Internet access and e-mail on their television sets using a service called WorldGate. Users access WorldGate's services on their televisions using analog or digital set-top converters, a remote control, and keyboard. WorldGate is a first generation interactive television system; to the user, it resembles WebTV, which provides similar services over phone lines rather than cable. WorldGate servers are located at the Click! headend and hubs, and they reformat Internet content for digital transmission to the set-top converters, which generate the signal to the subscriber's television. WorldGate is offered over Click!'s cable, but not over the DOCSIS cable modem. Unlike DOCSIS, it is a proprietary platform, so its technological evolution is controlled by WorldGate and its industry partners.

The disadvantage of WorldGate is that some Internet content is poorly displayed on a television set, as opposed to on a higher-resolution computer monitor. In addition, the platform does not support some commonly-used Internet applications, including RealVideo. WorldGate is designed for customers with limited Internet needs who do not own a computer.

IV. Results of Competition

The construction of the Click! Network resulted in facilities-based competition in the cable modem area. According to Wilson, a dramatic improvement resulted from AT&T's efforts to upgrade customer service and technology, presumably in response to the competitive environment created by the advent of Click! Wilson never received a complaint from a Click! Subscriber, at the same time as he received daily complaints from AT&T customers. After Click! began providing service, Wilson saw a significant improvement in the volume of complaints regarding AT&T's services. AT&T now offers telephone services, is beginning to offer video-on-demand, and is significantly more advanced than most cable systems.

V. The Tacoma Institutional Networks (I-Net)

Two I-Net systems operate in Tacoma, both running on the Click! network. Their respective franchise agreements with the City require both AT&T Broadband and Click! to construct an I-Net. AT&T proposed a managed network with monthly recurring costs. Click! proposed to construct fiber optic plant and install electronics at its incremental cost, with the City operating the network.

The City chose Click!'s model and arranged for AT&T to provide a capital grant rather than meeting its obligations with respect to an I-Net and origination sites. The City then used the capital grant money and franchise fees to pay for I-Net sites on Click!.

The agreement between the City of Tacoma and Click! requires Click! to pay a five percent franchise fee, one percent PEG and I-Net capital grant, and eight percent tax. Click! is required to construct, at incremental cost, fiber optic and coaxial cable plant to designated facilities.

Click! is also required to maintain and operate signal transport over two networks: 1) a hybrid-fiber coaxial network, and 2) a fiber optic SONET-based network.

The first Click! I-Net is an analog hybrid fiber-coax system that is a mirror of the cable television system. According to Lachel, 45 sites are connected to the HFC I-Net.

The network feeds video to a master control center in downtown Tacoma. The analog HFC has some capability for data and voice using a cable modem-based system similar to that on the Click! subscriber network.

The second I-Net includes fiber optics to the I-Net facility and provisions a circuit across the network, as specified by the City, using the Click! SONET backbone. Approximately 300 locations are delineated in the AT&T and Click! Franchise Agreements for potential I-Net use, but only 18 locations have been connected because of cost. The SONET network brings OC-3 (155 Mbps) capacity into each facility and enables the I-Net user to add and drop circuits at a facility depending on its requirements.

Appendix B: A Representative System in Portland, OR

CTC studied a large metropolitan system that is technologically typical of HFC cable architectures around the United States and examined its capabilities from the point of view of open access. To this end, CTC studied the AT&T Broadband cable system in Portland, Oregon.

With its standard HFC architecture, the Portland AT&T system is typical of the majority of current American cable systems. No form of access by multiple ISPs has been offered over this system. However, there is no technical reason why, properly equipped, that system cannot offer either a separate-channel or a policy-based router plan (discussed in Section III), provided that AT&T deploys the necessary equipment and works in cooperation with ISPs.

A CTC engineer attempted to meet with AT&T staff and to tour the cable system in October 2001, but AT&T refused to meet with CTC. As an alternative, CTC obtained extensive information regarding the system from David C. Olson, the Director of the Mount Hood Cable Regulatory Commission, the regulatory body overseeing the cable system that encompasses Portland. Mr. Olson conducted a follow-up discussion with AT&T staff in December 2001 and obtained further information CTC requested for the Report.[42]

I. Network Background and Architecture

The Portland cable system was constructed as a branch and tree system in the late 1970s and early 1980s for one-way entertainment services. The system was initially operated by Paragon/Time Warner and TCI in the East Multnomah County and City of Portland franchise areas. AT&T took over the whole system in early 1999 as part of its purchase of TCI. As a condition of the transfer of the cable system to AT&T, the City attempted to require that it open its system to multiple ISPs. AT&T challenged this decision in the courts, and the requirement was eventually voided.

Later in 1999, AT&T began an upgrade of its systems to HFC and has completed upgrades throughout the City. AT&T was able to address the limitations of the original network by adding fiber optic plant lashed to its existing cable, and upgrading its headend and cable plant electronics for cable modem and telephone services. The network has backup power in the cable plant and a redundantly-routed fiber optic backbone ring.

With respect to service issues, Olson reported that Portland customers have significant problems with AT&T, especially poor response time for telephone calls. The City had fined AT&T $180,000 as of the end of 2000 for not answering the telephone in accordance with FCC and City standards.

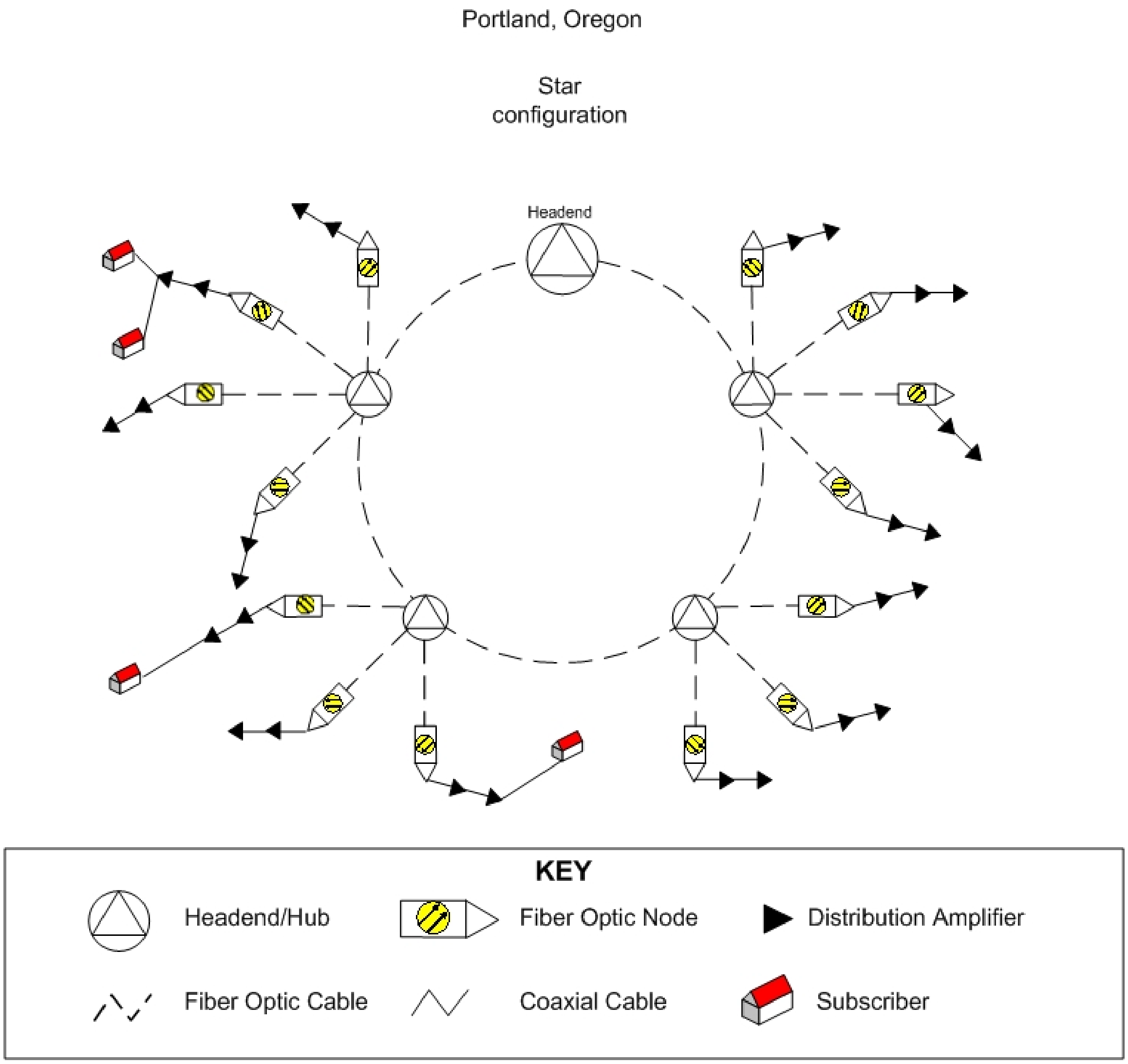
[42] CTC wishes to acknowledge and thank Mr. Olson for his tireless efforts to obtain information for this Report. CTC's analysis of the Portland AT&T system would have been impossible without Mr. Olson's assistance.

AT&T's broadband network in Portland has the following features:

- Fiber optic backbone between headend and six hubs.
- 1751.75 miles of cable plant.
- Star configuration of fiber optics between hubs nodes serving between 650 and 675 homes.
- Six fibers from hubs to each residential node.
- 750 MHz capacity, coaxial cable plant, two-way activated.
- Two to four-hour battery backup at each power supply diesel generators at headend and hubs.
- Video lineup originated from headend.
- SONET and Gigabit Ethernet fiber optic transport backbone between hubs.
- Electronic status monitoring of hubs.
- Electronic status monitoring of headend, hubs, power supplies, nodes, amplifiers, and customer premises to the parts of the system where cable TV, broadband Internet, and cable telephony are all offered.
- Where status monitoring is active, it is monitored 24 hours a day, seven days a week, 365 days a year.
- Seventy-five analog video channels.
- 180 digital video channels.
- Eight public, educational, and government (PEG) channels;
- Scientific Atlanta and GI/Motorola set-top converters for analog subscribers are available for purchase.
- GI/Motorola set-top converters for digital subscribers.
- Internet and digital video available.

Figure B-1 shows the main fiber architecture of the system. In Portland, AT&T uses a star configuration for distributing fiber from the hubs to neighborhood nodes, with a single connection between each node and its hub.

Figure B-1: Portland Network Architecture



II. Cable Modem Network

Cable modem services have been migrated from Excite@Home to AT&T WorldNet on AT&T Broadband, which handles all aspects of customer installation, provisioning, and service as the single ISP in the area. Excite@Home served as the sole ISP on the system until AT&T migrated users to AT&T WorldNet following the bankruptcy of Excite@Home. AT&T WorldNet is currently the only ISP offered on this system. As of this writing, there are no plans to offer competing ISPs.

The AT&T cable modem network has the following characteristics:

- DOCSIS 1.0 compliant CMTS and cable modems.
- Local cache stores recently requested content.
- All CMTS equipment located at the headend.

AT&T has placed some restrictions on the use of its cable modem network. These include:

- No capacity guarantees.
- Customers are restricted to maximum 1.5 Mpbs downstream and 128 kbps upstream speed.
- Limitations on subscribers hosting servers, operating VPNs, and conferencing software.
- Customers are allowed, with limitations, to connect multiple PCs and home networks to their cable modem.

III. The Portland I-Net

The agreement between the City of Portland and AT&T Broadband requires the cable operator to pay a five percent franchise fee, three percent PEG capital grant, and all applicable taxes. Additionally, AT&T Broadband is required to construct fiber optic and coaxial cable plant to designated facilities at incremental cost.

The Portland I-Net consists of high-capacity sites and low-capacity sites. High-capacity sites have capacities of 180 MHz both upstream and downstream between each site and its corresponding fiber node. Low-capacity I-Net sites have a minimum of eight MHz upstream and 12 MHz downstream capacity. The low-capacity I-Net system has the following features:

- One four-slot CMTS at the headend connected to all the I-Net sites.
- CMTS only routes data within the city network, effectively forming a LAN for the City I-Net sites.
- Six hubs: five in East Portland, one in West Portland.
- Six fibers between sites and nodes.
- Two fibers to an additional node at the site, with a coaxial drop to the site, and four dark fibers directly to the site.
- A total of 290 nodes.
- Six fibers between hubs and headend.
- Video can be originated from any I-Net site.
- Twenty percent of sites share a node with another site.

As of December 4, 2000, 61 sites were in operation over the I-Net. Video applications have been supported successfully by the low-capacity I-Net, but data and Internet usage has had bandwidth problems. All Internet traffic from every site in the City I-Net currently travels through one cable modem to a router in a central Portland building, creating a substantial bottleneck. Proposed solutions to this problem include connecting fiber from the I-Net CMTS directly to the Internet router. A proposal has also been made to connect the AT&T I-Net to the IRNE Network, a fiber network already constructed by the City of Portland. The IRNE Network contains a backbone in Portland that could be extended by the I-Net to distribute connectivity to all I-Net sites.

Appendix C: Technical Description of Branch and Tree Architecture

"Branch and tree" coaxial cable topology refers to the architecture of cable systems that have typically not been upgraded since 1995. These systems are also known as "legacy" systems because their architecture dates from the earliest days of cable in the 1950s and 1960s.[43]

I. Technical Description of Branch and Tree Architecture

Branch and tree systems utilize dated technology that reflects the origin of cable television as a one-way entertainment medium with no status monitoring systems or architectural redundancy. Early cable television systems started as centralized antennas on hills that received over-the-air television signals and transmitted them by cable to homes that could not receive over-the-air signals. In later years, cable systems added additional signals to their offerings by receiving programming over satellite dishes. In this way, cable became a transmission medium for superstations, national news, sports, and movies channels as well as for the original local broadcast stations. Cable was able to offer more programming alternatives and better quality than over-the-air television.

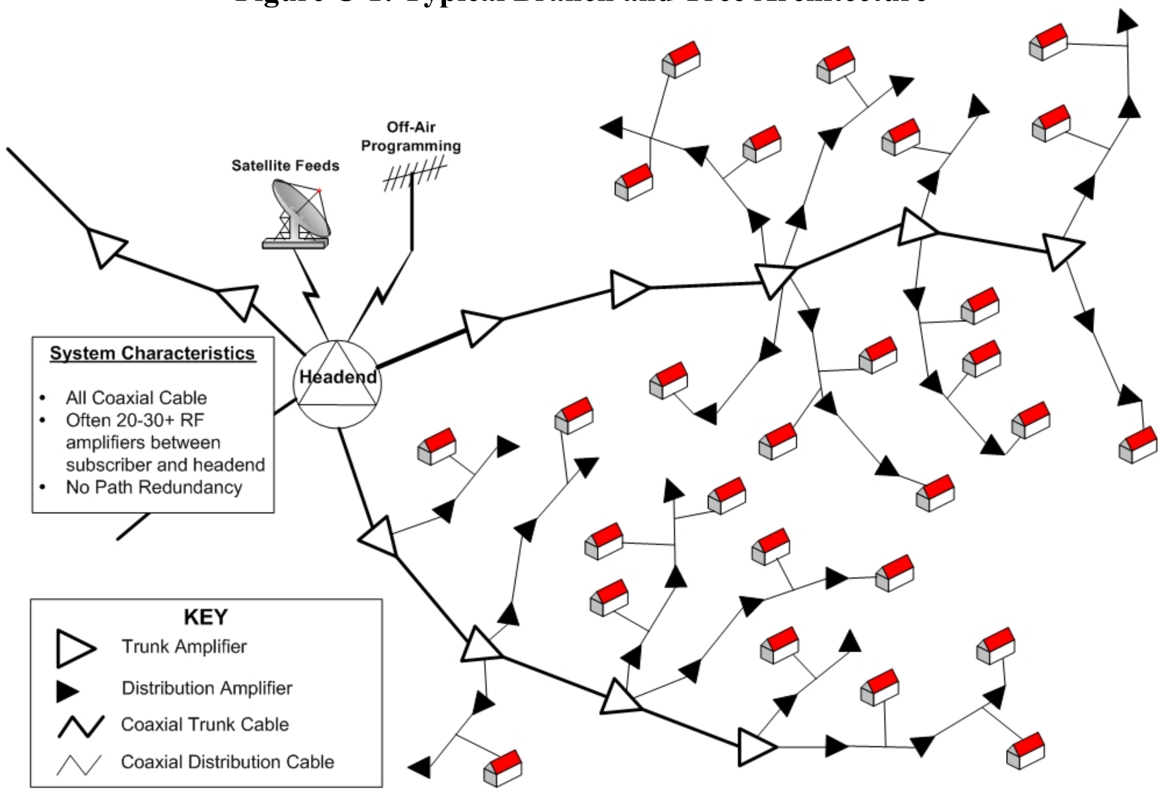
Architecture

The headend is at the center of a branch and tree cable system. It serves as the control center and reception point for all of the programming materials carried on the system. The trunk cables transport television signals from the headend to the most distant points in the franchise service area.

A typical branch and tree system is diagrammed in Figure C-1.

[43] After the most recent round of system upgrades in the late 1990s and early 2000s, most urban and suburban systems have been upgraded to HFC. Branch and Tree systems are found primarily in rural and less populated areas.

Figure C-1: Typical Branch and Tree Architecture



In a branch and tree system, the cable headend receives signals over two general types of antennas: off-air television antennas for local channels and satellite antennas (dishes) for long distance signals. For optimal signal reception, the antennas and headend are often located on a hilltop or other raised land area. Off-air antennas, which receive 55 to 890 MHz signals[44], are located on towers and aimed at television broadcast stations. Satellite dishes, which receive signals in the C band (3.7 to 4.2 GHz) and Ku band (11.7 to 12.2 GHz)[45], are aligned with their transmitting satellites in geosynchronous orbit.

Local television stations sometimes deliver their programs directly to the headend over fiber optic cable to bypass the reception and processing issues associated with radio frequency (RF) transmissions.

Branch and tree systems use coaxial cable to deliver these signals to subscribers. A signal traveling through coaxial cable must be regenerated every one-third to one-half mile by an amplifier. The amplifier serves to boost the signal, but also introduces noise and distortion into the signal and is a potential point of failure in the system.

The size of the area served by a single coaxial cable system is limited by the maximum number of trunk amplifiers that can be connected in series, or "cascaded," and still be

[44] Bartlett, Eugene R., Cable Television Technology & Operations, New York: McGraw-Hill, Inc., 1990, p.230.
[45] Ciciora, Walter et al., Modern Cable Television Technology, San Francisco: Morgan Kaufmann Publishers, Inc., 1999, p.337.

capable of providing a satisfactory signal to the most distant subscriber. As is illustrated in Figure C-1, the trunking network functions as the backbone for the cable system. Typical systems have trunk cable runs comprised of between 15 and 40 amplifiers in series from the headend to the most distant subscriber.

The distribution system, which passes by each subscriber residence, connects the home subscriber to the trunk cable. Scrambled signals can be recovered either by set-top converters at subscriber homes or by traps on the coaxial line which either block or pass certain channels.

Locations nearest the cable system headend receive the best signal quality because traditional coaxial cable architecture requires a long cascade, a large number of amplifiers connected in series. As the signals travel through the amplifier chain and coaxial cable, a gradual degradation of signal quality occurs. Signal quality will decrease to the point where it becomes unacceptable to the subscriber if there is a sufficiently long amplifier cascade between the subscriber and headend.

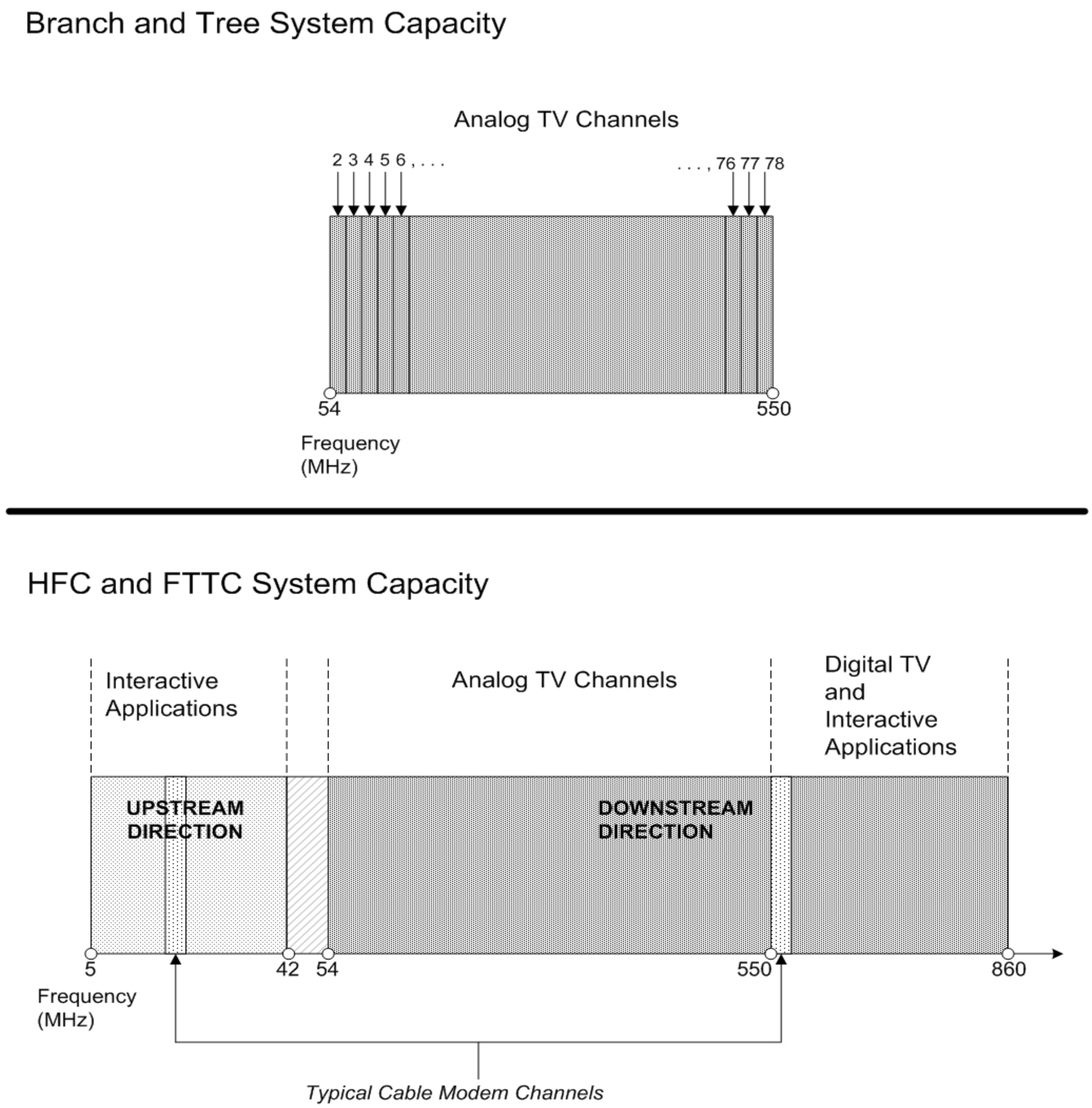
In order to service larger areas, cable operators must construct multiple headends or hubs or must devise special interconnection networks for connecting the systems. Multi-channel microwave links, "super-trunk" cable, and point-to-point fiber optic links are generally the most common technologies used for interconnection.

Bandwidth and Frequencies

Branch and tree systems have only sufficient channel capacity to support one-way, analog television signals. They typically range from 330 to 550 MHz, or 40 to 75 television channels. Figure C-2 illustrates how frequencies are allocated for cable television systems and how branch and tree system capacity supports only analog television channels in contrast to the categories of systems discussed below, which can also support digital TV and interactive applications.[46]

[46] Communications and Engineering Design (CED) 2001-2002 Frequency Allocation Chart.

Figure C-2: Typical Broadband Subscriber Frequency Allocation



Headend Operations

After they are received from the antenna tower, off-air television transmissions pass through a series of signal processors that prepare the signals for distribution from the headend through the cable. An amplifier increases the strength of the received signal so that it is suitable for processing. RF signal processors or modulators convert off-air antenna signals into those suitable for cable broadcasting.

Signals from satellite transmissions undergo a more involved process. After amplification, the signal frequency is downconverted to a lower spectrum (usually 950 – 1450 MHz) because signal loss at the C and Ku satellite bands is too high for transmission through the cable to the headend.[47] The signal is then sent from the dish to the satellite receiver in the headend building where it is further amplified, downconverted, demodulated to baseband frequency, and filtered. Filtering removes noise from adjacent channels and isolates each signal.

As most satellite signals are scrambled to avoid signal theft, a descrambler is used on the incoming transmission. An integrated receiver-decoder (IRD) often performs both receiving and descrambling operations in newer headends.[48] A modulator converts the processed satellite signals to the proper RF channel frequencies for coaxial television reception. Commercial advertisements can be inserted into predesignated ad spots in the programming. Premium and pay-per-view channels are scrambled. A combiner links the individual modulator and processor outputs to the cable system.

Figure C-3 illustrates typical signal flow of a branch and tree headend.

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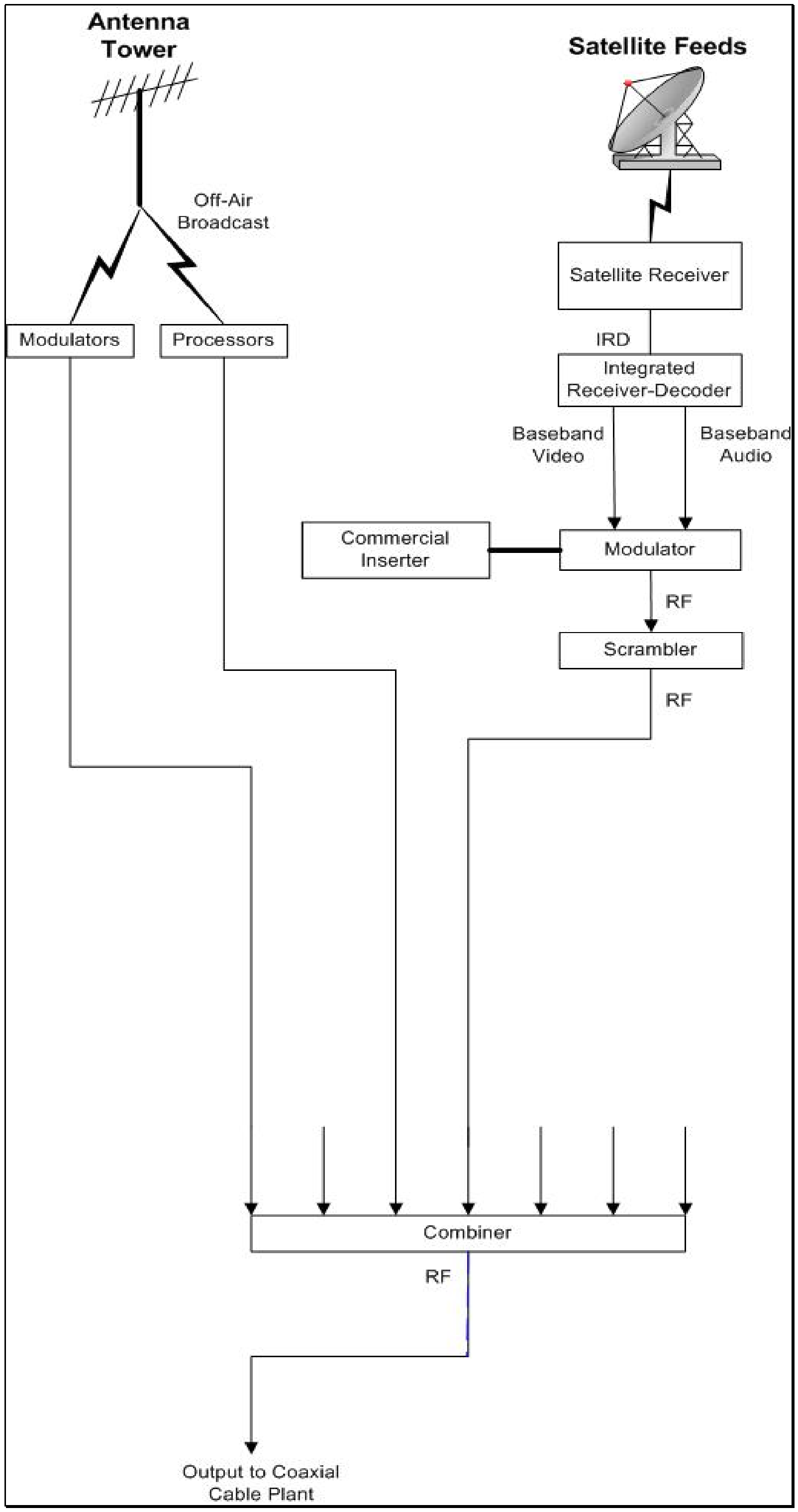
[47] Ciciora, et al., Modern Cable Television Technology, p.275.
[48] Ibid., p.360.

Figure C- 3: Branch and Tree Headend



II. Technical Limitations of Branch and Tree Architecture

There are significant technical limitations with this architecture. The large physical size of the network results in a large number of potential points of failures. All subscribers beyond a failure point experience system outages if a failure occurs in a trunk amplifier located between the headend and the end of the network. In a large cable system, an individual trunk cable might be part of a link that serves tens of thousands of subscribers. A failure at or near the headend can result in a substantial number of subscribers experiencing an outage.

Maintaining the system is an expensive and extensive task, because every trunk amplifier must be checked and adjusted relative to the other amplifiers, a challenge comparable to tuning a group of musical instruments.

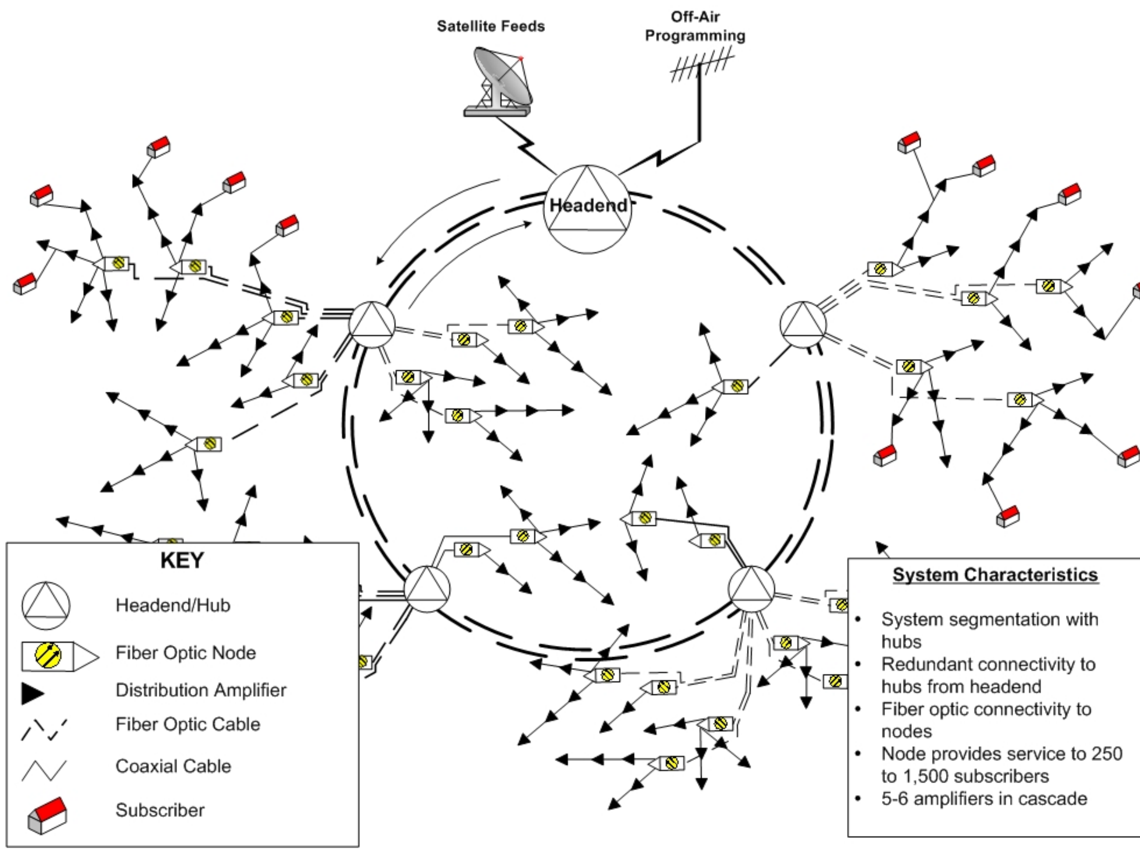
Branch and Tree Architecture Precludes Two-Way Service and Open Access

All-coaxial systems cannot offer two-way services other than rudimentary pay-per-view and telemetry. Two-way operation is precluded by the large amount of system noise in the upstream direction and by the lack of fiber optics and, therefore, of significant capacity. A branch and tree system is based on one trunk. This is in contrast to more recent architectures, in which the system is segmented (essentially, multiple trunks are created by construction of neighborhood fiber optic nodes that translate and boost the signal) to enable each node to reuse channels and thereby multiply capacity for cable modem users.

Appendix D: Technical Description of Hybrid Fiber/Coaxial Architecture

Since the mid-1990s, most American cable networks have incorporated fiber optic technology. These systems use fiber optic cable to link the headend to neighborhood coaxial cable in an architecture called Hybrid Fiber/coaxial (HFC). In the neighborhoods, the traditional coaxial cable distribution remains but with upgrades to enable two-way operation. Figure D-1 illustrates HFC architecture.

Figure D-1: Modern Hybrid Fiber/Coaxial Architecture



I. Technical Description of HFC Architecture

Generally, the evolution of cable networks from the branch and tree configuration to modern HFC networks has entailed construction of fiber optics from the headend to intermediate "hubs" and then eventually to "nodes" in each neighborhood. The nodes contain active devices that convert the fiber optic signals to RF signals for delivery over existing coaxial cable. This architecture has enabled the provision of two-way services and has greatly increased the reliability and quality of the signals offered over the cable system.

Hub and Node Segmentation

In an HFC system, signals leave the headend through laser transmitters that convert signals from RF format into light. Narrowcast lasers send signals bound for specific nodes, and higher power broadcast lasers transmit video signals that are shared by all nodes. Broadcast laser transmissions typically transmit the video programming to all nodes and are optically split along the network path as needed. Fiber optic signals are transmitted by way of hubs and are then received by nodes that convert the signal into RF for coaxial distribution to subscribers. Nodes also contain laser transmitters that send upstream data originating from subscribers back to laser receivers in the headend.

Distribution facilities, known as "hubs," interconnect fibers to the neighborhood node areas and are intermediate between headend and node in a metropolitan area system. The hubs vary in size depending on the design philosophy or complexity of the network; however, they are usually stand-alone facilities with continuous backup battery power. The hub facilities receive their signals from the headend, usually by two discrete transmission paths to ensure that loss of an interconnection cable at one location will not create a single point of failure.

Hubs connect over fiber optic cable to neighborhood nodes, where the fiber interfaces with the coaxial distribution cable. The area served by a neighborhood node is referred to as the node area. Systems are typically designed with node areas that support between 100 and 2,500 residential dwelling units. Smaller node size allows for higher two-way capacity, along with greater system reliability.

The number of amplifiers between the headend and subscriber is reduced to less than eight in an HFC system. The shorter cascade lowers the signal degradation and reduces the number of potential failure points. An HFC system might typically have a capacity of 750 to 860 MHz, used to support a variety of analog and digital video services, two-way interactive data, and telephony.

HFC systems enable the reuse of system capacity for different neighborhood nodes. In other words, the segmentation of the system into separate nodes enables narrowcasting to individual node service areas, much as if each area were a different cable system. This segmentation enables the system to have adequate two-way capacity for telephone, Internet service, and video-on-demand. With increased network capabilities comes increased flexibility as well as technical complexity, since different combinations of multiple services are available.

HFC architecture enables a system simultaneously to broadcast cable channels systemwide and to narrowcast services that are specific to a neighborhood node. Transmissions from data, telephony, and pay-per-view can be sent to individual users based on their service node.

Bandwidth

Figure C-2 of Appendix C illustrates the allocation of bandwidth in a typical modern cable system. In the forward direction (from the headend to the subscriber) the available bandwidth could be in excess of 800 MHz. In the return path, information sent from the subscriber to the headend, the bandwidth is limited to a narrower range. As shown in Figure C-2, the spectrum from 5 to 40 MHz is available for transmissions back to the headend, for a total effective bandwidth of less than 35 MHz.[49] This asymmetry exists because cable was originally designed as a one-way technology maximizing bandwidth to the consumer.

Interactive services include pay-per-view and video-on-demand ordering, cable modem network status monitoring, and telephony. If services are to remain in operation during power outages at the subscriber's home, additional power redundancy must be built into the HFC network. The redundancy may be in the form of power through the network, as is done over standard telephone networks, or power through a battery pack at the subscriber's home.

The size of the node area is a critical performance parameter because all of the bandwidth for interactive services must be shared among the users connected to the node. For example, a node serving 500 homes with a cable modem penetration of fifty percent might need to service up to 250 users simultaneously. In contrast, a smaller node serving 150 homes with the same penetration level would only be required to service 75 homes simultaneously, essentially providing three and one-half times as much usable bandwidth for each subscriber.

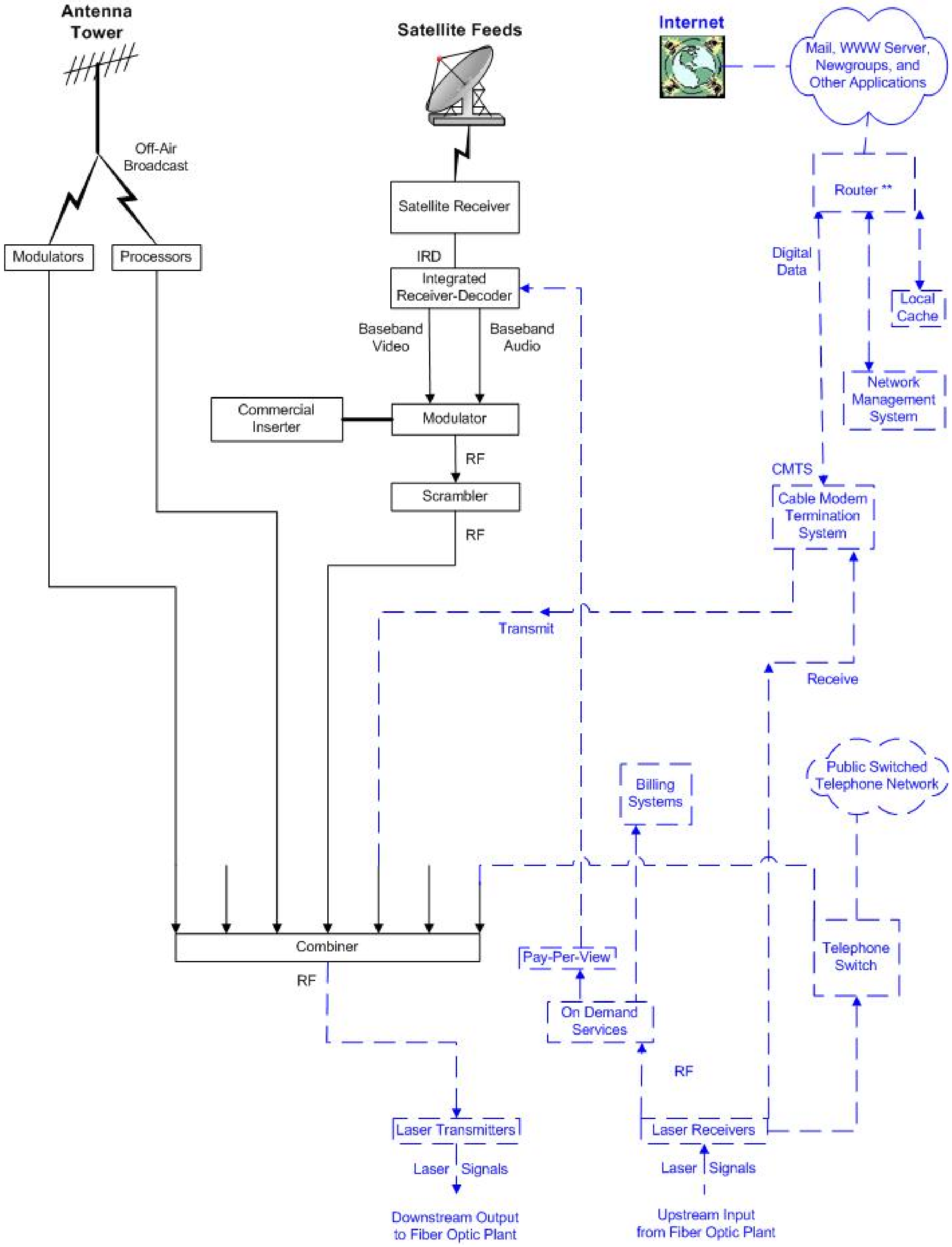
Headend

HFC system headends have similar receiving antennas and processing equipment to branch and tree systems, but with additional equipment to accommodate such two-way services as high speed Internet and telephony.

Figure D-2 illustrates a typical HFC headend.

[49] Ibid., p.577.

Figure D-2: Hybrid Fiber/Coaxial Headend*



*Dashed lines indicate components and services not present in branch and tree systems.
**In a PBR-based open access scenario, this router would be a policy-based router with direct connections to multiple ISPs and the Internet.

Redundancy

HFC system headends include system redundancy that was not a priority in branch and tree systems. Redundancy typically includes backup power and redundant HVAC. Redundancy also includes failsafe communications technologies such as SONET backbone rings and data and telephone equipment with redundant power supplies, chassis, and modules. Headend facilities are equipped with battery uninterruptible power supplies and diesel or natural gas generators that continuously power the headend in the event of a power failure. Status monitoring devices in the system headend monitor the signal and power systems in the cable network. Monitoring equipment can then notify maintenance staff of any problems that need attention before the problems affect subscribers.

Staffing Needs

Introduction of advanced cable technologies necessitates a corresponding upgrade in the skills of system staff. A 24-hour staff presence is needed in the headend or data center to detect and troubleshoot problems. Other parts of the network should be configured to alert staff of problems.

Repair personnel must also have expertise in fiber splicing. Customer service and installation staff must be versed in computer hardware and software. Installing cable modems at subscriber homes involves knowing how to install PC peripherals, dealing with a wide variety of customers and their computers, and being able to recognize user hardware and software which may or may not be compatible with the components to be installed. Procedures must in place to escalate problems to regional or national staff or to vendor support in the event that these issues cannot be resolved by system staff.

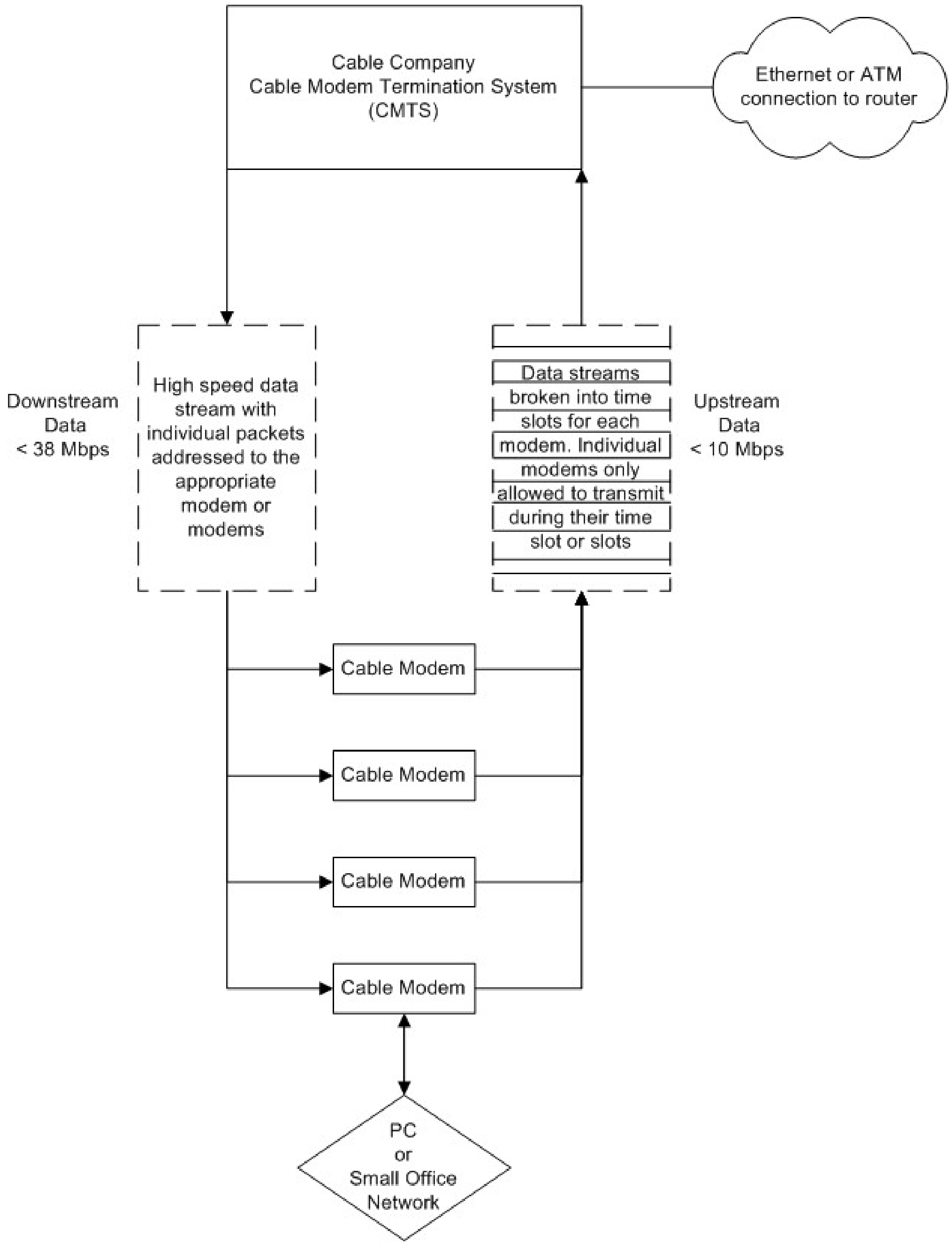
Operation of a Cable Modem Network

Cable modem network operation is comparable to Ethernet packet data networks, where many users utilize a shared medium. The modem is connected to the network by either the subscriber or an installer. Once on the network, the modem communicates with a cable modem termination system (CMTS), a device that sets the power level of the transmissions and assigns the modem one or more time slots for upstream transmission. All downstream data is sent out in one shared stream, with each modem reading only authorized information addressed to it. Upstream data is arranged into slots, where each modem "speaks" during its assigned time slots.[50] Business or high-end customers may receive more time slots or higher priority.

Cable modem transmission is illustrated in Figure D-3.

[50] "DOCSIS Cable Modem Technology." David Fellow and Doug Jones, *IEEE Magazine*, March 2001.

Figure D-3: Cable Modem Transmission



Digital video and phone services are offered on separate channels. As telephone technologies become integrated with Internet Protocol (IP), voice and video will be capable of being combined into the same channels as cable modem data. The same headend equipment, probably a CMTS, would serve as the headend interface device for all services.

The CMTS also interfaces RF cable plant with the cable operator's Ethernet or ATM packet data network. As is illustrated in Figure D-2, a router connects the CMTS to the

Internet backbone, to an associated ISP, or to servers for mail, the web, news, and chat. Various local servers may also connect to the router at the headend for caching of frequently viewed web sites. Other content sources include video servers for video-on-demand that handle subscriber requests for access to scheduled programs.

DOCSIS: Evolving Cable Modem Standards

The dominant industry standards that govern data transfers on cable networks are known as Data Over Cable Service Interface Specification (DOCSIS). DOCSIS was developed by the Multimedia Cable Network System, a coalition of the predominant members of the cable industry. DOCSIS 1.0 was originally prototyped in 1997 and approved by the International Telecommunication Union (ITU) in 1998.[51] The DOCSIS 1.0 specification supports downstream data rates from 27 Mbps to 36 Mbps and upstream rates from 320 kbps to 10Mbps.[52] Most operational cable modem systems in the United States are DOCSIS 1.0 compliant.

More than 30 vendors currently produce DOCSIS-1.0-compliant cable modem products. CableLabs, the research institute of the cable industry, certifies compliance with DOCSIS. In 1999, CableLabs, issued a new set of specifications known as DOCSIS 1.1. The new standards defined new functionality and enabled cable operators to provide guaranteed bandwidth or Quality of Service (QoS), for cable modem users. Key enhancements of DOCSIS 1.1 include QoS and packet fragmentation capabilities. DOCSIS 1.1 provides the bandwidth and latency guarantees for toll-quality voice, dedicated business-class data services, and multimedia applications across a shared cable modem access network. Under DOCSIS 1.1 tiered services can be more reliably delivered and modem-addressing is made less complicated.[53]

DOCSIS 1.1 is currently only in trial use. Full adoption of DOCSIS 1.1 involves a number of necessary steps, including: 1) development by cable companies of improved CMTS data transportation schemes; 2) fulfillment by ISPs of 1.1 specifications; and 3) efforts by cable modem vendors to produce products that will work with a DOCSIS 1.1 system.

Caching

An ISP may cache (store locally) the information that subscribers request from the Internet. Content caching may improve network performance. When a user on the network visits a web site, the web server downloads the site from the Internet and sends it to the user's cable modem and also saves a copy of the site in a cache. As the cache space fills up, the oldest site files on the disk are cleared as the newest files are saved. If a user requests a site while it is cached at the headend, the server can download the site

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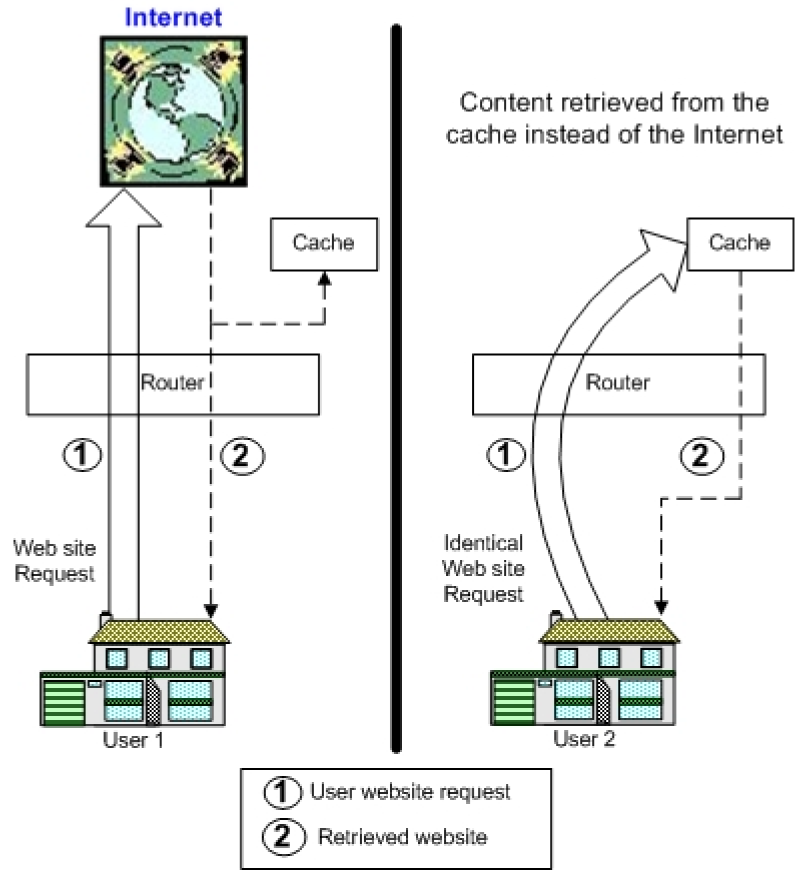
[51] "Cable Modem Standards and Specifications," http://cabledatacomnews.com/cmic/cmic3.html.
[52] "Key MCNS DOCSIS Technical Specs," http://www.cabledatacomnews.com/cmic/cmic3b.html.
[53] "DOCSIS 1.1 Sounds All-Aboard SIGNAL," Craig Kuhl, *Communications & Engineering Design*, October 2001, http://www.cedmagazine.com/ced/2001/1001/id1.htm.

directly from the cache to the user instead of using the Internet to access the web site again.

Multiple caches can be linked together to form cache hierarchies as well. If a site is not currently saved on a particular cache, the web server can try to retrieve the site from a cache at a regional ISP operations center, which is still faster than downloading from the Internet. This results in a faster download for the user and reduced traffic on the network.

Figure D-4 illustrates one use of caching. In this illustration, User 1 requests a site that is not currently cached, and the site is downloaded to the server cache as well as to the User. When User 2 requests the same site, it is obtained from the cache, eliminating the steps of going through the Internet to find and retrieve the site.

Figure D-4: Site Caching



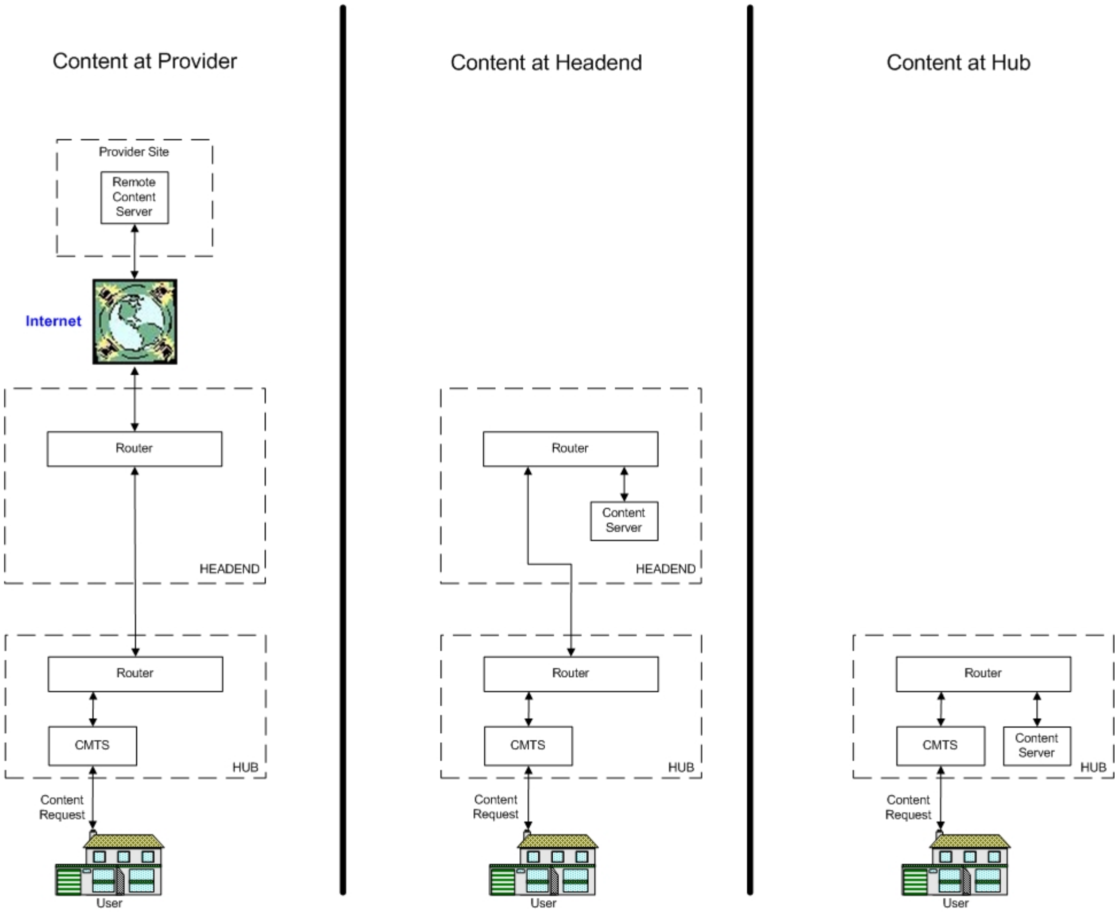
Locating Content Locally

Guaranteeing high quality video-on-demand and interactive services may require more extensive data and processing capability at the headend or regional network operations center (NOC) rather than a the facilities of the Internet content provider. In this scenario, content providers such as Intertainer.com, who supply live and stored video and interactive games, station their content sources and processing power at local headends or regional NOCs.

As with site caching, distributing and moving data closer to the subscriber can increase file access speed and reduce bandwidth consumption on the Internet backbone. A content server at the headend can deliver programming to users faster and more reliably than a remote content server across the public Internet. Delivering content from headend servers also reduces Internet traffic and network congestion.

A network of smaller servers throughout the Internet also increases redundancy and allows different geographic areas to have customized video availability. Three different content server placement scenarios are illustrated in Figure D-5.

Figure D-5: Locating Content Locally



II. Advantages and Limitations of HFC Architecture

The use of fiber optic cable in HFC systems provides a significant number of advantages over all-coaxial branch and tree systems. These improvements include:

- Fiber backbone with greater capacity than coaxial trunk cables.
- Ability to segment neighborhoods based on nodes, increasing available capacity for each subscriber.
- Reduction in active components, decreasing noise.
- Higher reliability and more cost effective maintenance.
- Fiber replacing much of the coaxial cables plant, reducing susceptibility to unwanted electromagnetic interference.

HFC systems have the potential to offer high-speed Internet service with hundreds of times the upload speed of conventional phone line services. In practice, properly operating cable modem networks operate about three times as fast as telephone services in the upstream direction and twenty-six times as fast in the downstream direction.[54] HFC capitalizes on the fact that the cable pipe is the largest bandwidth pipe into most residences and that cable architecture can be modified in a cost-effective manner to deliver packet-based data networking to customers. Effectively, all of the customers on a cable modem network are on one Ethernet-based local area network, as if they were in the same office building or campus. This is a great advantage for delivering fast download speeds to customers. Video-on-demand, subscription video-on-demand, and telephone services can also be offered over HFC networks.

HFC systems also offer significant reliability, as well as capability to monitor problems and outages, such that customer complaints are not the sole form of status monitoring, as they are in branch and tree systems. As the Internet becomes a more critical part of economic and emergency infrastructure, that reliability becomes crucial. Customers rely on the telephone infrastructure for critical services and will increasingly demand the same reliability from cable modem infrastructure for Internet and telephone services.

Significantly, HFC systems are capable of offering open access, as is described in detail below. AT&T is currently offering ISP choice on a trial basis on its HFC system in Boulder, Colorado. AT&T is reportedly planning to offer open access statewide in Massachusetts in 2002.[55]

The shared HFC architecture also creates limitations for the network. For example, security concerns necessitate that packets on the network be encrypted or scrambled to protect the information of subscribers sharing a segment. The architecture also does not offer a ready-made solution to offer a range of service levels to different customers. Finally, the network architecture makes it more difficult to separate the provider of the physical architecture from the provider of the Internet connection and Internet services, relative to a physical architecture where each user has a dedicated physical connection from a home or business to the ISP's routers. All of these challenges have solutions that are being tested and implemented in the cable industry.

Another limitation of the HFC architecture is that extensive additional fiber construction and terminal equipment are required to scale HFC systems for significantly greater bandwidth per customer. There exists a hard capacity limit per node area. The limitation is imposed by the need for data services to go through HFC-based router equipment in the cable headend. In all existing and planned cable modem systems, the hardware limits each network segment to 40 or less Mbps capacity. In order to increase the capacity available to a subscriber, the cable operator must segment its system to progressively smaller node areas. Even at maximum segmentation, HFC will have a hard limit of 40 Mbps per user. This is in contrast to fiber optic technologies, that transport hundreds of thousands of Mbps, and that can be easily scaled to higher speed as technology advances

[54] AT&T Broadband Welcome Letter, http://help.broadband.att.com/faqprintable.jsp?name=downstream_rate_management.

[55] "A Tale of Two Trials," Leslie Ellis, *Communications & Engineering Design*, May 2001, http://cedmagazine.com/ced/2001/0501/05d/htm.

by changing the equipment at the ends of the fiber and leaving the cable plant itself unchanged.

HFC-based equipment is also more specialized than equipment for fiber optic communications and is thus manufactured by fewer companies. This affords the cable operator less flexibility than an ISP using telephone or carrier facilities.

Appendix E: Technical Description of Fiber-to-the-Curb Architecture

The third category of systems, known as fiber-to-the-curb (FTTC), continues the trend of deploying fiber deep into the network. As nodes are segmented into smaller areas, the number of users on a node decreases and available bandwidth and system redundancy increase. In a variation of FTTC architecture, "fiber-to-the-home" (FTTH) systems deploy fiber all the way into residences. As of the current writing, there exist only a few FTTC systems in the United States, and the cable industry has not announced plans to upgrade most systems to this level.

The following section describes a network infrastructure that combines the physical architecture of existing FTTC systems, which has been deployed in a few communities, with an advanced headend and hub concept that incorporates existing, tried technologies, although it has not been deployed. This architecture represents the next generation of cable network construction because of its flexibility in providing either cable-based or fiber-based services, its capability to directly connect multiple service providers to subscribers, its operational robustness, and its almost unlimited capacity per subscriber. For these same reasons, this architecture serves as the basis for the model public interest architecture described in the body of the Report.

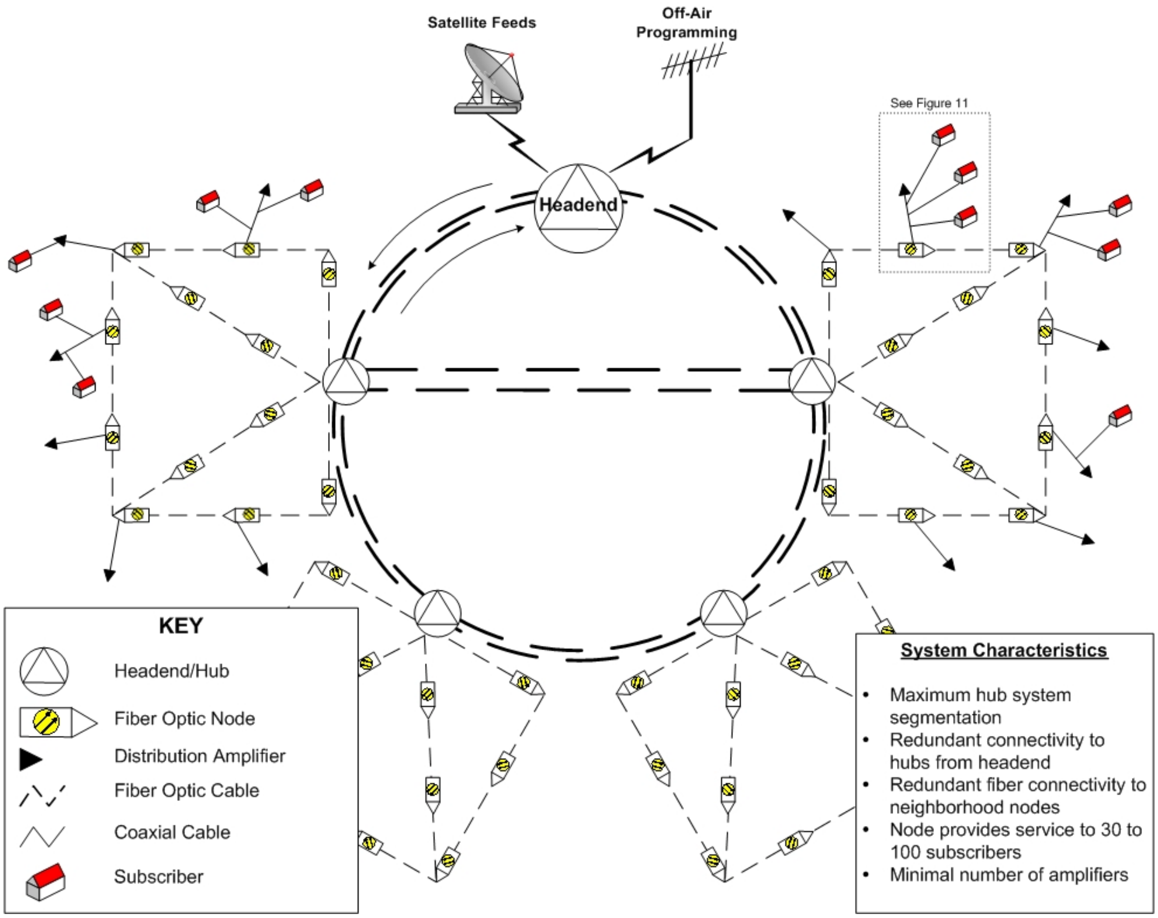
I. Technical Description of FTTC Architecture

FTTC systems can provide more advanced high-speed interactive services than do HFC systems. An FTTC system can simultaneously offer interactive television, video-on-demand, and higher capacity data and Internet access. The deployment of fiber optics deep into neighborhoods enables the provider to offer all of the applications possible in HFC systems, and to operate with increased reliability and redundancy.

FTTC architecture is characterized by headends and hubs interconnected with fiber in multiple rings. In addition, fiber rings extend to neighborhood nodes, with 10 to 150 homes per node. The fiber follows city and neighborhood streets past residences, with more than one transmission path to the headend or hub for each node. Redundant transmission paths ensure that loss of an interconnection cable at one location will not create a single point of failure. Although this discussion is specific to cable networks, FTTC principles are also applicable to a carrier who provides its services over twisted-pair telephone lines.

FTTC architecture is illustrated in Figure E-1.

Figure E-1: Fiber-to-the-Curb Architecture



As envisioned here, FTTC systems have sufficient capacity to offer individual subscribers a choice between, on the one hand, cable-modem based services for the home and small office, and, on the other hand, premium carrier-grade direct fiber optic services. Additional fiber optics enable a residential or business subscriber to obtain fiber optic connection at relatively low installation charge, providing the option of receiving higher speed symmetrical services on pipeline unmanaged by the cable operator. This is an attractive option for a user who requires high capacity. It may also be desirable for a customer who cannot send information through a shared cable modem system because of specialized applications, security needs, or a need to connect directly to a specific network.

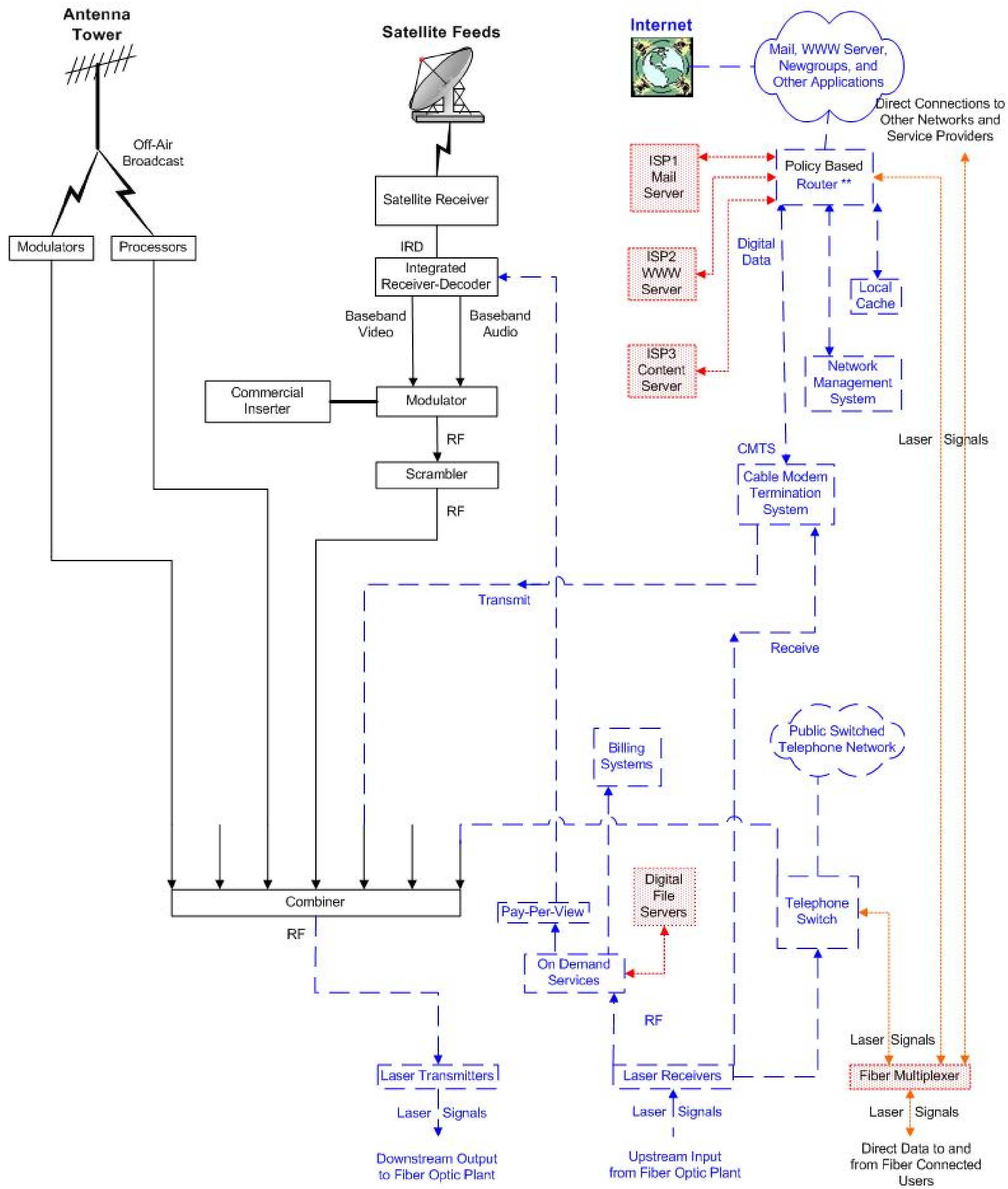
In addition to the equipment included in HFC headends, FTTC systems may include digital file servers for video-on-demand and interactive television services for video-on-demand subscribers. As more advanced and lifeline services are introduced on the system, more system monitoring equipment may need to be installed in the headend and in the physical plant.

Users desiring Gigabit Ethernet or other premium high-speed service will connect via fiber directly into the headend or hub router or SONET multiplexer, bypassing the CMTS equipment. This can be accomplished by offering direct fiber users a managed service in which they connect to cable company routers, or by offering users opportunity to connect to other service providers in a co-location area in the headend or hub.

Figure E-2 illustrates an FTTC headend or network operations center. FTTC headends include:

- SONET-based fiber multiplexer equipment for telephony and fiber customers.
- Packet switches and routers between customers and the Internet.
- Status monitoring of signal parameters and operation of field equipment.
- Remote monitoring of equipment, HVAC, and intrusion at hub sites.
- Cache servers.
- Co-location of facilities for multiple service providers.
- Servers for interactive television, video-on-demand, subscription video-on-demand, and web content (potentially multiple competing providers in the co-location area).
- Back-office infrastructure for subscriber and service provider provisioning and billing.
- Multiple survivable Tier 1 connections to the Internet from multiple providers.
- Staffing for 24 hours per day and seven days per week.

Figure E-2: Fiber-to-the-Curb Headend*



* Dotted lines and shaded boxes indicate components and services not present in an HFC system.

The few companies currently using FTTC include:

- 21st Century Communications (now RCN) in Skokie, Illinois.
- Bell South in Atlanta.
- Qwest Choice TV in Phoenix, Omaha, and Boulder.

The City of Palo Alto has a small, one-year, FTTH trial underway.[56] An FTTH system is planned in Grant County, Washington by the local Public Utility District. Reportedly,

> When completed in 2005, the Zipp [Grand County] network will contain some 50,000 miles of fiber in its effort to reach 40,000 homes, businesses, and farms throughout Grant County. To date, the network passes about 7,000 homes with approximately 2,000 customers "lit" and receiving services.[57]

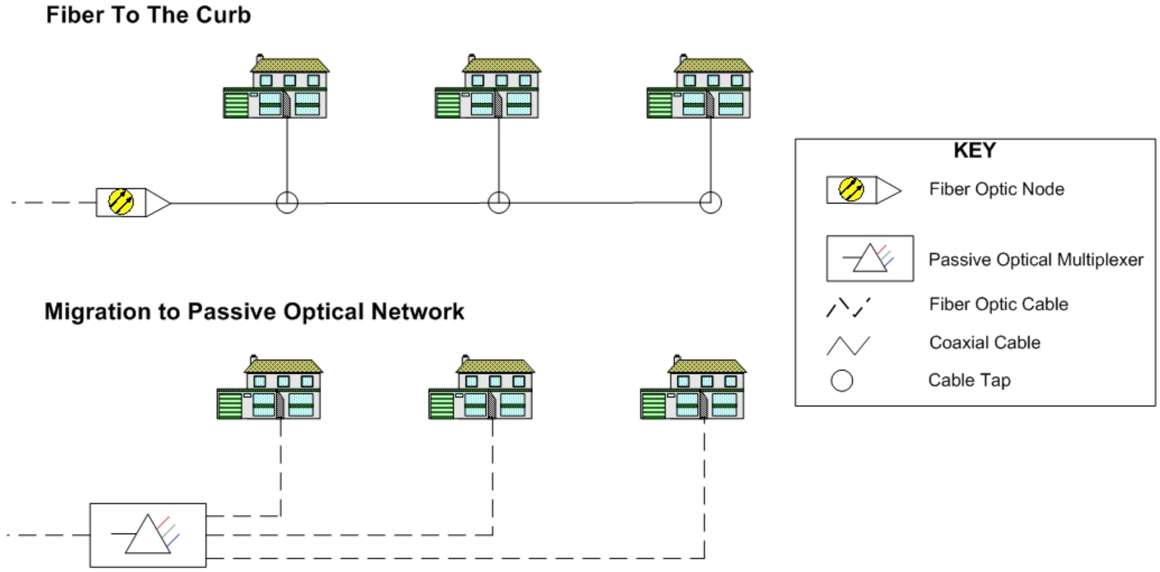
II. Advantages of FTTC Architecture

Once constructed, FTTC architecture more economically facilitates the construction of fiber directly to those subscribers who request additional bandwidth, such as businesses and residents who run home businesses, telecommute, or are early adopters of new technology. With the ability to connect individual users with dedicated fiber optics, capacity is almost unlimited. Reliability is increased by replacement of active electronic components and coaxial cables by temperature and RF resistant fiber optic networks. In addition, the subscribers are able to connect via a range of services, including 10/100/1000 Mbps Ethernet, ATM, and dedicated fiber optics known as “dark fiber.”

Scalability is high with FTTC because of the high density of fibers and coverage of nodes. The system can be upgraded, in its entirety or by neighborhood, to a fully fiber-optic passive optical network (PON) by: 1) constructing fiber to users’ homes, and 2) installing multiplexers at node locations, as shown in Figure E-3. Migration of FTTC to PON would not only eliminate the active components, but would also increase system scalability with almost unlimited capacity available to each home.

[56] Robert Pease, “Gauging the Future of FTTH,” Lightwave, November 2001.
[57] Robert Pease, “Rural Washington county pioneers optical broadband services,” Lightwave, February 2002.

Figure E-3: Migration from Fiber-to-the-Curb to Passive Optical Network
(from Figure E-1)



This model should be of interest to new cable operators and operators constructing networks in new developments, campuses, and apartment buildings because an FTTC system may be the optimal choice when building a new network. Its advantages include the following:

- Fiber optic cable costs approximately the same per-mile as coaxial cable.
- Either fiber optic or cheaper coaxial-based equipment can be used.
- The system addresses the limitations of HFC technology.

Appendix F: Summary Comparison of Three Types of Architecture

	Branch and Tree	**Hybrid Fiber/Coaxial**	**Fiber-to-the-Curb**
Capacity	330-550 MHz (45-80 TV channels)	750-860 MHz (80 analog TV channels, hundreds of digital video, music channels)	Same as HFC; effectively unlimited for direct fiber subscribers
	one-way	two-way	two-way
Typical phone capability per customer	None	1-2 phone lines*	Same as HFC; effectively unlimited for direct fiber subscribers
Typical data capacity per customer	None	128 kbps upstream, 1-2 Mbps downstream	Same as HFC; with option for direct fiber with 1000+ Mbps data, both ways
Digital TV capability	Yes	Yes	Yes
Number of active components in series	Up to 40 amplifiers	Up to 8 amplifiers	Up to 2 amplifiers; Direct fiber subscribers have no active components in outdoor cable plant
Backup power	At headend	At headend, hubs, and power supplies**	At headend, hubs, and power supplies**
Video-On-Demand capability	No	Yes***	Yes***
Redundant Architecture	• None	• Between headends and hubs	• Between headend and hubs • For all fiber in system

* Depends on powering and degree of redundancy in network

** Depending on architecture, subscribers receiving telephone service may have backup power at subscriber premises

*** Depending on capability of servers at headend or hub and the number of simultaneous users of the service