Telcordia Technologies

Performance from Experience

Economics of Internet Offload and Voice / Data Integration

A Telcordia Technologies Perspective by Dr. James Gordon and Dr. Amir Atai

Abstract: The telecommunications industry is entering an exciting and challenging period. The traditional circuit-switched telephone network is proving increasingly inadequate to deal with the demands being placed on it. In the core of the network, new technology has reduced packet switch prices well below circuit switch prices. This is pressuring traditional network operators to upgrade their networks, and has also created a new class of packet-based network operators. Meanwhile, at the edge of the network, new services such as internet access and electronic commerce are stimulating subscriber demand for high speed data access.

Between the core of the network and its edge lies some critical territory: the local copper loop. In spite of new access technologies (wireless, cable, etc), copper loop will be the means by which most subscribers access the network for some time. Consequently, the challenge for established network operators is to find efficient ways of deploying data technology and services, while working within the constraints imposed by existing copper loops. This paper explores the costs associated with a number of internet offload architectures. These are combined voice / data network architectures, which allow dialup internet traffic to be re-directed off the telephone network and onto data networks for more cost-effective transport. Offload architectures are of interest not only because they can substantially reduce the cost of transporting internet traffic, but also because they are an initial step towards internet telephony and more extensive voice / data integration.

1. Introduction

For participants in the telecommunications market, these last few years leading up to the millennium could be characterized in Charles Dickens' immortal words as the 'best of times and the worst of times' [1]. Just as the industrial revolution created social and technological upheaval in nineteenth century England, providing rich material for Dickens' novels, the present revolution in telecommunications has upset the best laid plans of both carriers and equipment providers, creating enormous opportunities for some and the potential for failures, mergers, losses and buyouts for others.

The rapid growth of data traffic — most notably internet traffic, but also intranet, work at home (WAH), and small office / home office (SOHO) traffic — first became apparent three years' ago, at which time there was general press coverage of congestion on LEC (local exchange carrier) networks, and other internet-related problems. At that time, it was easy to dismiss dialup internet traffic as simply another challenge, that would be dealt with in due course, allowing business to return to normal.

However, data traffic has continued to grow rapidly, to the point where it will soon overtake traditional voice and fax traffic on many carriers' networks. And it is now generally recognized that the telecommunications industry is in the early stages of a large-scale transition from the traditional circuit-switched voice paradigm to a new packet-switched data paradigm. As noted in [3], 'the center of mass in the telecommunications industry is shifting away from traditional voice technology to data networking. High speed public data networks are needed to support a range of advanced telecommunications and information services that will become available in the near future, including commerce over the web, multimedia applications, and internet telephony.'

In two earlier papers, the authors described some of the problems caused by internet traffic on the Public Switched Telephone Network (PSTN), and documented current thinking on internet 'offload' architectures [2,3]. The term 'offload architecture' refers to a combined voice / data network architecture, that allows dialup internet data traffic to be re-directed off the PSTN and onto data networks for more cost-effective transport. We recognize that the term 'offload' suggests the somewhat narrow, short-term aim of 'helping' the PSTN. *In fact, it is important to realize that offload architectures being proposed by the industry are merely the first step towards more advanced architectures that will achieve true voice / data integration.*

This paper continues the theme of the previous two white papers by exploring some of the issues surrounding internet offload and voice / data integration. It discusses some general trends in network evolution, and analyzes the motivations of various industry players for deploying data services such as internet telephony and xDSL. Its main focus, however, is on the economic benefits of data offload. Having reached a point where the technical alternatives for internet offload are generally understood, carriers will presumably base their architecture / deployment decisions on the economic pros and cons of the various solutions. This paper summarizes some of Telcordia's analysis and conclusions regarding the business case for internet offload architectures.

2. Network Evolution

There are at least two fundamental changes occurring in the telecommunications world, both of which represent transitions from one generation of technology to the next. First, there is a transition from analog subscriber line access to digital access. The PSTN has experienced this type of transition in the past. In its early days the PSTN was completely analog. With the advent of digital electronics, trunks in the backbone transmission network were first converted to digital technology, followed by tandem switches, and then access switches.[1] The final stage in this progression of digital technology from the core of the network outward is the conversion of the local loop from analog to digital.

This conversion has started to occur with the rollout of new technologies such as cable modems, LMDS and xDSL. For new entrants to the local access market (i.e., competitive LECs or CLECs), cable modems and LMDS represent an opportunity to by-pass the ILEC (incumbent LEC) networks, and reach out to customers with new high speed access technologies. If they choose to do so, CLECs have the luxury of building digital access networks from scratch (e.g., LMDS networks). However, they are then faced with developing an operations support systems (OSSs) infrastructure to manage the new technology.

To remain competitive, ILECs have the option of deploying ADSL or some other xDSL variant, or of buying into the new technologies themselves (e.g., cable modems). Because of their embedded base of equipment, the adoption of xDSL will necessarily be a gradual one for ILECs, and is unlikely to provide any 'shortcut' to digital access. Regardless of how this competition plays out, deployment of digital access will require substantial investment on the part of both ILECs and CLECs.[2]

The second fundamental change in the network is the move from circuit-based voice-only service to packet-based voice and data services. Packet-based services are deployed on packet-switched technology and protocols (e.g., Frame Relay, ATM, TCP/IP), rather than traditional circuit-switched technology. They include basic data transport as well as advanced data services.

Basic data transport is attractive because of the low cost of data switches relative to voice switches.[3] This type of service simply provides a data (e.g., TCP/IP) pipe through the network, without necessarily supporting any higher layer applications. Where digital access service is available, data transport is provided by default (to give subscribers access to data applications outside the LEC network). However, data transport can also be provided without digital access. For example, a LEC can terminate dialup data calls at remote access servers (RASs) within its network, and then transport calls from the RASs to external service providers (e.g., internet service providers (ISPs)) via a data network. This is precisely the scenario being considered for internet offload architectures.

In future, value-added advanced data services will be offered in conjunction with basic data transport. Advanced services could include, for instance, web site hosting, email, security access / firewalls, teleconferencing, fax over IP (FoIP) and voice over IP (VoIP). To offer these services a carrier will need to provide more sophisticated network switching and signaling capabilities than for simple data transport. For example, the carrier will need to support application servers (e.g., email hosts, databases) and data signaling nodes (e.g., VoIP gateways between the IP and SS7 networks). Currently, ISPs provide some of these advanced services (e.g., web site hosting, firewalls) though they are limited to services which require signaling only on the data side of the PSTN / data interface (e.g., RADIUS). Future services will in general require more sophisticated signaling, based on PSTN / data signaling gateways.

3. Industry Players and Economic Drivers

How fast will the above changes occur? How quickly will the PSTN be converted from analog to digital access? And when will high-speed data services be generally available to residential subscribers? These questions are difficult, because the answers depend on many variables, including technical issues, economics, demand for new services, competition between carriers and between suppliers, and regulatory constraints. However, as a starting point for discussion we offer the following brief analysis.

Figure 1 shows the key industry players relevant to this discussion. Incumbent LECs are the established access

[1] There are still analog (e.g., crossbar) switches in service in the public network.

[2] Note that CLECs could also gain access to the ILECs' xDSL equipment via unbundling of the local loop.

[3] The term 'switch' is used here in a generic sense to include routers, IP switches, tag switches, etc.

providers, who 'own' the copper loop and local exchange switches. Competitive LECs are competitors to the ILECs in the local exchange market. CLECs are typically not as well-established as ILECs, and may simply be resellers of ILEC access. Alternatively, CLECs may attempt to by-pass the ILECs by building their own access networks, using cable modems, LMDS, etc. IXCs include traditional inter-exchange carriers, new entrants to the long distance market, and companies in the business of building alternative (e.g., IP) transport networks. Internet service providers (ISPs) range from small (companies providing service within a local geographical region (ISP2)) to large (companies with national networks (ISP1)). Smaller ISPs may require direct connections to only a few ILEC or CLEC switches. Larger ISPs typically try to minimize their facilities by back-hauling traffic across IXC networks to a few centralized locations.

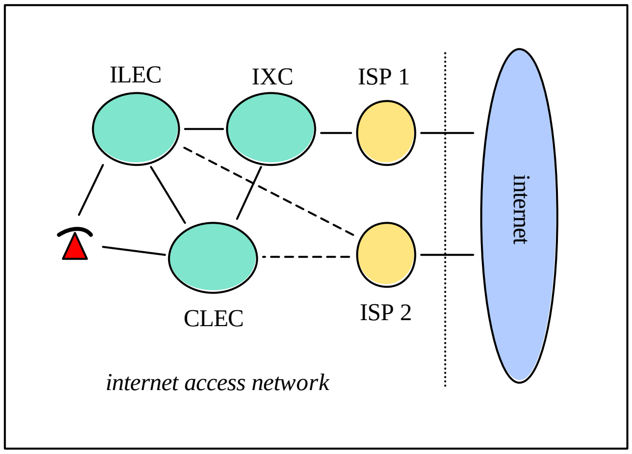

Figure 1: Internet Access Network

The distinctions in Figure 1 are sometimes blurred. While regulatory constraints can prevent ILECs from operating as ISPs (except through separate subsidiaries), the same restriction may not apply to CLECs. Consequently, the CLEC and ISP in Figure 1 could be the same company. This combination could position the CLEC well to offer not only data transport, but also future advanced data services. In a similar vein, we note that some ILECs have applied for regulatory approval to set up 'long distance' data networks. If this arrangement is approved, the ILEC and IXC in Figure 1 would become one company. This would put the ILEC in an improved position to offer data transport, and possibly other data services.

Before discussing each of these industry players in more detail, it is useful to consider the main economic drivers behind the rollout of data access, basic data transport, and advanced data services:

1. *The high cost of carrying data traffic on the PSTN.* As noted in earlier studies [2,4,5,6], long holding time data calls create problems for the PSTN, principally because the PSTN was never designed to economically carry this type of traffic. Traditional circuit-based resources (switches and trunks) in the PSTN are an inappropriate technology for carrying dialup data calls. The practical impact of this is that ILECs are losing money by carrying internet traffic (see below for quantification of this effect). This provides a strong reason for the ILECs to get into the business of data offload (i.e., basic data transport). Note that this is a 'negative' reason. The issue for ILECs is cost avoidance, rather than the creation of any new services or revenues.

2. *The low cost of data switching equipment.* With the advent of wave division multiplexing (WDM) technology, the transmission capacity of optical fiber has risen by one or two orders of magnitude. This means that the cost of transmission capacity for both voice and data networks (measured in kilobits per second (KBPS) or megabits per second (MBPS)) has dropped dramatically, leaving switching as the major component of overall transport costs. However, on a per-MBPS basis, the cost of data switches is at least an order of magnitude less than voice switch costs. For example, in rough terms a DS-0 voice trunk termination (64 KBPS) on a telephone exchange costs around $300. This works out to about $4000 per MBPS of switching capacity. At an assumed price of $6000 for a DS-3 port (45 MBPS), the price of data switches is around $130 per MBPS. The data to voice cost ratio could therefore be on the order of 1/30, and this ratio is likely to decrease as the cost of data switching equipment continues to drop. The low cost of data switches therefore provides a major incentive for the establishment of data-based (e.g., IP) networks. [4]

3. *Customer demand for data services.* The continued growth of the internet and electronic commerce bear witness to customer and business demand for data services. Existing services such as internet access and web site hosting will soon be supplemented by more advanced services such as VoIP. While there is certainly demand for data services, the critical questions are: How large is the demand? What is customers' willingness to pay for these services? And what technological advances are needed to stimulate that demand and grow a major industry? Clearly, VoIP can

[4] The costs in this paragraph are intended to be approximate figures representative of current industry costs. The direct comparison of voice and data switches may not be entirely fair, since voice switches tend to incorporate many capabilities and features that are not (yet) implemented in data switches. However, the basic point is inescapable: data switches cost significantly less than voice switches.

be successfully sold without the need for residential data access. However, other advanced services (e.g., video telephony, teleconferencing) will probably not be viable until high speed data access becomes generally available at affordable rates. The strength of demand or momentum behind data services is difficult to quantify at present, though it could become a powerful economic driver in the future.

4. Implications of Reciprocal Compensation

At the present time one could possibly add a fourth economic driver to the above list: reciprocal compensation. 'Reciprocal compensation' refers to a general class of agreement, whereby a LEC that transports or terminates a local call that originated with another carrier, can receive compensation or payment from the originating carrier. For example, reciprocal compensation agreements specify the amount that an ILEC must pay a CLEC for terminating the ILEC's calls (and vice versa). A key observation is that reciprocal compensation agreements apply only to calls which are deemed to be local, according to the Telecommunications Act of 1996 (TA96). Compensation for the transport of inter-state / long distance calls is handled via a different framework. In most cases, reciprocal compensation payments are based on the aggregate minutes of use (MOU) that flow between the adjacent networks.

Reciprocal compensation agreements have become unpopular with some ILECs for the following reason. It is possible for a CLEC to transport internet access calls from an ILEC to an ISP (e.g., from the ILEC to ISP2 in Figure 1). In this case the CLEC will obtain reciprocal compensation payment from the ILEC for the internet MOU flowing from the ILEC into the ISP. (Subject to on-going legal action, internet access calls are deemed to be local calls and therefore subject to reciprocal compensation.) Note, however, that there is negligible traffic in the other direction, since virtually all internet calls terminate at the ISP. Consequently, the flow of money is all from the ILEC to the CLEC. By attracting ISPs through very competitive rates, it is possible for CLECs to derive substantial payments in this way, to the point where CLECs may be able to build a business case around this type of middleman 'service'.

Is this situation, is reciprocal compensation fair to ILECs? Or, more importantly, is it fair to the ILEC's customers, since they may ultimately bear the cost through increased rates? ILECs might argue that, in its above form, reciprocal compensation adds insult to injury. Not only must they expend considerable sums on PSTN infrastructure in order to support internet traffic, for little additional revenue. (Most customers access ISPs via flat-rate calling plans that generate no additional revenue for internet calls.) But they are also forced to pay CLECs compensation for a 'token' transport service, that involves comparatively little investment in transport or switching equipment, and chiefly exploits the ILECs' access network and customer base.

However, a priori there is no reason why a CLEC should not perform this service, providing it meets a real market need and is economically viable. A key question is whether the reciprocal compensation paid to CLECs constitutes fair and reasonable compensation for their equipment and operational costs. If it is not, reciprocal compensation is subsidizing a service that might otherwise be uneconomical, and the ILECs have a case for attempting to change the system. If it is, one can hardly blame the CLECs for offering the service, and the problem becomes one solely for the ILECs. In the latter case, ILECs are once again faced with the issue of how to generate some new revenue to cover their internet-related costs, given that they are generally committed to flat-rate service for residential customers (i.e., no usage based tariffs), and that they are also legally prohibited from imposing access charges on ISPs.

As a final comment on reciprocal compensation, we note the following alternative philosophical position. One can take the view that the current system is not broken, it is simply being mis-applied. Regardless of the details, ILECs' current difficulties with reciprocal compensation can be seen as a symptom of carrying data traffic on a voice network, which is an inappropriate use of voice technology. Certainly, ILECs cannot be blamed for failing (along with pretty much everyone else) to predict the rapid growth in internet traffic and the World Wide Web (WWW). Nevertheless, in a commercial world that operates according to 'survival of the fittest' and Darwin's Theory of Evolution, reciprocal compensation provides strong motivation for ILECs to move internet traffic off the PSTN and onto data networks.

In this view, reciprocal compensation becomes another instance of the high cost of carrying data traffic on the PSTN (economic driver #1 above), rather than a breakdown of the existing rules and regulations pertaining to the voice network. And the ILECs' current difficulties with reciprocal compensation can be dealt with most constructively by developing data networks and working towards voice / data integration, rather than by changing the voice network (and its regulations) to suit the needs of data services. We note that regulatory bodies will play an important role in promoting data networks and services, partly through the development of new regulations and guidelines for data networks, and partly through their decisions to modify (or not modify, as the case may be) existing regulations for the voice network.

5. Outlook for Data Services

Based on the above material, the positions of ILECs, CLECs and ISPs with regard to internet offload may be summarized as follows. For ILECs, the most immediate reason for internet offload is to avoid the costs associated with carrying dialup internet traffic on the PSTN. This is particularly true if one considers reciprocal compensation to be an internet-related PSTN expense. However, while ILECs are motivated by a short term need to implement some form of internet offload, they are also facing long term competition from new carriers who are building lower cost networks based on next generation technology (e.g., IP switches), or who are attempting to attract customers with advanced services (e.g., cable modems).

The ILECs' response to these pressures is a balancing act between short term cost avoidance and long term strategy. As discussed in Section 5, an ILEC may be able to significantly reduce the impact of dialup internet traffic on the PSTN, simply by rearranging PSTN network elements to more efficiently carry internet calls. For example, substantial cost savings can be achieved through the use of so-called 'PRI hubs'. However, this type of data-less offload strategy is unlikely to provide a smooth migration path to future data services. The ILECs would perhaps be better served by an integrated strategy, which combines some form of modem-based offload (e.g., deployment of RASs within the network), with xDSL for high-end customers. This latter type of strategy will not only achieve cost avoidance through internet offload, but will also position the ILEC to take advantage of low cost data transport, and offer future data-based services such as VoIP. And, importantly, it will allow the ILEC to remain competitive with CLECs.

In contrast to ILECs, CLECs are not motivated by cost avoidance. In fact, some CLECs benefit by carrying internet traffic on their networks through reciprocal compensation, and so it is in their interest to retain this traffic where possible. CLECs are under at least two competitive pressures. First, some of the larger ISPs would like to move their modems closer to subscribers, in order to reduce long distance backhaul charges. ILECs can help them do this by locating ISP modems in ILEC end offices, which incidentally provides the ILECs with the dual advantage of internet offload. Because of their larger networks, ILECs have more flexibility in where to locate modems, and can therefore use this type of modem relocation service to attract ISPs away from the CLECs. For their part, CLECs have the freedom to aggregate dialup traffic across LATA boundaries, which means that in some situations they can provide ISPs with an overall lower cost solution.

A second competitive pressure is for the CLECs to keep pace with ILECs' deployment of new technology such as xDSL. Currently, xDSL tariffs are high enough to discourage rapid deployment, so there is little pressure for CLECs to offer xDSL on a widespread basis. However, if ILECs decide to offer xDSL at a significantly lower cost, e.g., as part of an integrated internet offload strategy, the deployment of xDSL could accelerate. Then, if they wish to stay competitive in the data access / services market, CLECs would need to follow suit. When investing in new data equipment, CLECs are presumably on much the same footing as ILECs. They can no longer, for example, exploit the cost differential between new equipment and an older embedded base of ILEC PSTN equipment. In order to remain competitive, CLECs will therefore need to develop efficient methods of offering data access to subscribers e.g., by means of a by-pass solution such as cable modems, or by gaining access to ILEC xDSL equipment at competitive rates through network unbundling. Alternatively, CLECs could make their data access services more attractive, by bundling them with ISP services.

The outlook for ISPs is based on the expectation that the internet will continue to grow, and will become a mainstream tool for business and information exchange. It follows that ISPs are likely to evolve over time from simple modem managers to more sophisticated providers of services such as web site hosting, video conferencing, information retrieval, etc. In fact, a number of larger ISPs no longer see modem management as an integral part of their business, and may in fact be prepared to hand off this role to other service providers (e.g., ILECs, CLECs or IXCs) if their operational requirements (for security, software upgrades, etc) can be met. These larger ISPs are positioning themselves as content providers and / or operators of backbone data networks. Nevertheless, the ISP industry is still in startup mode, and for many ISPs the primary business is still managing modems and providing basic internet access.

ISPs can only be helped by the deployment of data access technologies and data networks, since this will greatly expand the range of services they can offer their customers. However, unlike ILECs and CLECs, ISPs are not yet in a position to directly influence the shape and form of public data networks. They do not yet have a sufficient customer base to have a major influence on network evolution or, if they do, they have not yet found their voice. Once high speed data access and transport services become more generally available, ISPs will presumably be in a position to expand their product offerings, and become much larger users of network infrastructure and services. At that point, the ISPs will be in a position to influence network evolution, e.g., by adopting or promoting some technologies versus others. At present they are largely passive on issues of network evolution.

6. Cost Modeling

In order to discuss internet offload architectures, we adopt the following terminology. An 'ingress switch' is a PSTN access switch to which subscriber lines are connected. An 'egress switch' is a PSTN switch to which an ISP is connected. It is estimated that approximately 30% of all LEC switches are egress switches. Internet calls originating at an ingress switch will, in the present mode of operation (PMO), be routed through the PSTN interoffice facilities (IOF) to an egress switch, following the same path as regular voice calls. Internet offload architectures may be classified into four categories:

- Non-data solutions are those which represent some variation on the present mode of operation. They involve rearranging existing PSTN elements so that they can more efficiently carry dialup internet traffic, e.g., by providing a shorter route and / or dedicated PSTN facilities between the ingress switch and ISP. No new types of PSTN equipment are deployed.

- Pre-switch solutions involve re-direction of internet calls on the line side of ingress switches. As shown in Figure 2, internet calls are intercepted before they reach the ingress switch, and are re-directed onto a packet network, avoiding both the ingress switch and IOF. Pre-switch solutions require one to deploy some new type of line termination. This can be costly, and so in a pre-switch solution it is usually assumed that only a percentage of subscriber lines will be offloaded, i.e., those belonging to the heaviest internet users. By targeting heavy internet users, one minimizes the cost of line terminations, while maximizing the amount of traffic offloaded.

- Post-switch solutions involve re-direction of internet calls on the trunk side of ingress switches. Post-switch architectures require remote access servers (RASs) to be located somewhere behind the ingress switch in the PSTN. Internet calls are routed from the ingress switch to a RAS, and from there onto a data network (see Figure 2). Note that in this scenario internet calls by-pass some or all of the PSTN's IOF, but still pass through the ingress switch.

- Finally, combined architectures merge two or more of the above solutions. In a combined pre- and post-switch architecture, for example, all internet calls are intercepted by default on the trunk side of the ingress switch, and routed onto a data network. However, in addition to a default post-switch internet call routing mechanism, one might also deploy pre-switch offload on a percentage of heavy users' lines. In this way one can achieve greater offload savings than in either a pure pre-switch or a pure post-switch architecture.

The remainder of this section summarizes the results of Telcordia's cost modeling of internet offload architectures, which was carried out with a spreadsheet-based model of PSTN and data network costs. The model quantified the cost of supporting internet traffic using various offload architectures versus the PSTN, and sought to answer the following strategic questions for carriers: Will it be cost-effective to deploy some general class of offload architecture? And, if so, approximately how much could it save with respect to the PMO? Note that the model was intended to be vendor independent. It used representative, industry average values for network equipment. Also, it considered only the costs associated with offload architectures, not revenues. In the case of services such as ADSL it may be possible to derive new revenues from the offload architecture, in addition to the cost savings that one obtains by getting internet traffic off the PSTN. These

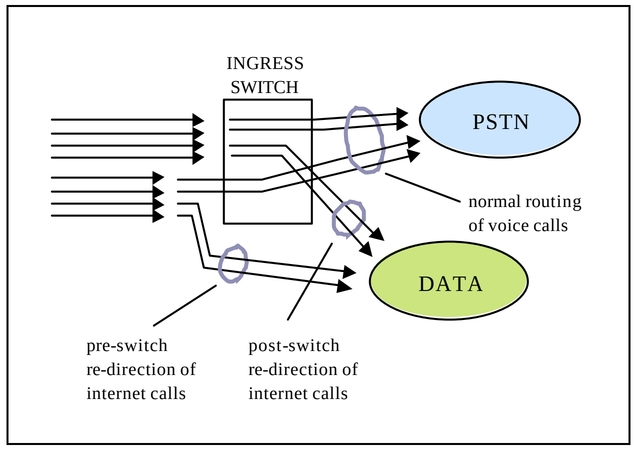

Figure 2: Pre- and Post-Switch Offload Architectures

revenues were not included in the model per se, though their implications are discussed below.

Telcordia's model nominally considered a geographical region containing a large number of subscribers / lines. Each line was assumed to generate a base level of non-internet (i.e., voice) traffic, plus an incremental amount of internet traffic. While the level of non-internet traffic was assumed to be the same for all lines, internet traffic was assumed to be distributed between heavy and light users. The distribution of internet load across lines was captured in a 'load function'. This function was an important input parameter in determining the optimal percentage of lines to offload in pre-switch architectures. Telcordia derived its load function from data collected over the past two years.

Telcordia's study considered three internet growth scenarios: conservative, median and aggressive. For each scenario, the cost model calculated the optimal monthly per-line savings that one can obtain (relative to the PMO) by deploying the relevant offload architecture.[5] In order to make the results more comprehensible, all of the costs / savings were then converted from a monthly per-line figure into the equivalent annual cost / savings for a large carrier with 20 million (20M) access lines. That is, monthly per-line savings were multiplied by 12 x 20M in order to project the annual savings that would be obtained by an RBOC-size local exchange carrier.

The assumed levels of internet traffic in the three growth scenarios are given in Table 1 below, for both the traditional busy hour (TBH) and the internet busy hour (IBH). (The traditional network busy hour, used for engineering purposes, occurs in the mid-morning or mid-afternoon. The internet busy hour is around 11PM. The presence of a second (internet) busy hour complicates network engineering. See below for further discussion.) Note that the units of traffic in Table 1 are CCS, equal to one hundred seconds of call time. For comparison, the level of voice traffic in the TBH is usually in the range 2-6 CCS per subscriber line. Also note that the ratio of TBH to IBH loads varies in the three scenarios. The conservative scenario was intended to model internet usage as it is today, with significant use of the internet at night for recreation, and less use during the day. The aggressive scenario assumed that internet use during the day would grow substantially, due to use of the internet for electronic commerce, distribution of mainstream business information, etc. In the aggressive scenario, the TBH load is therefore greater than the IBH load, reflecting that the internet has become a business tool.

Table 1: Growth Scenarios (CCS per internet user)

year	% pen. (†)	conservative scenario		median scenario		aggressive scenario	
		TBH	IBH	TBH	IBH	TBH	IBH
1998	20	0.75	1.50	0.75	1.50	0.75	1.50
1999	28	1.00	1.70	1.40	2.00	2.10	2.40
2000	36	1.25	1.90	2.05	2.50	3.45	3.30
2001	44	1.50	2.10	2.70	3.00	4.80	4.20
2002	52	1.75	2.30	3.35	3.50	6.15	5.10
2003	60	2.00	2.50	4.00	4.00	7.50	6.00

† "% pen." is percent penetration, i.e., the percentage of subscriber lines that are used, at one time or another, for internet access. It is a measure of the percentage of internet users within the population of telephone subscribers.

6.1 PMO Costs

The cost of supporting internet traffic in the PMO is due in the first place to the additional trunks and switching resources required to carry that traffic. In addition to this capital investment cost, there are operational costs associated with installing and managing the new equipment. Finally, as discussed above, one could take the view that reciprocal compensation is an internet related cost.

The results below deal only with the first of these costs, i.e., the capital investment in network infrastructure. As a rough rule of thumb, operational expenses are often assumed to be about 15% of equipment costs. Reciprocal compensation is clearly an important issue for ILECs, CLECs and ISPs, though it is not easy to accurately quantify. If one assumes that 50% of internet traffic is subject to reciprocal compensation (i.e., requires an ILEC to compensate a CLEC), and a reciprocal compensation rate of one cent per minute of use, then based on the internet growth scenarios in Table 1 reciprocal compensation could cost a 20M-line ILEC on the order of $1.4B (1.4 billion dollars) over the next 5 years in the conservative growth scenario, or about $3.3B in the aggressive scenario.[6] Given that a 20M-line LEC might be expected to generate profit of $1B plus per year, these figures are sufficiently large to make reciprocal compensation a priority issue for all parties. While reciprocal compensation is not quantified in more detail here, it is clearly an important source of internet related costs for ILECs.

With regard to capital infrastructure costs, Telcordia estimates the unit monthly cost of carrying a TBH CCS of voice traffic is around $3. That is, when network infrastructure investments are amortized into monthly costs, and averaged over the number of CCS in a traditional busy hour, the result is $3.[7] The equivalent monthly cost for internet traffic is estimated to be $5. The difference between these results requires explanation. The impact of internet traffic on the PSTN is complicated by fact that there are two busy hours in the network: the traditional busy hour and the internet busy hour. In the presence of internet traffic, some network equipment will continue to be engineered to the TBH. However, as internet traffic grows, more and more of the network will be engineered to the internet busy hour. Because the network must be sized to accommodate traffic in both busy hours, it is necessary to deploy more equipment (i.e., trunks and lines) than would be required to meet *either* the TBH load *or* the IBH

[5] The word ‘optimal’ is used here since, in the case of pre-switch architectures, maximum savings will be obtained only if an optimal percentage of subscriber lines are off-loaded. Too few or too many lines will produce sub-optimal savings. The optimal percentage of lines to off-load is an output of the cost model.

[6] These figures assume that volume of internet traffic in a day is equal to 10 times the load in the internet busy hour, and that there are 200 (working) days in a year.

[7] This figure is based on equipment costs only. It does not allow for a range of other LEC operating expenses, such as corporate overhead, taxes, universal service fund, etc.

load individually. If the cost of this additional equipment is attributed to the incremental internet traffic (which may or may not be a fair approach), one concludes that a unit of internet traffic costs more to transport than a unit of voice traffic.

However, the presence of non-overlapping demands in two distinct busy hours is not the only reason for the difference between the unit costs of voice and internet traffic. As internet traffic continues to grow, the average load per access line in the PSTN will gradually climb into regions where traditional switch designs are no longer economical. Traditional line peripherals are based on the concept of concentration: multiple access lines are concentrated onto a smaller number of trunks for transport across the network. This works fine as long as the network is subject to traditional load levels. However, internet traffic can raise the total level of traffic in the network to the point where switch line peripherals need to be de-loaded (i.e., can not be fully utilized). This has already occurred in egress switches, to which ISPs are connected via multi-line hunt groups, and will increasingly occur in ingress switches and tandems, unless internet traffic is offloaded from the PSTN. The steady growth in the internet load per access line has the effect of reducing the efficiency, and increasing the cost, of the PSTN.

When the above two effects are combined, they imply that a unit of internet traffic costs significantly more to transport than a unit of voice traffic: $5 versus $3. The size of this cost differential is large. It represents a 66% increase in costs over the voice figure of $3 per CCS. It is therefore not difficult to see how internet traffic could substantially increase PSTN costs. Based on Telcordia's calculations, when projected over 5 years, the cumulative cost of supporting internet traffic in the PMO could amount to $3.2B in the conservative scenario, or as much as $8.5B in the aggressive scenario. (All figures are for a 20M-line LEC.) At the high end, the $8.5B figure translates into an additional cost of approximately $7 per line per month. It is unlikely that LECs can recover these costs by directly charging either internet users or ISPs, so internet costs will either need to be absorbed by LECs, passed onto their entire customer base without regard to whether the customers are internet users or not, or minimized through other means.

Clearly, if you're a LEC, absorbing these costs is undesirable. Passing them onto all customers raises issues of fairness. Is it fair to expect non-internet users to subsidize internet users and ISPs? If one rejects these two options, then the only remaining option is for LECs to minimize the impact of internet traffic through intelligent management, and hope that the regulatory environment encourages the timely development of data networks and services. In the near term, in attempting to minimize internet related costs LECs have two basic options: (i) They can adopt a 'wait and see' approach, in which they would intelligently manage internet traffic within the PSTN using existing equipment, while they wait to see what technological or market developments might create new solutions. Or (ii) they can pro-actively adopt an offload strategy, that would get internet traffic off the PSTN and onto existing data networks which provide more efficient transport. In the remainder of this paper, we analyze several variants of these approaches to see which are the most cost-effective.

6.2 Non-Data Architectures

A couple of strategies have emerged for reducing the cost of internet traffic within the PSTN, without introducing any new classes of network equipment. The first is to deploy primary rate ISDN (PRI) on a widespread basis as the preferred method of connecting ISPs to PSTN switches. In fact this shift has been in progress for some time. Several years ago it was common for ISPs to connect to LEC switches via 1MB business lines and multi-line hunt groups (MLHGs). This created congestion on egress switch line peripherals, which are typically designed to concentrate traffic. The high volumes of traffic funneling into ISPs meant that egress switch line peripherals had to be de-loaded, making them less efficient and more expensive.

While PRI connections have the ability to concentrate traffic, they also have the capability to carry traffic in a non-concentrating mode. In the latter case they act like trunks, rather than subscriber access lines. If one provisions PRI equipment to be non-concentrating, this equipment becomes a more efficient and cost-effective means of delivering internet calls than analog 1MB lines, and in addition provides ISPs with a number of D-channel signaling capabilities that they find useful for managing their modems. PRI has therefore proved popular both with LECs and ISPs, to the point where there are backlogs of PRI orders.

A second strategy for reducing PSTN costs is the so-called 'skinny tandem'. These are tandem switches with reduced functionality, the capability to accommodate large numbers of PRI ports, and with a much lower per-trunk cost than regular tandems. Whereas a trunk termination on a regular tandem could cost $200 or more, a skinny tandem could reduce this cost to $50 or less, assuming that one deploys them in sufficiently large numbers to achieve economies of scale. They are being built by several vendors, who see internet offload as one of their main applications. The strategy is to route internet calls to these tandems, and then via PRI 'trunks' to ISPs. Due to their reduced functionality, skinny tandems will not necessarily support all of the call processing and call routing capabilities of regular tandems. However, this may be acceptable, given that they are designed to handle data calls which do not require regular calling features.

PRI does not necessarily have to be used in conjunction with skinny tandems to support internet traffic. One can, for example, connect ISPs to a regular tandem via PRI to achieve cost savings. This scenario will be referred to here as RTAPH (regular tandem as PRI hub). For additional savings one can replace the regular tandem with a skinny tandem. This scenario is referred to as STAPH (skinny tandem as PRI hub). Telcordia modeled the costs associated with both the RTAPH and STAPH scenarios. In the case of RTAPH, it was estimated that savings with respect to PMO could amount to $1.1B over 5 years in the conservative growth scenario, or $2.9B in aggressive scenario. The savings for the STAPH scenario are larger: $2.1B in the conservative scenario and $5.3B in the aggressive scenario.

The STAPH savings are substantial, representing more than 60% of PMO costs. Of the architectures considered in this paper, the greatest offload savings ($6.4B in the aggressive scenario) are produced by a combined architecture (see below). The STAPH savings fall short of this result but are still respectable, which raises the question as to why one should bother with data offload architectures, when one can in fact obtain substantial savings via a non-data (e.g., PRI hub) architecture.

When evaluating the STAPH architecture versus data-oriented architectures, there is however one important point to keep in mind. The non-data architectures described above require that ISPs maintain their own remote access servers (RASs). Consequently, the RASs are not included in the STAPH and RTAPH cost calculations. In contrast, the data-oriented architectures considered in subsequent sections all include RASs as an integral part of the architecture. And the cost of the RASs is therefore included in the corresponding cost calculations. When comparing the STAPH architecture with a data offload architecture, one must allow for the fact that the data architecture is providing a service to ISPs (i.e., modem maintenance and management), from which the LEC can derive some additional revenue.

How much revenue can a LEC expect to derive from modem management? Telcordia's cost modeling assumed a per-port RAS cost of $200. This capital investment translates into an amortized monthly cost somewhere around $7. On top of this there will be the operational cost of maintaining the RASs, performing software upgrades etc. Assume for the sake of argument that each modem port costs a LEC about $10 per month total. Based on the internet penetrations in Table 1, and assuming a ratio of 10 internet users per modem port, a 20M-line LEC would require from 0.2M (0.2 million) to 0.6M modems to serve 50% of internet traffic over the next 5 years. (That is, we assume that the LEC terminates 50% of internet traffic on its own modems.) If the LEC passes this cost onto ISPs (plus some reasonable profit margin), this would provide the LEC additional income on the order of $50M per year (again assuming that 50% of ISPs subscribe to the service).

This is not the end of the story. As discussed above, ISPs can save on their long distance backhaul costs by deploying modems close to subscribers in LEC end offices. This strategy reduces ISPs' leased circuit backhaul charges by virtue of the multiplexing gain on the modems' data side. Large ISPs' backhaul costs can be an order of magnitude greater than their modem management costs. If a LEC were to offer ISPs a modem management service that would not only relieve them of the task of maintaining and managing modems, but would also significantly reduce their long distance costs, it appears quite feasible that this type of service could provide the LEC with revenue of around $200M a year, or $1B over 5 years. This revenue would effectively enhance the cost savings provided by data offload architectures, relative to non-data offload architectures. In evaluating the data offload architectures discussed below, relative to the non-data architectures described above, one should therefore allow for additional revenue on the order of $1B over 5 years, that could potentially derive from LEC-based modem management.[8]

Finally, we again note the relevance of reciprocal compensation, and the position of the FCC and other regulatory bodies with respect to this issue. The non-data offload architectures described above are subject to reciprocal compensation. They deliver internet calls to ISPs in exactly the same way they are delivered now: via the circuit-switched network. This factor provides an additional reason for ILECs to go with a data offload architecture, assuming that

[8] The accounting may actually be more difficult than suggested here, for the following reason. The above analysis assumes that ILECs will derive revenue for modem management services at the expense of long distance carriers, who will lose part of the revenue they were previously obtaining for backhauling internet traffic. In fact, some or most of the backhaul revenue may go to the ILECs themselves for intrastate toll traffic. In this case, rolling out modem management services would decrease the ILECs' own backhaul revenues. That is, in a very simple view, the ILECs would be under-mining their own revenues. However, we make the point that these backhaul revenues are in any case at risk due to competition from CLECs. If ILECs choose not to help ISPs reduce their backhaul costs by locating modems close to subscribers, CLECs probably will (e.g., by means of network unbundling), and the backhaul revenues will be lost to the ILECs whatever happens. If one makes the simplifying assumption that current backhaul revenues are 'at risk', and should therefore be discounted from the cost analysis, the above calculations remain valid.

they can avoid reciprocal compensation by delivering internet 'calls' via data networks.

If reciprocal compensation is determined (by regulatory bodies) not to apply to internet packets delivered via data networks, then ILECs can essentially eliminate reciprocal compensation by deploying data offload networks. In effect, internet calls would be terminated on modems inside the ILEC networks, and only data would be forwarded to ISPs via intermediate (e.g., CLEC) networks. Whether or not this represents a solution to the ILECs' reciprocal compensation problem will depend partly on the FCC's stance on whether data traffic constitutes local or interstate traffic. From a technical viewpoint, the best outcome of the current legal process regarding reciprocal compensation would be one which ensures that if data is transported over data networks, then reciprocal compensation (for that data) occurs at rates which are in line with the costs of data switches and equipment. If this principle holds, the cost differential between circuit-switched and packet-switched network equipment will itself drive internet traffic (i.e., data) off circuit-switched networks and onto data networks, where it belongs.

6.3 Pre-Switch Architectures

Telcordia modeled two types of pre-switch architecture: (i) an ADSL architecture, and (ii) a generic pre-switch adjunct (PSA) architecture. In the ADSL architecture, customers who subscribe to ADSL service have their lines upgraded from analog terminations to ADSL terminations. This is assumed to require an investment by the LEC of $500 per line, plus some cost for linking the ADSL DSLAM to the ingress switch. (This link carries voice traffic.) From the DSLAM, data traffic goes directly onto a data network (e.g., an ATM network), by-passing the ingress switch and PSTN. For this study, the cost of data switching was assumed to be $6200 per DS-3 port. The $500 investment per ADSL termination assumes that the subscriber (not the LEC) is responsible for buying a customer premises ADSL modem, at a likely cost of several hundred dollars. As noted above, ADSL will generate additional revenues for the LEC, which are not accounted for in Telcordia's model.

In a PSA architecture, pre-switch adjunct equipment is placed between subscribers and the ingress switch in order to filter out internet calls, and re-direct them onto a data network. Available PSAs are based on digital loop carrier (DLC) systems, for example those conforming to the GR-303 standard. Subscriber lines are moved from their ingress switch terminations onto the DLC remote digital terminal (RDT). The RDT either through-switches voice calls to the ingress switch via the DLC connection, or re-routes data calls to a RAS and data network. In contrast to ADSL, a PSA architecture retains the subscriber's original analog line, although this line is terminated on a PSA rather than the ingress switch. Conceptually, both architectures perform the same function of intercepting and redirecting data calls, so that they by-pass both the ingress switch and PSTN.

LEC costs associated with the PSA architecture are the capital investment in each PSA termination (assumed to be $400), costs associated with the link from the PSA to the ingress switch (common to ADSL), data network costs (common to ADSL), and the capital investment in RASs (not incurred in ADSL). By default, Telcordia's model assumed that the LEC has to invest in new DLC / RDT equipment for each PSA line termination. However, if the LEC already has DLC and RDTs deployed, the incremental investment for internet offload will be significantly less. In the latter case, the PSA / RDT termination cost of $400 and the cost of the link from the PSA to the ingress switch are replaced with the cost of upgrading the switch and RDT software to accommodate the internet offload application. The cost of these software upgrades were assumed by Telcordia to be $75 per PSA termination. This factor could make a PSA approach more attractive to LECs that already have some DLC deployed, though only to the extent that the deployed base of DLC overlaps heavy internet users.

It is important to note that both the ADSL and PSA approaches require the LEC to invest in new line terminations, which are relatively expensive. In general, it would not be cost-effective to convert every line to a PSA or ADSL termination. For one thing, only a fraction of users are internet users, and much of the investment would be wasted. For another, even internet users themselves range from consistently heavy users through very light users. The strategy with pre-switch architectures is therefore to offload only a fraction of subscriber lines, specifically those corresponding to the heaviest internet users. Offloading heavy internet users provides the greatest savings for the least investment.

In a PSA architecture, subscriber lines can be moved on and off PSAs transparently to the subscriber. It is therefore up to the LEC to identify heavy users, and decide how many and which lines should be moved onto PSAs. In an ADSL architecture, customers themselves will decide whether or not they subscribe to ADSL, and the LEC cannot directly control which lines are offloaded. However, it is likely that ADSL will appeal most strongly to heavy internet users, and so the end result will be the same: heavy users will opt for the service and light users will not. We note that a LEC exerts indirect control over the percentage of heavy users subscribing to ADSL through its ADSL tariff.

In both architectures, Telcordia's cost model captures the tradeoff between pre-switch line termination costs (proportional to the number of offloaded lines) and offload savings (proportional to the volume of traffic that is offloaded), and determines the percentage of lines that should be offloaded in order to achieve optimal savings. The results reported below assume that this optimal level of savings is in fact achieved. If, for example, the percentage of customers who subscribe to ADSL is more or less than the optimal percentage, offload savings will be somewhat less than the figures given below. The magnitude of the decrease will depend on how far one diverges from the optimal percentage of offloaded lines.

Lastly, we note that an important assumption of Telcordia's analysis is that the LEC receives a 'credit' for each ingress switch termination that is replaced by a PSA or ADSL termination. That is, we assume that the analog line card, which is replaced by the PSA or ADSL termination, can be re-used elsewhere within the network, and is not lost to the LEC. This assumption improves the cost-effectiveness of pre-switch architectures. Were one to adopt the alternative assumption that the displaced termination is worth nothing, pre-switch savings would be less than reported below, perhaps by about 20%.

As before, Telcordia calculated the cumulative savings over 5 years that would be obtained by a LEC using a PSA or ADSL architecture. For a PSA architecture, in the conservative growth scenario, the savings amount to $0.9B, and require up to 11% of lines to be moved onto PSAs. In the aggressive growth scenario, PSA savings are $4.9B, and the optimal percentage of offloaded lines grows to 21%. If one assumes that DLC and RDTs are already deployed for 20% of internet users, then the conservative PSA savings and optimal percentage of offloaded lines increase to $1.1B and 13% respectively. Similarly, the aggressive PSA savings and percentage of offloaded lines increase to $5.3B and 23%. Finally, for an ADSL architecture, in the conservative growth scenario, savings were estimated to be $1.0B, requiring up to 11% of lines to be converted to ADSL. In the aggressive growth scenario, ADSL savings were $5.6B, and the optimal percentage of lines to offload increased to 21%.

Of these pre-switch architectures, ADSL produces the greatest savings. However, the PSA approach may not lag far behind ADSL, assuming that there is some percentage of digital loop carrier equipment already deployed in the network. In the aggressive internet growth scenario, ADSL savings are comparable to those obtained in the STAPH architecture – $5.6B versus $5.3B (see Section 5.2). In contrast, in the conservative growth scenario, ADSL savings are only about half those of the STAPH architecture – $1.0B versus $2.1B.

This highlights an important point. The savings provided by pre-switch architectures in conservative growth scenarios (or alternatively in the near term) are small, since the low volume of internet traffic will not produce sufficient savings to compensate for up-front investment in line terminations. It is only in aggressive growth scenarios (or in the medium to long term), as the per-line volume of internet traffic grows, that pre-switch architectures start to pay off. The cost of transporting a CCS of internet traffic in pre-switch architectures is low, due to the low cost of data equipment. For a PSA architecture it is around $2 per TBH CCS, while for ADSL it is around $0.10 per TBH CCS. These figures should be compared with a per-CCS cost of $5 in the PMO. When the volume of internet traffic per line becomes sufficiently large, these low transport costs more than compensate for the investment in pre-switch line terminations.

Finally, it is interesting to discuss the potential impact of ADSL tariffs on internet offload.[9] In setting ADSL tariffs LECs have two options. First, they can treat ADSL as a standalone service, and set the tariff sufficiently high to cover all of their ADSL related costs plus some profit margin. Alternatively, provided they have the regulatory freedom to do so, they could price ADSL below cost, in order to stimulate ADSL penetration and achieve greater internet offload savings. Of course, the second strategy would only make sense if the net benefit to the LEC were greater than that provided by a standalone ADSL service. However, this could well be the case. Currently, LECs appear to be following the standalone model, and are setting ADSL tariffs relatively high. This runs the risk of turning ADSL into a second ISDN: high tariffs could keep ADSL penetration so low as to prevent economies of scale in equipment pricing, and ensure negligible impact both on the network and on LEC revenues. In this case, ADSL plays a negligible role, both as a service and as a form of internet offload.

However, suppose that for each dollar a LEC takes off the ADSL tariff, ADSL penetration rises by X%. And assume that each rise in ADSL penetration of X% translates into internet offload savings of $D per line. If D turns out to be greater than one (based on actual data or models of service uptake), then each dollar that the LEC takes off the ADSL tariff could produce more than one dollar in offload savings. If D were significantly greater than one, a case could be made for reducing the ADSL tariff below cost, in order to maximize the LEC's overall financial position. In effect, one would be treating ADSL as part of an integrated strategy for voice / data integration, and accepting a loss on the ADSL service itself, in order to maximize total financial gain.

Depending on how the numbers fall out, this approach could be financially attractive to a LEC over the next 5 years. However, is it viable as a longer term strategy? Clearly, in the future, after most internet traffic has been

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[9] Our comments on ADSL apply equally to other forms of digital subscriber loop: SDSL, IDSL, etc.

offloaded from the PSTN, LECs do not want to be in the position of losing money every month on each ADSL termination in the network. The long term attractiveness of reducing the ADSL tariff is not quantified here, since it requires more detailed modeling and study. However, we make the following observations. First, if the ADSL tariff is sufficiently attractive, then ADSL terminations will presumably become as ubiquitous as analog modems, and economies of scale should substantially reduce the LECs' ADSL equipment costs. This factor will certainly help the ADSL cause. Second, in the long term one should not be attempting to cost-justify ADSL (solely) as a traditional PSTN service. ADSL is an enabling technology, which will make it possible for LECs to transition to a data mode of operation, and achieve substantial savings in their core networks through data transport. Consequently, we believe ADSL should be evaluated as part of an integrated strategy for voice / data integration, rather than as a standalone PSTN service.

6.4 Non-Data Architectures

Telcordia evaluated two main flavors of post-switch architecture: (i) those in which ISPs are connected to LEC switches (tandems or end offices) via PRI, and (ii) those in which the ISP-LEC connection is via SS7 trunks. (See Figure 3.) The latter type of architecture is more sophisticated, since it employs SS7 signaling for call setup, and

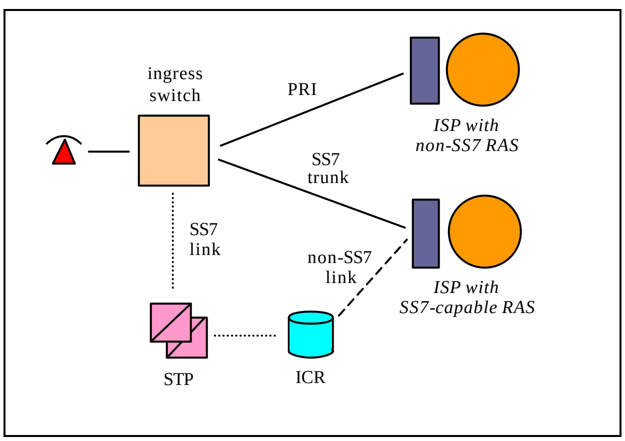

Figure 3: PRI and SS7 Based Post-Switch Offload

potentially has access to SS7 / AIN capabilities for internet call routing, modem management, etc. The SS7 approach also requires a new type of node within the SS7 network, referred to here as an internet call routing (ICR) node. The ICR node acts as a signaling gateway between the PSTN and data networks. On one side it employs SS7 signaling for internet call setup with PSTN switches (e.g., ingress switches). On its other side it uses a non-SS7 protocol to signal the RASs to accept incoming internet calls.

The ICR node in this context has much in common with signaling gateways that have been proposed for internet telephony. In fact, ICR and internet telephony functions may be merged in the future in a single node, with a common set of protocol requirements.

Within the above architectures one has several options as to where internet calls are offloaded. For this study it was assumed that in the PMO, internet calls originate at ingress offices and are routed via a single tandem to the relevant egress switch. That is, internet calls traverse two 'hops' in the PSTN. With regard to internet offload, one has the option of re-directing calls out of the PSTN: (a) immediately after they pass through the ingress switch, (b) immediately after they pass through the tandem, or (c) after they pass through the egress switch. Option (c) provides the least savings. It simply replaces the ISP analog line peripherals in the egress switch with PRI or SS7 trunks. Option (b) provides greater savings, since one is by-passing the egress switch and adjacent trunks. Option (a) provides the greatest post-switch savings, since in that case internet calls by-pass all PSTN elements except the ingress switch.

LECs have pointed out that although option (a) in principle provides the greatest offload savings, it requires modems to be distributed at a potentially large number of ingress offices. This could entail significant operational costs in deploying and maintaining the modems. In contrast, option (b) would require modems to be located at a smaller number of tandem offices, which would minimize operational costs. Some of the operational issues with option (a) are as follows.

First, it is likely that more staff would need to be trained and routinely involved in modem management and maintenance in option (a) than in option (b). Second, modems are currently unreliable and require significant maintenance. However, a percentage of ingress offices are unmanned, or infrequently manned, making it difficult to maintain modems at those offices. This is less likely to be the case with tandem offices. Third, modems require connection to network management OSSs, to ensure timely upgrades to operating software, bug resolution, etc. (This issue is of particular concern to ISPs.) This aspect of modem management may be easier to arrange if the modems are centralized in tandem offices, instead of distributed at end offices. Telcordia's study did not attempt to quantify these types of operational costs. However, it did evaluate the equipment savings in options (a), (b) and (c) above, so that the greater savings in option (a) can be weighed by LECs against the added operational costs that are incurred.

Another available architectural option, in both the PRI and SS7 approaches, is to use a skinny tandem rather than a regular tandem in option (b). As discussed in Section 5.2, skinny tandems have low per-port costs, and are designed to achieve high PRI and trunk densities. When used for internet offload, they have the potential to reduce transport costs, and increase offload savings. Accordingly, Telcordia added a fourth option – option (d) – to the above three. Option (d) is the same as option (b), except that the regular, full functionality tandem in option (b) is replaced in option (d) with a reduced functionality skinny tandem. The remainder of this section provides estimated savings for post-switch PRI and post-switch SS7 architectures with options (a), (b), (c) and (d). These savings are summarized in Table 2 below. As always, the figures in Table 2 represent cumulative savings over 5 years for a 20M-line LEC. Two figures are given in each cell. The first represents savings in the conservative internet growth scenario. The second is savings in the aggressive internet growth scenario.

Table 2: Estimated Post-Switch Savings (cons. – aggr.)

arch.	option (a)	option (b)	option (c)	option (d)
PRI	\$1.2B – 3.2B	\$0.7B – 1.9B	\$0.3B – 0.6B	\$1.7B – 4.3B
SS7	\$1.9B – 4.9B	\$1.4B – 3.5B	\$0.9B – 2.2B	\$1.7B – 4.4B

Table 2 shows that post-switch SS7 architectures will generally provide greater savings than PRI architectures. This is due to the lower cost of trunk equipment versus PRI equipment. PRI is an access / distribution technology, and PRI equipment must therefore support a range of capabilities (e.g., D-channel signaling) that are not required of trunks. This makes PRI more expensive than trunks. Of course, the implication of using SS7 trunks to connect ISPs to the PSTN is that one requires additional SS7 infrastructure, including ICR nodes. However, the cost of this infrastructure is small relative to other cost elements, making SS7 more cost-effective than PRI. We also note that the savings produced by both architectures drop substantially as one moves the offload point further away from the ingress switch. This provides the motivation for moving RASs as close as possible to the ingress office and subscriber.

The \$1.9B – \$4.9B savings provided by a post-switch SS7 architecture with option (a) are comparable to the \$2.1B – \$5.3B savings provided by the STAPH architecture (skinny tandem as PRI hub) discussed in Section 5.2. As noted in Section 5.2, a post-switch offload architecture could also bring in additional revenues from ISPs, for modem management / modem pooling services. This revenue stream might perhaps amount to \$1B over five years, and would not occur were the LEC to go with a non-data (e.g., STAPH) solution. *A post-switch SS7 solution is therefore attractive from the viewpoint of cost-savings and potential new revenues, and is technically aligned with internet telephony architectures.* However, on the negative side, the post-switch SS7 architecture with option (a) has a number of operational issues (see above), which would need to be resolved for successful implementation.

6.5 Combined Architectures

In general, pre-switch architectures have low transport costs. This is particularly true of ADSL, where there are no RASs involved. (Traffic goes directly from ADSL DSLAMs into an ATM network.) For this reason, pre-switch architectures become more and more attractive as the internet usage per subscriber line grows. When per-line internet usage becomes sufficiently high, the transport savings provided by a pre-switch architecture will outweigh the initial investment in line terminations, and the architecture will provide substantial net savings. Transport costs in post-switch architectures will never be as low as in comparable pre-switch architectures, since the ingress switch remains in the call path. However, post-switch architectures require zero investment in new line terminations (i.e., terminations on or in front of the ingress switch), and so they can generate savings from day one. For this reason, post-switch architectures are attractive when the internet usage per subscriber line is low to moderate.

Combined architectures incorporate the strengths of both pre-switch and post-switch architectures. In a combined architecture (as in a pure pre-switch architecture), the percentage of lines that should be moved onto alternative pre-switch terminations is a ‘variable’. The optimal value for this variable (i.e., the optimal percentage of pre-switch lines) is that value which maximizes overall savings. At low levels of per-line internet usage, the optimal percentage of pre-switch lines will be small, and the combined architecture will be predominantly post-switch. As internet usage grows, the optimal percentage of pre-switch lines will increase, and the architecture will become more and more pre-switch. A combined architecture therefore has the potential to provide the best of both worlds, and generate maximum savings, provided one can determine the optimal percentage of pre-switch lines corresponding to a given level of internet traffic. Telcordia’s cost model provides a framework for determining the optimal percentage of pre-switch lines (both in pure pre-switch and combined architectures).

Telcordia’s study considered two combined architectures: (i) a combined post-switch / PSA (pre-switch adjunct) architecture, and (ii) a combined post-switch / ADSL architecture. In both cases, the post-switch part of the architecture was an SS7-based post-switch architecture, in which internet calls were offloaded immediately after the ingress switch. That is, the post-switch part of the architecture was consistent with option (a) in Section 5.4. In the case of the post-switch / PSA architecture, the cumulative savings over 5 years ranged from $1.9B in the conservative internet growth scenario to $5.9B in the aggressive growth scenario. To achieve these savings, it was necessary to move from 2% (conservative) to 12% (aggressive) of lines onto PSA terminations. In the case of the post-switch / ADSL architecture, the savings ranged from $2.0B in the conservative growth scenario to $6.4B in the aggressive growth scenario. These savings required from 4% (conservative) to 14% (aggressive) of lines be moved onto ADSL terminations.

As expected, in the conservative growth scenario, the savings provided by the combined architectures are approximately the same as those provided by the pure post-switch architecture. In a conservative growth scenario, the pre-switch part of the architecture remains small, and adds little or nothing to the overall savings. In contrast, in the aggressive growth scenario, the pre-switch part of the architecture becomes more significant and contributes more to the overall savings. For example, in the post-switch / ADSL architecture, the combined architecture produces savings of $6.4B, as compared with $4.9B for the pure post-switch architecture (see Table 2 above).

A combined architecture can therefore provide substantial offload savings in all growth scenarios. At a minimum, it can provide the savings that would be obtained from a pure post-switch architecture. This ensures that a combined architecture is an attractive choice for the short to medium term. In addition, provided the LEC is able to maintain an optimal or near-optimal percentage of pre-switch lines, the combined architecture will provide further pre-switch savings, over and above those provided by the post-switch part of the architecture. These pre-switch savings will maximize the cost-effectiveness of the combined architecture in the long term.

Adopting a combined architecture removes some of the risk associated with pure pre-switch architectures. In a pure ADSL architecture, for example, it may be difficult for the LEC to accurately control the percentage of ADSL subscribers, e.g., by setting the ADSL tariff. In a combined architecture, the LEC can afford to be conservative in setting this tariff, until customers' usage patterns and receptiveness towards ADSL are well established. In the short term, the post-switch part of the architecture will provide offload savings, even if ADSL penetration is negligible. In the medium to long term, once everyone is comfortable with ADSL, the LEC can afford to promote ADSL service, e.g., by reducing the ADSL tariff, in order to maximize its overall financial position. In summary, a combined architecture provides an attractive method for merging (i) a digital access service such as ADSL, with (ii) a post-switch / VoIP type architecture, to provide a better strategy for both internet offload and voice / data integration.

7. Conclusions

The main focus of this paper is the LEC business case for internet offload. Now that the technical and architectural options for internet offload are well understood, LECs will presumably base their deployment decisions on the overall cost-effectiveness of various strategies. In its economic analysis of internet offload architectures, Telcordia quantified the equipment costs associated with the present mode of operation (PMO), as well the potential savings provided by 15 offload architectures. We did not attempt to accurately quantify a number of related factors, for example revenues from new services such as ADSL and modem management, and the operational costs associated with modem management. These factors were not modeled because they are not equipment costs per se. Nevertheless, they have an impact on offload economics, and are therefore discussed above, mostly in qualitative terms.

The 15 offload architectures considered by Telcordia were classified into four categories: (i) non-data solutions, (ii) pre-switch solutions, (iii) post-switch solutions, and (iv) combined solutions. Non-data architectures attempt to minimize costs by carrying traffic more effectively on the PSTN. No new classes of equipment are employed. All of the other architectures are designed to move internet traffic off the PSTN, and onto data networks, so that it can be transported more efficiently. Pre-switch solutions require internet traffic to be re-directed off the PSTN before it reaches the ingress switch. This can be done via pre-switch adjunct (PSA) equipment, or new access technology such as ADSL. Post-switch solutions allow internet traffic to pass through the ingress switch, before intercepting it at some point within the PSTN, and re-directing it to a data network. Combined architectures merge a pre-switch and a post-switch architecture, to provide better savings under all traffic conditions.

Telcordia's conclusions were based on a spreadsheet model, which captured the equipment costs associated with the PSTN, SS7 and data networks. The model accounted for factors such as the presence of two busy hours in the network (traditional and internet busy hours), and the distribution of internet load between heavy and light internet users. In the case of post-switch architectures, one assumes that all internet traffic is captured and re-directed onto data networks. However, pre-switch architectures require investment in new line terminations (i.e., PSA or ADSL terminations), which are relatively costly. Consequently, pre-switch architectures attempt to move only a percentage of subscriber lines onto pre-switch terminations, specifically those associated with heavy internet users. By selectively offloading the lines of heavy internet users, pre-switch architectures maximize offload savings while minimizing the investment in new terminations. The problem of determining the optimal percentage of pre-switch lines arises for both combined and standalone pre-switch architectures. In both cases, Telcordia's model provides a framework for determining the optimal percentage of pre-switch lines, as a function of per-subscriber internet usage.

Table 3 gives the estimated cost of supporting internet traffic in the PMO. It also lists the four top performing offload architectures, in terms of cost savings. They are a combined post-switch / ADSL architecture, a combined post-switch / PSA architecture, a non-data STAPH (skinny tandem as PRI hub) architecture, and a pure post-switch architecture. In all cases, the post-switch component of these architectures is an SS7-based architecture, which assumes that internet calls are re-directed onto a data network immediately after passing through the ingress switch. Table 3 lists savings for the three internet growth scenarios defined in Section 5: conservative, median and aggressive. All figures are in billions of dollars, and represent cumulative costs / savings for a 20M-line LEC over the next five years (1998 - 2003).

Detailed comments on the pros and cons of various offload architectures are given in the body of the paper, along with explanations as to why the architectures in Table 3 perform well from a cost-savings viewpoint. At this point we make some more general comments regarding these architectures. It is interesting to note that as many as three categories of offload architecture are represented in Table 3: STAPH is a non-data architecture, PSW / SS7 is a post-switch architecture, and COMB / ADSL and COMB / PSA are combined architectures. The only missing category is pre-switch architectures. The reason for this is as follows.

Table 3: PMO Costs and Offload Savings ($ billions)

architecture	conservative	median	aggressive
PMO	$3.2B	$5.0B	$8.5B
COMB / ADSL	$2.0B	$3.3B	$6.4B
COMB / PSA	$1.9B	$3.1B	$5.9B
STAPH	$2.1B	$3.2B	$5.3B
PSW / SS7	$1.9B	$2.9B	$4.9B

For reasons explained in the body of the paper, pre-switch architectures perform well only when per-line internet usage is high. If per-line usage is low, pre-switch architectures involve too much up-front investment in pre-switch line terminations to produce substantial savings. In general, pre-switch architectures are good as a supplement to post-switch architectures — i.e., in a combined architecture — rather than as standalone solutions.

We note that a non-data architecture — the STAPH architecture — is among the top four performers. However, one should not ignore the point made in Section 5.1. The STAPH architecture requires that ISPs continue to operate and maintain their own modems, which is an expense for them. In contrast, all of the other (data-oriented) architectures assume that the LEC owns and maintain modems inside its own network, or will provide a direct data feed by means of ADSL. In the data-oriented architectures, the LECs are therefore providing a service to ISPs (i.e., a modem management service), for which they could expect to derive additional revenues. In Section 5.1, it was estimated that these additional revenues could amount to as much as $1B for a 20M-line LEC over 5 years. The savings provided by the data-oriented architectures could therefore be effectively boosted by $1B relative to the STAPH architecture in Table 3.

The best performing architectures, from the viewpoint of offload savings, are the two combined architectures. The $6.4B savings provided by the COMB / ADSL architecture represents about 75% of PMO costs. If one adds an additional $1B of modem-related revenue onto the COMB / ADSL savings, then the total amount re-couped by the LEC would be $7.4B, or about 87% of PMO costs. Although the COMB / PSA architecture does almost as well, there are obvious strategic reasons for preferring the COMB / ADSL architecture. Because it is a digital access method, ADSL (or some variant thereof) represents the future of telecommunications. By incorporating digital access, a combined post-switch / ADSL architecture provides a migration path from the current PSTN to future data-oriented networks and services. For this reason, the COMB / ADSL architecture represents a sound long term strategy for voice / data integration.

Finally, it is appropriate to conclude the report with a comment on reciprocal compensation. The focus of this paper, and the previous papers [2,3], has been on (quantifiable) technical and cost issues relating to internet offload and voice / data integration. However, it is important to realize that there are other non-technical factors which will have as much, and possibly more, of an impact on the evolution of future networks. Reciprocal compensation is one such factor, in the regulatory domain. In the body of the paper we suggest that, from an ILEC viewpoint, reciprocal compensation can be seen as one of the costs or penalties of carrying internet traffic on a voice network. Depending on the evolving regulatory framework for data services, it may be possible for ILECs to avoid reciprocal compensation, by delivering internet calls via data networks rather than the traditional PSTN. This would provide added financial incentive for ILECs to deploy offload architectures.

Assume that reciprocal compensation will cost a 20M-line LEC on the order of $3.3B over the next 5 years in an aggressive growth scenario, as calculated in section 5.1. If an ILEC were able to avoid this cost, then the net savings obtained by an offload architecture could reach as high as $10.7B (i.e., $7.4B plus $3.3B). That is, the LEC would avoid capital expenditure of $8.5B (PMO costs), and would effectively gain an additional $2.2B through modem management services and reduced reciprocal compensation. Lastly, deploying an offload architecture will create opportunities for the LEC to deploy new services (e.g., IP telephony) which can generate additional revenue. The authors hope that the ideas advanced in this paper will stimulate further analysis and evaluation of data-oriented architectures and services.

Acknowledgments

As with the authors' previous white papers, the main objective of this paper was to stimulate industry debate and discussion on the solutions for the internet congestion problem. The views expressed here are those of the authors, and do not represent the views of Telcordia. The authors gratefully acknowledge discussion with many industry members including members of the ITESF, and many Telcordia subject matter experts.

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Acronyms

ADSL	asymmetric digital subscriber loop
ATM	asynchronous transfer mode
CCS	centum call seconds
CLEC	competitive LEC
DLC	digital loop carrier
FoIP	fax over IP (internet fax)
IBH	internet busy hour
ICR	internet call routing (node)
ILEC	incumbent LEC
IOF	interoffice facilities
IP	internet protocol
ISP	internet service provider
IXC	inter-exchange carrier
LEC	local exchange carrier
LMDS	local multipoint distribution service
MLHG	multi-line hunt group
MOU	minute of use
OSS	operations support system
PMO	present mode of operation
POP	point of presence
PSA	pre-switch adjunct
PSTN	public switched telephone network
RAS	remote access server (modems)
RBOC	Regional Bell Operating Company
RDT	DLC remote digital terminal
RTAPH	regular tandem as PRI hub
SOHO	small office / home office
SS7	signaling system # 7
STAPH	skinny tandem as PRI hub
TBH	traditional busy hour (mid AM or PM)
TCP	transmission control protocol
VoIP	voice over IP (internet telephony)
WAH	work at home
WDM	wave division multiplexing
xDSL	some flavor of digital subscriber loop

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