Open Access to Cable Data Networks

Emy Tseng
Sharon Eisner Gillett

Introduction

The networks that are generically referred to as "cable" today began their lives with a particular purpose: the distribution of television signals within a community. Given this history, cable networks have always operated under a regulatory regime separate from telephone networks'. Telephone systems are regulated as common carriers: telephone network services must be made available to all potential customers in a non-discriminatory fashion. Cable networks, in contrast, are not subject to the requirements of common carriage: cable system operators are under no legal obligation to make their networks available to anyone who wants to use them to distribute content (for example, a new television channel), and have in fact historically exhibited a high degree of vertical integration between conduit (cable networks) and content (TV channels).

As ever more cable systems gain the capability to connect their subscribers to the Internet, this reality has sparked an intense legal wrangling and debate over the issue that is referred to as "open access."[1] Should cable systems with the capability to transmit data be required to allow any service provider to access customers through the cable network? Or is the current industry structure—in which service providers can only gain direct access to a cable system if they succeed in negotiating an agreement with the cable operator—a more appropriate way forward?

Proponents of open access point to the benefits that accrue to consumers[2], such as low prices and rapid innovation, from the current high degree of competition among

Internet Service Providers (ISPs).[3] Common carriage is viewed as having directly contributed to this competitive intensity: because ISPs were able to use the public telephone network to provide Internet access to consumers, without asking permission of the phone companies, many did so. Therefore, the argument goes, the transition to broadband Internet access will be marked by a significant reduction in (if not the death of) the competitive intensity of the ISP industry. Consumers will prefer broadband, and broadband cable networks will provide access to only one ISP, unlike the many ISPs accessible through the telephone network (whether dialup or DSL). The darkest cloud looming on the horizon in this view of the future is the fear that a monopolistic ISP would use its market power to manipulate content availability, thereby prejudicing what people can see, hear and read on the Internet.

Proponents of the status quo point to the chilling effect that common carriage would have on network investment.[4] Upgrading cable systems to provide broadband data transmission requires large investments. If network operators either cannot reap the benefits of these investments, or must share the returns with unaffiliated ISPs, they are less likely to make them. By this argument, the imposition of open access would slow or stop progress toward universal availability of broadband.

Fence-sitters argue that although common carriage is a good idea in theory, imposing it on existing vertically-integrated cable networks is another matter entirely.[5] In this view, the argument is not about whether ISPs can sell services to cable customers (they're all connected through the Internet, after all), but at what price. Imposing open access, so this story goes, is really a way of imposing price regulation, and therefore likely to cause more harm than simply letting market forces take their course–even if some of the markets are not as competitive as one might like.

Most of the debate about open access to date is hampered by the lack of a clear picture of how open access might actually be accomplished in practice. If, for example, there really were no reasonable technical way of achieving open access (as some in the cable industry have argued[6]), then the theoretical arguments in favor of open access would be largely irrelevant. Similarly, how is one to evaluate the claim that regulation would do more harm than good without some idea of which aspects of the problem might require regulation?

The aim of this chapter is to fill this gap. Rather than taking a stand on whether open access is right or wrong, we answer the questions of how it can be achieved, what costs it imposes on cable network operators, and what issues it raises for the relationships between cable network operators and the companies who want to provide services over their networks.

What is Open Access?

What exactly is meant by open access? Table 1 provides a non-exhaustive list of different forms of open access, depending on what layer of the networking protocol stack is to be "opened" to service providers other than the cable operator and its affiliated broadband ISP.[7]

Table 1: Open Access Alternatives

Layer	*Potential Methods*
Application	Gateway (customer chooses portal)
Network and/or data link	Tunneling; Routing based on source address
Physical	Spectrum unbundling; Separate facilities

A simplistic form of open access is provided at the application layer when customers are able to configure their Internet applications to use the service providers of their choice. For example, a customer on a broadband cable network may use Web-based email that is provided by a company (such as Yahoo) that is unaffiliated with the cable ISP. Or she may configure an email client to retrieve mail from an account with an ISP other than the cable operator's (for example, the ISP and email address she used before having the option of subscribing to broadband). Similarly, she may configure her Web browser to visit AOL's member web site by default, so that it looks (almost) as if AOL is her ISP.

Of course, in these last two examples, the customer must have an account with another ISP or with AOL, for which she pays separately. Paying twice is generally considered unacceptable, both to the consumer and to the second service provider. Furthermore, service providers prefer not to have the public Internet in between their facilities and their subscribers, because of the loss of control this currently involves over the quality of service, and correspondingly the potential for future services, delivered to the subscriber. This chapter does not consider application-level methods of providing open access any further.

Open access at the physical layer is similarly straightforward to understand, yet impractical to implement. The ultimate open access would be achieved if each ISP reached customers over its own facilities – a nightmare scenario, however, for those poor municipal employees charged with keeping streets from being dug up once a day. Somewhat more realistic is the notion of spectrum (also called frequency) unbundling, in which separate channels of the cable network are set aside for each ISP delivering service over the network. Spectrum unbundling has the virtue of extreme simplicity – each ISP has its own separate sandbox to play in, as it were – but it cannot realistically be supported in the cable networks that currently exist, mainly because upstream spectrum is extremely scarce in these systems. Dividing this spectrum in fixed ways, such that spectrum is devoted to a particular ISP whether they are carrying any traffic at that moment or not, is impractically inefficient. However, spectrum unbundling should not be ruled out as a mechanism for future networks with more generous up and downstream spectrum allocations.

In practice, most open access trials currently underway use mechanisms that operate at the network and/or data link layers. The most commonly used mechanisms are tunneling and source address-based routing, which we explain in detail below. These mechanisms operate almost completely transparently to users. They do, however, force users to take some kind of action to select their ISP, in contrast to current cable modem services in which the ISP choice is bundled into the service provided by the cable operator, and the user need not log in to use the network. The user's action may be as simple and static as a one-time sign-up, comparable to what DSL users currently do when they select which ISP's DSL service to purchase. Or it may be something more dynamic such as a login screen, presented to users each time they reboot their PC, or whenever they wish to change service providers.[8]

Open Access Cable Architecture

Both tunneling and source address-based routing build on top of existing cable data networks, converting them from the closed (i.e. single, affiliated ISP) architecture pictured in Figure 1, to the open (i.e. multiple ISP) architecture pictured in Figure 2.

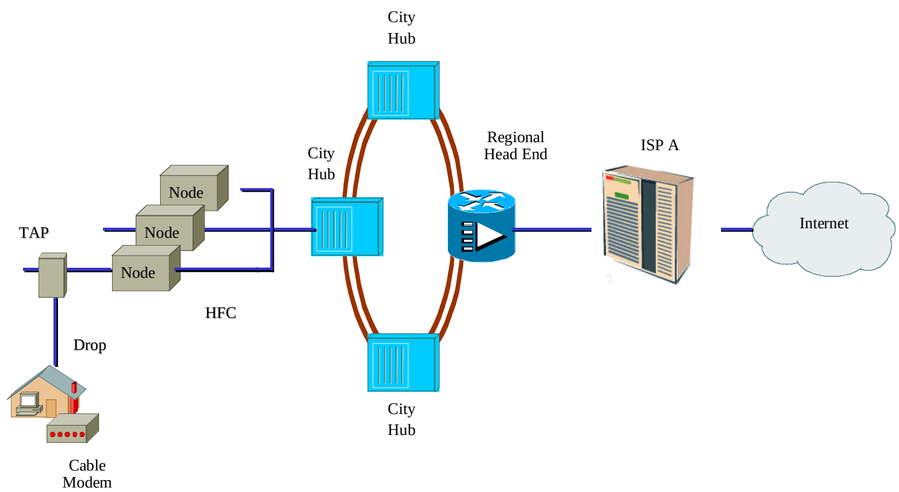

Figure 1. Closed Access Cable Data Network Architecture

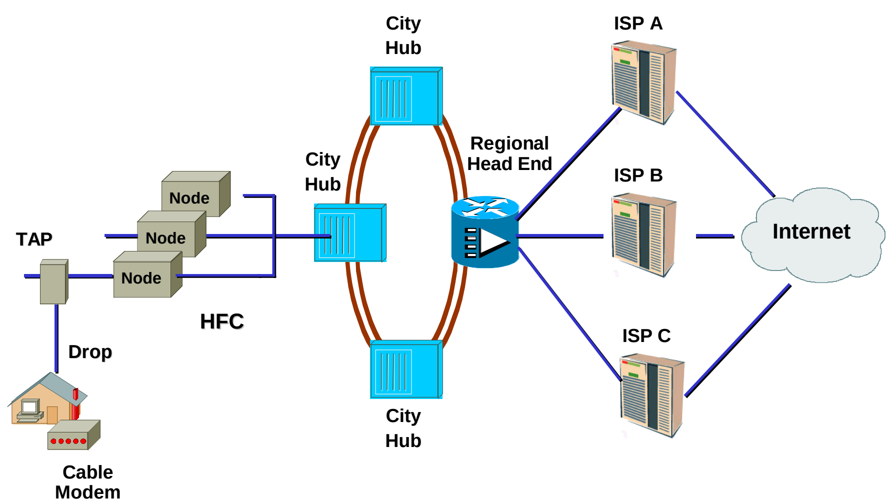

Figure 2. Open Access Cable Data Network Architecture

Both the closed and open architectures have in common the network elements on the left side of Figures 1 and 2, from the cable subscriber to the regional head end. Because this portion of the network is under the control of the cable operator, we refer to it as the cable data network. It includes cable modems connected to PCs in subscribers' homes; coaxial cable connecting modems to neighborhood nodes; and fiber optic cables connecting neighborhood nodes to city hubs and city hubs to each other and the regional head end.[9] To get a sense of the scale of such networks, consider that a neighborhood node typically serves 500-1,000 homes, of whom 50-500 might subscribe to cable modem service; a city hub (also known as a local head end) serves anywhere from 20,000-100,000 homes;[10] and a regional head end serves anywhere from 150,000 to 1,000,000 homes.[11]

The cable data network may be either bridged or routed, a choice that affects the implementation of open access (explained in more detail below). In a bridged network, equipment called bridges in the city hubs connect different network segments together into one single logical network, sharing all packets among the different network segments. Because this scheme does not scale very well, most cable data networks today are use routers instead of bridges. The cable data network is divided into sub-networks, and the routers deliver traffic only where it needs to go, conserving bandwidth. Most cable data networks are routed networks.

City hubs contain cable modem termination systems (CMTS) that provide, in effect, the other end of the connection that begins with the modem in the subscriber's home. Unlike DSL and dial-up modem connections, the CMTS creates a shared Ethernet-style local area network, rather than a dedicated, point-to-point link. Open access could be implemented by allowing multiple ISPs to access each CMTS. In practice, however, the point of multiple access is usually positioned at the regional head end, as shown in Figure 2. This approach is consistent with the interconnection of the closed access ISP to the cable data networks at the regional head end (Figure 1), and therefore a simpler extension of existing practice. Equally important, it is a more cost-effective approach, because the regional head end serves so many more users than each CMTS.

The open access architecture pictured in Figure 2 only works if the cable data network knows how to route traffic properly to and from subscribers of multiple ISPs. This requirement creates numerous challenges. For example, traffic coming from subscribers must be routed to their selected ISP's network. Normally, traffic is routed based on the shortest path to its final destination. Open access therefore requires something other than the destination address to indicate that the designated ISP's network should be part of the path. Traffic traveling toward subscribers may also pose a problem, since the subscriber's Internet Protocol address may appear foreign to the cable data network.

Source address based routing (source routing, for short) and tunneling are two technical approaches to dealing with these issues. Source routing works by making subscribers part of the cable data network—in other words, assigning the subscriber's Internet Protocol (IP) address from the pool associated with the cable data network—and modifying the routers within that network to treat these subscribers specially. Tunneling, in contrast, uses the ISP's address pool to identify subscribers, and hides the resulting foreign address from the cable data network. The following sections explain these two approaches in more detail.

Source Address Based Routing

Ordinarily, traffic is routed based on the shortest path to a destination address. Policy routing is a mechanism for routing packets based on criteria other than the shortest path, such as source address, data type, current network traffic level, traffic type (e.g. interactive versus batch), etc.[12] Many commercial router products currently support policy routing. Network operators usually use these policies to manage network traffic and quality of service. With source routing, a policy is used to route traffic based on the source address of the data packet in addition to the destination address. In order to implement source routing, all of the cable data network's routers need to be capable of policy routing.

In an open access implementation, source routing uses the source IP address of the subscriber's data packets to route traffic to a specific ISP. Each subscriber's IP address is associated with the subscriber's chosen ISP. The cable data network routers' routing tables are updated with an entry associating the subscriber's IP address with a path to the designated ISP's network. The routers then use the IP address to route traffic from the subscriber through to their ISP.

The cable data network assigns and administers the IP addresses for subscribers on behalf of all the ISPs.[13] The cable data network's address space is divided into different pools, each pool dedicated to a specific ISP. The subscriber's PC gets assigned an IP address from the pool of IP addresses associated with the chosen ISP. Since the subscriber's IP address is part of the cable network's address space, traffic bound to the subscriber is handled normally.

The cost to implement open access using source routing depends on the number of routers that need to be upgraded to support policy routing. This number varies widely based on the existing configuration of a cable data network. The cost could be nothing if all the routers support policy routing, or the cost of an upgrade (software and/or hardware) to existing routers.

Tunneling

Technology

Figure 3 illustrates how tunneling is used for open access. Conceptually, each ISP operates a router at the regional head end that directs traffic between the rest of the ISP's network (including the rest of the Internet) and the cable data network subscribers who have selected that ISP. Traffic travels between the subscriber and her selected ISP inside of a so-called tunnel—technology that wraps the traffic with address information local to the cable data network, so that the ISP's "foreign" address information is hidden while the traffic is in transit through the cable data network..

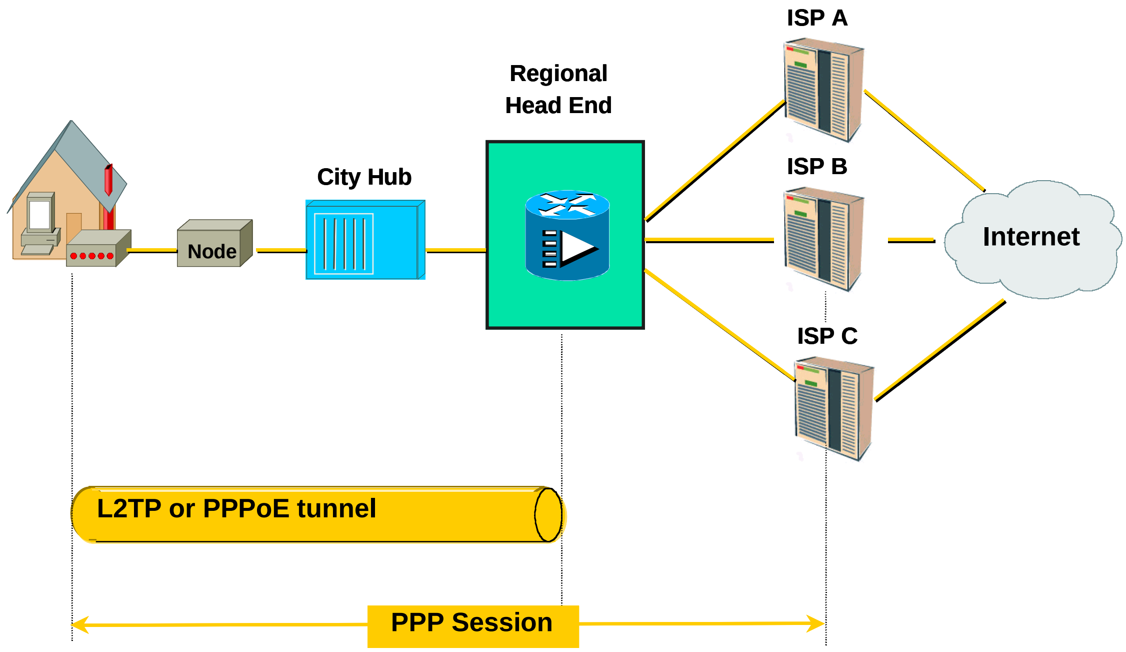

Figure 3: Tunneling Architecture

In practice, a separate physical router for each ISP is not needed at the regional head end. Instead, a device known as an access concentrator can be installed by the cable operator. Access concentrators can be thought of as *uber* routers in that they support the functions of multiple physical routers within a single piece of equipment.[14] They also implement the technology needed to support tunneling.

Multiple commercial access concentrators are currently available.[15] These devices have been more commonly used in DSL deployments than in cable data networks. Because DSL networks have been required from the outset to support multiple ISPs, the ability of access concentrators to support multiple virtual routers has been more essential to DSL deployments. However, the technology is applicable to both kinds of networks, and some access concentrators have the capability to handle DSL, cable modem and dialup Internet access traffic within a single system.

Access concentrators support a range of functions and features, many of which are driven by requirements other than open access. One such requirement is subscriber management: the ability to track which services each subscriber has signed up for, measure usage and other information needed for billing, automate service plan changes, etc. Another popular driver is Virtual Private Networking (VPN), i.e. supporting the ability of subscribers to connect through the public Internet to a corporate intranet in a secure fashion, as if they were connecting from within the intranet. Tunneling is used to support VPN, and as a result can also be applied to the open access problem.

A tunnel is created by client software on the subscriber's PC when it establishes a Point-to-Point Protocol (PPP) session, or virtual dedicated connection, between the subscriber and the specified ISP. To the subscriber, tunneling looks much like dialup (absent the noisy modem tones and the long waits), because PPP is the same protocol used to establish connections to the Internet over dialup access links.[16]

PPP sessions are supported by one of two lower-level tunneling protocols, depending on whether the cable data network is bridged or routed. If it is bridged, then PPP over Ethernet (PPPoE) is used to enable PPP to traverse a Layer 3/Ethernet network.[17] PPPoE encapsulates PPP frames within a PPPoE packet that contains an Ethernet header. Since PPPoE is a layer 2 protocol, the subscriber PC is known only by the MAC (i.e. layer 2) address within the cable network. Outside the cable network, the PC is known by the global IP address. The ISP assigns the global IP address for the subscriber PC.

If the cable data network is routed, then the Layer 2 Tunneling Protocol (L2TP) is used to provide a dedicated connection (a L2TP tunnel) over which the PPP session is established.[18] L2TP encapsulates an IP packet within another IP packet, implementing a double IP layer. When L2TP is used, the subscriber PC is assigned two IP addresses: one that is locally valid and used within the cable data network, and another that is globally valid and used when packets traverse the rest of the Internet.

With L2TP tunneling, it is also possible to establish a tunnel directly between a subscriber's PC and a server at the selected ISP. In this architecture, no access concentrator is needed at the regional head end, at least for the purpose of supporting open access.[19] Cable data network operators are less likely to prefer this architecture, however, because of the lack of visibility it gives them into the traffic carried on their network.[20]

Cost

The cost to implement open access using tunneling depends on a number of factors, including whether the cable data network is bridged (i.e. uses PPPoE) or routed (i.e. uses L2TP) and how many tunnels need to be open simultaneously. This section explains a simple model that was constructed to get a sense of the capital cost per cable modem subscriber that must be incurred by the cable operator to support tunnel-based open access.

This model only considers the incremental capital costs of upgrading an existing cable data network to support open access. Cable infrastructure upgrades, such as the installation of a hybrid fiber-coax network and two-way capability, are assumed to have already been made by the cable operator and are therefore outside the scope of the model. The cost of physical connectivity from ISPs' networks to the regional head end is also excluded from the model because it is assumed to be the responsibility of the ISPs.[21]

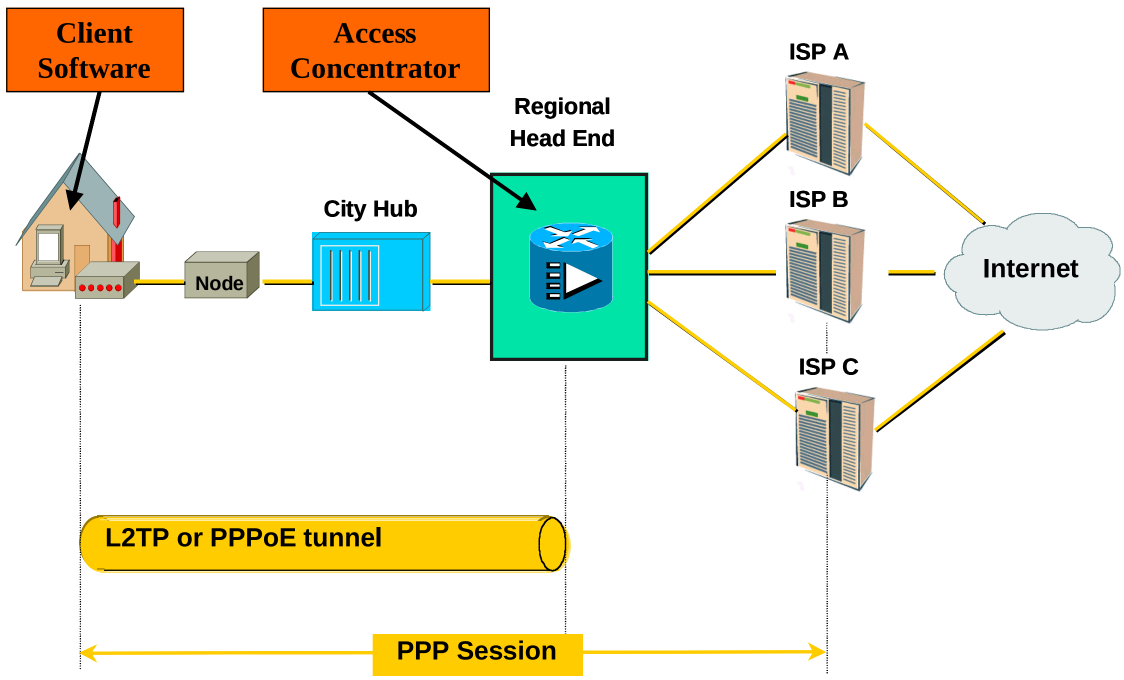

Figure 4: Equipment needed for tunneling

As Figure 4 illustrates, tunneling requires the cable operator to install one or more access concentrators in the regional head end as well as client tunneling software on subscriber PCs. The incremental capital cost of open access therefore consists of the cost per subscriber of these two elements.

- **Client Tunneling Software Cost**

PPPoE and L2TP client software is available from several vendors.[22] If the subscriber were to purchase this software herself, it would cost on the order of $20-40 per license.[23] In that case, there would be no cost to the cable operator. However, a more likely scenario is that the cable opeator buys licenses and provides the client software to subscribers. In that scenario, client software licenses can be purchased in bulk at $1 per subscriber.[24] The model therefore uses $1 for this cost.

- **Access Concentrator Equipment Cost**

The cost of an access concentrator depends on how many simultaneous client connections it supports. Because tunneling adds virtual connections to what would otherwise be a connectionless architecture, it introduces a cost element to cable data networks that scales with the number of simultaneous users, not just the amount of traffic they send. Tunneling, in other words, makes the economics of cable modem networks a little more like DSL networks.

The number of client connections supported by access concentrators varies depending on the vendor and model. A cable data network operator's total costs for access concentrators will depend on detailed purchase patterns over time—whether they choose to overprovision the network up front, or make incremental upgrades to the network as they add subscribers. To simplify the analysis, the model represents access concentrator equipment costs in terms of the average cost per client connection.

This average cost ranges from $20-$70 per L2TP connection and $2.00-$8.75 per PPPoE connection.[25] The variation arises from economies of scale (the more connections are supported, the less each one costs). Because these ranges are not very large, the model simplifies the analysis even further by taking the midpoint of observed data points within these ranges, resulting in average costs of $45 per L2TP client connection and $6 per PPPoE client connection.[26] These prices reflect volume discounts to the cable operator of twenty to thirty percent.

Because not all subscribers will necessarily be connected simultaneously, computing the cost of the access concentrator per subscriber requires scaling the cost per client connection down by the fraction of subscribers connected at any given moment.

The model uses a relatively large default value of eighty percent for this "percent of client connections online" parameter, with sensitivity tested in the range from 40-100 percent.[27] Intuitively, the high default value is justified by two assumptions:

- Many subscribers will simply leave their connections open whenever their PCs are on, whether or not they are actively using the network, because of the "always on" nature of the cable data network (and the lack of any financial penalty for remaining connected); and
- With the increasing adoption of home networks, more home PCs will remain on all the time, and therefore always connected.

Table 2: Cost of Tunneling

Tunneling Method	*Incremental Capital Cost per Subscriber*
L2TP (Routed networks)	$37
PPPoE (Bridged networks)	$6

Scaling the access concentrator cost to a per-subscriber figure and adding the cost of the client software results in the total per-subscriber costs shown in Table 2. As this table illustrates, the resulting incremental costs per subscriber are quite modest. Even assuming all connections are left online all the time, as illustrated by the sensitivity analysis shown in Figure 5, the maximum cost per subscriber is only $46.

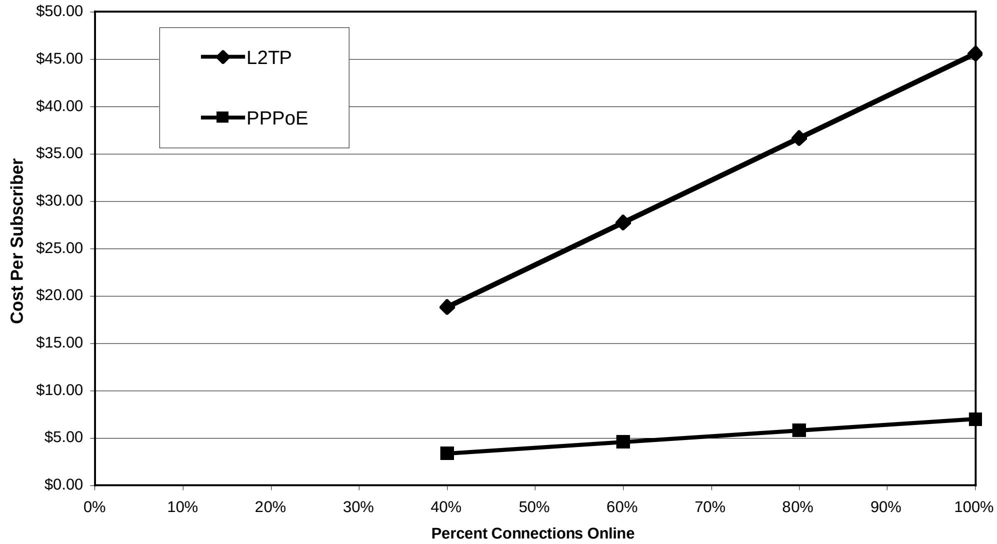

Figure 5. Sensitivity Analysis on Percent of Connections Online

Recall that these are capital costs, i.e. they are incurred once per subscriber, not once per month or year. At less than $50 per subscriber, open access is unlikely to impose a significant financial burden on a cable data network operator. This result suggests either that open access is financially trivial to implement, or that the costs it imposes are not adequately captured in capital terms. In other words, the real costs of open access may not lie in equipment purchases, but in the changes it requires to ongoing operations.

Conclusions

Open access to cable, meaning the sharing of one physical cable data network by multiple Internet service providers, is technically feasible and can be implemented in several different ways. The most promising approach is to interconnect the different ISPs to the cable data network at the regional head end, and support this configuration with commercially available technologies such as source routing or tunneling (PPP plus PPPoE or L2TP).

The incremental capital costs of implementing open access in this way are quite modest. Tunneling, for example, incurs a one-time cost of only $46 per cable modem subscriber under the model's most conservative assumptions. Under a different (but still reasonable) set of assumptions, namely, that cable data network operators are installing policy routers and/or access concentrators anyway for other reasons, open access incurs essentially zero incremental capital cost.

This finding does not mean that open access is trivial and imposes no costs on cable data networks. Rather, it means that the issues and costs involved in supporting open access arise from sources other than equipment purchases. Although the following discussion identifies operational costs associated with open access,[28] quantifying such costs remains an area for further research.

Coordination of IP address management is one source of operational costs. Cable data network operators must already coordinate with their affiliated ISPs to manage the assignment of IP addresses to subscribers. Open access intensifies both the magnitude and the nature of this problem: cable operators need to coordinate with more ISPs, and the relationships are likely to be less cooperative because these ISPs will not be organizational affiliates.

Similarly, open access requires the cable data network operator to share aspects of customer care and network management with non-affiliated ISPs. When new subscribers are added, or existing ones experience problems or make changes to their service, information must be properly communicated among several unaffiliated companies. If subscribers are not to be driven to distraction (or to the competition, where it exists) by finger pointing and long waits to resolve service problems, cable data network operators and the multiple, unaffiliated ISPs who interconnect with them will have to develop effective procedures for joint resolution of problems. Development of the necessary coordination processes, and the human relationships that support them, will take time and impose operational costs on all of the companies involved.

Because open access is a form of interconnection among IP networks, issues that have proved troublesome in the context of Internet interconnection will crop up in the open access context as well. These issues include how one network can guarantee and/or differentiate service quality to another (the so-called Quality of Service, or QoS, problem), and the direction and magnitude of payment flows among interconnecting networks.

QoS problems arise because the interconnecting ISPs share the resources of the cable data network. The cable operator must ensure that one ISP's users do not hog all the cable bandwidth, crowding out the users of other ISPs. Ensuring fairness will be especially important when the cable data network operates an affiliated ISP, because there will be a natural tendency for unaffiliated ISPs to suspect (if not claim to a judge) that the affiliated ISP receives preferred service at their expense.

Any scheme for fair resource allocation in the cable data network will have to be complemented by monitoring tools accessible to all of the parties. It will also have to be rich enough to support evolving Internet applications with different network service requirements, such as telephony, streaming video, or videoconferencing.

Although many technologies have been developed to differentiate and guarantee service quality (for example, diffserv and intserv), meaningful open access requires not just the existence of these technologies but also their cooperative adoption across network and organizational boundaries. Without transparent mechanisms that will enable ISPs and cable data network operators to write, monitor, and enforce performance contracts, open access is more likely to produce lawsuits than satisfied customers and industry partners.

As a form of interconnection, open access also raises questions about the direction and magnitude of payment flows between ISPs and cable data network operators. Disagreements over this issue have derailed several industry attempts to achieve open access through negotiation among the parties instead of regulatory fiat. ISPs see themselves as providing the services that make the Internet worth using in the first place. Cable operators see themselves as having invested to provide the fat pipe that makes the experience pleasant. Naturally, each party believes that its role is the more essential and therefore that it should own the relationship with the subscriber and receive the larger cut of her payment.

If the negotiating parties had similar levels of market power, these differences in perspective would undoubtedly have been reconciled long ago. The persistence of the open access policy debate is not surprising when one considers that most cable data network operators enjoy a monopoly position in their local market, while most ISPs face intense competition. Market-based agreements are more likely to arise in areas where the playing field is more level, i.e. communities where facilities-based broadband competition is emerging.[29] Of course, these are the same communities in which open access to cable is the least important, because ISPs can reach subscribers through other broadband options besides cable.

This analysis suggests that open access is unlikely to arise from market forces alone. It also suggests that the fence-sitters have a point: the real issue is the price of interconnection between cable data networks and ISPs. Regulation of that price is better accomplished by the market than by the government, if the market is not monopolistic (i.e. it has more than one broadband-capable last-mile network in it). Policies to encourage more last mile networks, then, are the best open access policies of all.

Acknowledgments

The authors gratefully acknowledge the financial and intellectual support of the industrial partners of the MIT Internet & Telecoms Convergence Consortium, listed at http://itel.mit.edu. Thanks also to Hao Chen, who gathered equipment cost data, and Kamal Latham, who developed the cost model.

References

Abe, George. 2000. *Residential Broadband*. 2nd Ed. Indianapolis: Cisco Press.

At Home Corporation. 1999. "The Technical Shortcomings of the GTE 'Open Access' Trial." <http://www.home.net/source/techdetails.html>.

At Home Corporation. 1999. "The Truth About Broadband Cable Modem Services." Excite@Home report. <http://www.home.net/source/thetruth.html>.

Bar, François, Cohen, Stephen et al. 1999. "Defending the Internet Revolution in the Broadband Era: Why Open Policy Has Been Essential, Why Reversing That Policy Will Be Risky," E-conomy™ Working Paper 12, Berkeley, August 1999.

Berresford, John W. 1999. "Access to Cable TV Systems Offering Broadband Service in the United States." *IEEE Communications*. October, 1999:114-16.

CCTA. 1998. "Technical Report on Alternative Methods of Providing Access For Internet Service Providers." CCTA Submission to CRTC In Response to Telecom Public Notice 98-9.

Cisco Systems, Inc. 2000. "Cisco 6400 Series Universal Access Concentrator." Product description. <http://www.cisco.com.>.

City of Los Angeles Information Technology Agency. 1999. "Broadband Access Report: Recommendations on a Policy and Implementation Plan for Open, Nondiscriminatory Access to Cable Architecture by Internet Access Providers."

Downes, Thomas A, and Shane M. Greenstein. 1998. "Do Commercial ISPs Provide Universal Access?" in Sharon E. Gillett and Ingo Vogelsang. editors. *Competition, Regulation, and Convergence*. Mahwah, NJ: Lawrence Erlbaum Associates.

Gillett, Sharon E. 1995. "Connecting Homes to the Internet: An Engineering Cost Model of Cable vs. ISDN." MIT Laboratory for Computer Science. Technical Report 654.

Huitema, Christian. 2000. *Routing in the Internet*. 2nd edition. Upper Saddle River: Prentice Hall PTR.

Lathen, Deborah A. 1999. "Broadband Today: A Staff Report to William E. Kennard, Chairman, Federal Communications Commission, On Industry Monitoring

Sessions Convened By Cable Services Bureau", October.
<http://www.fcc.gov/Bureaus/Cable/Reports /broadbandtoday.pdf>

Laubach, Mark. 2000. "Technical Considerations for CATV Open Access." <http://www.isp-planet.com/politics/wh_index.html>

Lemley, Mark and Lawrence Lessig. 2000. "The End of End to End: Preserving the Architecture of the Internet in the Broadband Era." Paper presented at the 28th Annual Telecommunications Policy Research Conference, Arlington VA, September, 2000.

Mamakos, L. et al. 1999. "A Method for Transmitting PPP Over Ethernet (PPPoE)." Internet Engineering Task Force RFC 2516.

Nortel Networks, Inc. 1999. "Broadband Service Node: Secure Cable & Wholesale Access." Shasta IP Services White Paper. <http://www.nortelnetworks.com/shasta>.

Nortel Networks, Inc. 1999. "Shasta 5000 Broadband Service Node". Product description. <http://www.nortelnetworks.com/shasta>.

NTS, Inc. 1999. "Subscriber PPPoE Client" and "VPN Client Software" Product descriptions. <http://www.nts.com>.

O'Donnell, Shawn. 2000. "Broadband architectures, ISP Business Plans and Open Access." Paper presented at the 28th Annual Telecommunications Policy Research Conference, Arlington VA, September, 2000.

Redback Networks, Inc. 2000. "Considerations for Large Scale IP Subscriber and Service Management". White paper. <http://www.redback.com>.

Redback Networks, Inc. 2000. “Subscriber Management System 10000”. Product description. <http://www.redback.com>.

RiverDelta Networks, Inc. 2000. “Eliminating Open Access Technology Barriers”. White paper. <http://www.riverdelta.com>.

RiverDelta Networks, Inc. 2000. “Broadband Services Router 64000”. Product description. <http://www.riverdelta.com>.

Sanford C. Bernstein & Co, Inc. and McKinsey & Company, Inc. 2000. “Broadband! A Joint Industry Study.”

Shea, Richard. 2000. *L2TP Implementation and Operation.* Reading, Massachusetts: Addison Wesley.

Simpson, W. 1993. “The Point to Point Protocol (PPP).” Internet Engineering Task Force RFC 1548.

Speta, James. 2000. “Handicapping the Race for the Last Mile?: A Critique of Open Access Rules for Broadband Platforms.” *Yale Journal on Regulation* 17:39-91.

Townsley, W. et. al. 1999. “Layer Two Tunneling Protocol ‘L2TP’.” Internet Engineering Task Force RFC 2661.

Tseng, Emy, Kamal Latham, Armand Ciccerelli, Hao Chen. 2000. “Open Access Cable Network: Technical Feasibility and Cost.” Course paper prepared for STP-308, John F. Kennedy School of Government, Harvard University, Cambridge, MA.

Wind River Systems, Inc. 1999. “WinVPN Client” and “WinPoET” Product descriptions. <http://www.windriver.com>.

[1] See (Berresford 1999).

[2] See (Bar, Cohen et. al. 1999).

[3] See (Downes and Greenstein 1998).

[4] See (Speta 2000).

[5] See (Lathen 1999).

[6] See (At Home Corporation 2000) for technical arguments against open access.

[7] See (City of Los Angeles Information Technology Agency 1999 and Laubach 2000) for more information about open access alternatives.

[8] For example, a user might choose to use El Cheapo ISP's service for reading email, but switch to El Premium ISP when she wants to make Internet-based phone calls or watch streaming video. Login screen settings can often be stored so that the burden on users is minimal.

[9] See (Gillett 1995) and (Abe 2000) for more detail on the hybrid fiber-coax (HFC) architecture and how it is used to provide data transmission.

[10] This value is based on the maximum scenario of peak usage data in (Sanford C. Bernstein & Co. 2000, p. 41).

[11] These values are based on data from Time Warner and AT&T, as related by Daniel Fryxell of Carnegie Mellon University.

[12] See (Huitema 2000) for more information about policy routing.

[13] The cable operator needs to coordinate the allocation of the address space with the ISPs.

[14] Access concentrators are also known as ISP managers, subscriber management systems, or broadband access nodes.

[15] The following access concentrator products were considered for this research: Redback Networks, Inc. Subscriber Management Systems, Cisco Systems, Inc. 6400 Access Concentrator, Nortel Networks, Inc. Shasta 5000 Broadband Service Node and RiverDelta Networks, Inc. Broadband Services Router 64000. See (Cisco Systems, Inc. 2000, Nortel Networks, Inc.1999, Redback Networks, Inc. 2000, and RiverDelta Networks, Inc. 2000) for product information.

[16] See (Simpson 1993) for more information about PPP.

[17] See (Mamakos 1999) for more information about PPPoE.

[18] See (Shea 2000) and (Townsley 1999) for more information about L2TP.

[19] ISPs would still be required to interconnect to the cable data network, i.e. install a router at the regional head end.

[20] This concern was raised in (CCTA 2000, p. 3.)

[21] This cost includes not just line charges but also the line termination equipment (connection cards) installed in the access concentrator.

[22] Vendors include RouterWare/WindRiver and NTS. These products are often resold by router vendors such as Redback. See (NTS, Inc. 1999, Wind River Systems, Inc. 1999) for product information.

[23] See (NTS, Inc. 1999) for pricing information.

[24] Personal communication, Redback sales representative. In fact, this cost may be zero in some cases because newer operating systems (such as Windows 2000) already include support for L2TP.

[25] These costs are derived from data provided by Redback and Cisco sales representatives. The endpoints of the ranges are determined by realistic regional head end configurations and subscriber penetration rates. Regional head ends are assumed to serve from 150,000 – 1,000,000 households. Cable modem penetration rates are assumed to vary from 6.4 percent (approximate average U.S. penetration rate in fall 2000) to 40 percent (penetration rate of Portland, Maine).

[26] Redback sales representatives and Dr. L. Alberto Campos of GTE Laboratories suggest that the costs per L2TP client are currently much higher than costs per PPPoE client because of the relative immaturity of the L2TP implementations. This disparity can therefore be expected to narrow over time.

[27] Based on maximum scenario of peak usage data in (Sanford C. Bernstein & Co., 2000).

[28] See (O'Donnell 2000) for further discussion about coordinating operations among different ISPs.

[29] Such competition may take the form of DSL services, broadband wireless, new fiber network buildouts, etc.