A First Person IP over HDSL Case Study

Wayne Smith
Director
Office of Information Technology
College of Business and Economics
California State University, Northridge
18111 Nordhoff St.
Northridge, CA 91330-8245
+1 818 677-6484
http://www.csun.edu/wsmith/
wayne.smith@csun.edu

Abstract

As many authors have articulated, the "last mile problem" is often cited as a persistent engineering obstacle in deploying residential broadband solutions. Additionally, some academic researchers may require completely unfiltered Internet access, short network paths to Internet2, SIP, QoS, IPv6, and other functionality that may not be offered by commercial ISP's. This paper describes how the author designed and developed a high-speed (>2 Mb/sec), residential IP connection by using a four-wire HDSL circuit terminated directly at an academic institution. Technologically, this was done by extending the Ethernet frame beyond the institution's physical boundaries with transparent MAC-layer forwarding controlled by relatively low-cost, dedicated HDSL transceivers. The process was strategically planned, documented, tested, and managed across seven individuals in four disparate organizations and the monthly cost per throughput capacity is significantly lower than typical ISP's in the region.

I. Introduction

What is the appropriate level of residential network connectivity for a student pursuing a Ph.D. in Information Science? As might be the case for Internet access for several categories of knowledge workers, this question not only doesn't have a straightforward answer, but this question leads to a number of ancillary questions as well. Is the work of a graduate student in a technology-related domain best served by an institutionally managed networking infrastructure or by a commodity Internet Service Provider (ISP)? If best (or better) served by an institution, how can that connectivity be implemented? Does the work of a doctoral student require better network connectivity, specifically Internet access, than other students? If so, how is this better access defined? What are the geographic, regulatory, technological, economic, and organizational issues involved? This paper describes the organizational strategy, technological architecture, engineering design, and operational deployment of a residential broadband solution for use by the author. As such, some of this paper is written in the first person.

There can be little question as to the critical role of Internet connectivity for success in today's society [2]. With respect to the education sector, some are even convinced that "information technology and the Internet promise to revolutionize American higher education" [6, p. 1]. Funding and deploying key technologies, including Internet access, are now critical institutional functions (see [8] for a summary). Students expect Internet access from nearly everywhere, including residences both on- and off-campus [4]. But residential connectivity, especially broadband connectivity, can remain elusive or uneven due to a variety of factors [3]. A number of writers have commented on the trials and tribulations of obtaining high-speed Internet access in residences. With respect to DSL in particular, one author has even described the events surrounding a new residential Internet access installation as "…a nightmare of customer 'service' interactions…" [7, p. 2]. Entire web sites have been set up solely for the purpose of permitting anecdotal postings of end-user experiences with DSL [15].

While the debate continues about the most appropriate role for the government sector in deploying advanced

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technology services, and more specifically, how the federal and state entities might collaborate [10], individuals desire pervasive and useful residential broadband connectivity. While the debate continues among many between the value of relatively content-neutral "open" access technologies and relatively rapidly deployable "closed" access technologies, some researchers in academia are working both at the regional level [14] and national level [5] to create, deploy, integrate, and evaluate next-generation internetworking capabilities for use not only by education and government, but in the future, for private industry as well. In proportion to the number of broadband installations, relatively little is documented in the academic literature regarding local implementation strategies and specific operational details. This paper offers both a detailed account of one such implementation and a perspective on the best (or better) answers for a residential broadband solution for a modern graduate student.

2. Functional Requirements

I am a doctoral student in the Information Science program at Claremont Graduate University (CGU). I am currently finishing my second year of an approximately six-year, part-time program. CGU is located in Southern California at the east end of the County of Los Angeles. CGU is part of the Claremont University Consortium (CUC) with several undergraduate colleges and loose linkages to two other graduate schools located in the immediate vicinity. CUC manages the shared administrative infrastructure, such as physical plant, security, libraries, and telecommunications. Each individual University manages it's own academic programs and some administrative functions, such as admissions and student services. Wide-area and inter-campus networking functionality is owned and managed by an inter-campus group called the Claremont Internet Networking Effort (CINE) and administered by a manager and a staff member in one of the affiliated undergraduate colleges in the consortium (Harvey Mudd College). I live near campus in Claremont and my Incumbent Local Exchange Carrier (ILEC) is Verizon.

At the level of theory, some new frameworks for the description of aggregate Internet adoption are beginning to emerge and become available for application [13]. At the level of practice, however, it may be difficult to precisely define individual residential networking requirements. The following detailed requirements are really more "ideal" than "required". Furthermore, both requirements and supporting technologies are changing, occasionally in emergent ways. As with many types of information technologies and information systems, it's never precisely clear whether applications drive engineering (a philosophy of defining "functional needs" first) or engineering drives applications (a philosophy of "build it and they will come").

Advanced Network Services. It seems reasonable to assume that doctoral students, as budding scholars and researchers, might be doing at least some work that is more advanced than Master's students, undergraduate students, adult learners, or in some cases, industry practitioners. While prescribing specific infrastructure needs might be beyond the scope of interest of a typical student, the capacity of the institutional electronic infrastructure, and further, information about each current and future component of that infrastructure, is of relevance and importance to an information science student. Both academically and professionally, information scientists straddle the middle ground between two very different reference disciplines—management and computer science. It should be noted that specific, academic-only networks encompassing the first four elements of the Open Systems Interconnect Model (Physical, Data Link, Network, Transport) are, even now, 33 years after the first packets flowed from the original IMP machines at UCLA, designed, constructed, and tested with the twin purposes of reducing inter-organizational boundaries within the higher education community and challenging conventional telecommunications deployments and concomitant technological frontiers [14]. Doctoral students in information science, particularly ones with an active interest in networking research, should have access to the appropriate electronic infrastructure to support the design, development, and assessment of next-generation Internet technologies, such as Internet2, IPv6, Session Initiation Protocol (SIP), multicast, Quality of Service (QoS), and other as-yet-to-be-developed network protocols and services.

Access Speed. As a doctoral student, I need to access a large number of papers, often in multi-megabyte Adobe Portable Document Format (PDF). This is particularly true of advanced research papers, such as conference proceedings and journal articles. Some important journals, such as the Communications of the Association of Information Systems are available *only* on-line, and often contain articles in excess of 30 pages or more. My first research course contained readings from more than a dozen important papers in the field. The papers were provided both online in PDF form and available for purchase in the bookstore. Access speed is important, especially when the papers need to be printed for classwork or as background material for research.

There seems to be little explicit documentation, however, of the residential broadband needs for an information science doctoral student. And although the on-campus *undergraduate* residences are wired with Ethernet connections, the on-campus *graduate* residences are not. The graduate residences are old and are scheduled to be removed in the next few years. One of the options that the University is considering is to sign long-term leases with neighborhood apartment owners rather than re-build new on-campus facilities that require on-going maintenance. If this new residential environment were to materialize, many students naturally would be *very* interested which data networking capacities are feasible in the University neighborhood.

Institutional Strategy. Although CGU has traditionally been a small, liberal arts graduate institution with an interdisciplinary focus, the CGU Information Science program does have technological components included both within coursework and as material on doctoral screening exams. Moreover, recent faculty hires and on-going community work by the Department's Claremont Information and Technology Institute (CITI) Center, indicate that the Information Science program is not only becoming more *technical*, but also more *technological*, in it's teaching, research, and service activities. In addition, I know that CGU has plans to upgrade its Local Area Network (LAN) backbone and CUC has plans to upgrade its Wide Area Network (WAN). The latter will be connected to Internet2 resources, including Abilene.

Telecommuting. As a technology manager at a different University some 60 miles away, I also have a strong interest in viable telecommuting. In Southern California, freeway traffic has steadily increased leading to an increase in vehicle commute times. Despite some initial steps at the regional level to reduce commuting pressures via telecommuting [18], no improvement is anticipated for the foreseeable future. Although I most often commute to work via the train, being able to conduct some work from my residence on an occasional basis is useful. Over time, this might include voice and video teleconferencing with both my staff and my organizational peers.

3. Alternatives

There were a number of alternatives that I considered before making my final decision to select High-bit-rate Digital Subscriber Line (HDSL) at the physical layer and Ethernet at the data link layer. Each option was analyzed along three broad dimensions--organizational, technological, and economic. Specifically, choices need to be made as to 1), which specific type of residential wide-area networking technology is most appropriate, 2), where the connection terminates both topographically (physical location) and topologically (service policies and configuration), and 3), whether any suitable and practicable design fits within the budget of a doctoral student.

The local cable provider (AT&T) doesn't provide IP service. AT&T expects to provide IP service in the future, but cannot articulate a deployment timeline. The local ILEC does not current offer ISP over xDSL service, but a number of other ISP's do. The ISP's (such as Earthlink and Ultimate Internet) generally provide commodity services to consumers, not advanced services, such as IPv6, multicast, and QoS. Presumably, those services can be enabled for custom-design deployment architectures at some (unknown, but probably prohibitive) monthly recurring cost. Note that just because a protocol (e.g., SIP) is *technologically* "supported" in the TCP/IP architecture doesn't necessarily imply that the protocol is enabled or *organizationally* "supported" by any given ISP.

There are no LMDS or MMS service providers in the area. DirectWay offers IP service via satellite, but limits contiguous bandwidth use even over IPv4. It is doubtful that a celestial solution by itself would scale in the short- or long-run to meet the functional requirements for an network researcher.

The campus does not currently offer off-campus wireless LAN service and does not intend to in the foreseeable future. The campus does offer 56 K/b/sec dial-up service for $5 month. Although the contention rate for this service is low, for all intents and purposes, the bandwidth provided by this technology architecture is at its theoretical limit.

4. System Feasibility and Decision Processes

As illustrated in Figure 1, I chose to implement an IP & HDSL system terminated at my institution. Conceptually, this network design involves 1), provisioning a private-line circuit from my residence to the institution, 2), obtaining, locating, and configuring the appropriate electronics, 3), obtaining the correct IP service, and 4), testing the end-to-end performance of the system. A number of interrelated questions drawn from different subject domains were relevant to this process.

There was one open question of a regulatory nature—

R1. Is there an appropriate tariff in California that permits a private-line circuit between any two facilities (including between a "business" and a "residence")?

Organizationally, there were four open questions—

O1. Can I get permission to terminate a custom telephony circuit and co-locate any necessary electronics at my institution?

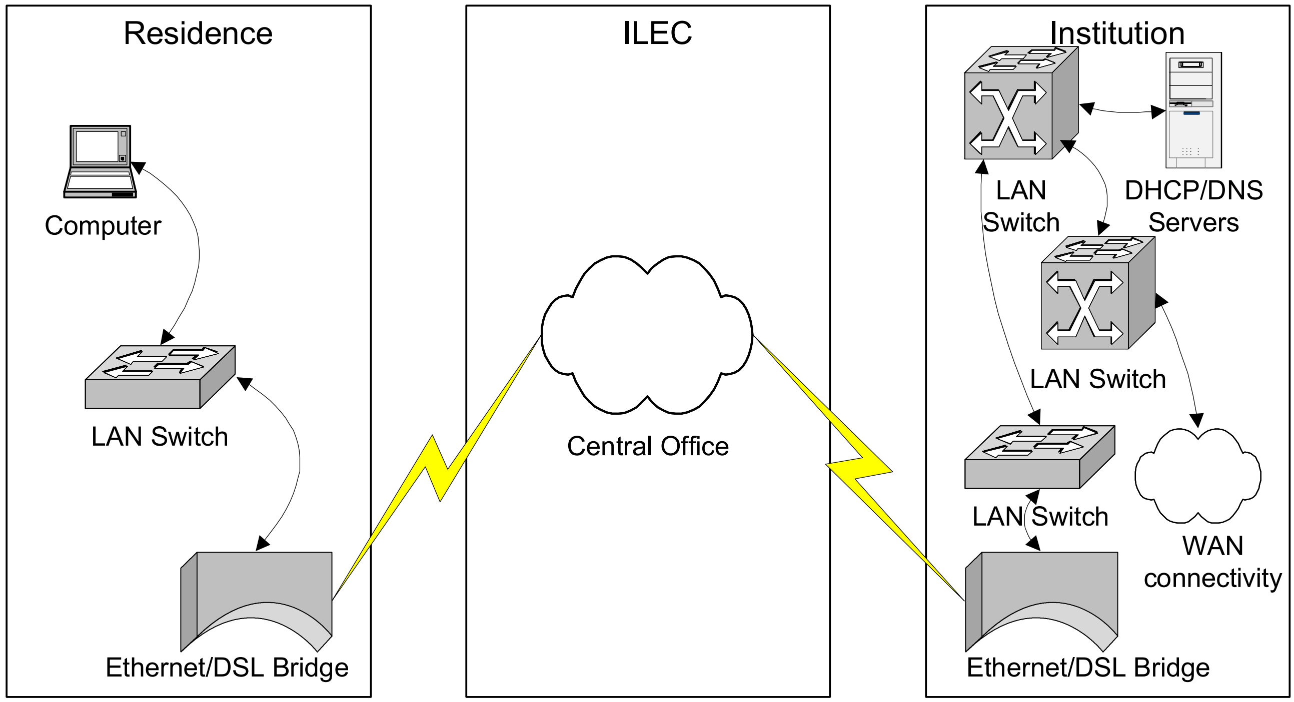

Figure 1. Network Architecture Summary

O2. Can I get permission to connect the co-located electronics to the inter-college consortium Virtual Local Area Network (VLAN) backbone?

O3. Can I get permission to create a switched connection from the college consortia VLAN backbone to the Class B subnet for my specific college?

O4. Can I get both standard DHCP service and a fixed (static) IP address?

Technologically, there were three two open questions—

T1. Is it possible to provision a loop from my residence to the institution that is suitable for some type of HDSL connectivity?

T2. What is the maximum throughput that can be realized?

T3. Is the connection reliable and maintainable?

Economically, there were two open questions—

E1. What are the costs (installation and recurring charges) for a custom circuit?

E2. What are the costs (procurement and on-going maintenance) for HDSL equipment?

In general, the critical decision path in the planning, analysis, design, and implementation sequence is as follows:

R1, 01, T1, E1, E2, O2, 03, T2, 04, T3

If the answers to any one of the questions *R1* (it's not permitted by statute), *O1* (permission cannot be obtained from organization A), *T1* (the issues at the physical layer, most notably wire availability and loop distance, cannot be resolved), and *E1* (the recurring circuit costs are prohibitively expensive) are negative, then this IP solution is not deployable at all. If the answers to one or more of the questions *E2* (the equipment procurement costs are expensive), *O2* (permission cannot be readily obtained from organization B), O3 (permission cannot be readily obtained from organization C), *T2* (the connection speed is low), *O4* (no static IP address), and *T3* (the system isn't reliable) are negative, then this IP solution is deployable, but sub-optimal.

The questions as enumerated in this paper are written in a form that lead to a collection of individual binary answers, most of which can be evaluated in the prescribed sequence. However, the associations among the decision criteria embedded within the various questions are deceptively subtle. Moreover, the perspectives of various stakeholders vary widely *vis-à-vis* the nature of the questions themselves, the corresponding technological and organizational boundaries, the perceived, real, or normative value of likely outcomes, or simply the depth of analysis required to sufficiently address any particular question. Because of industry

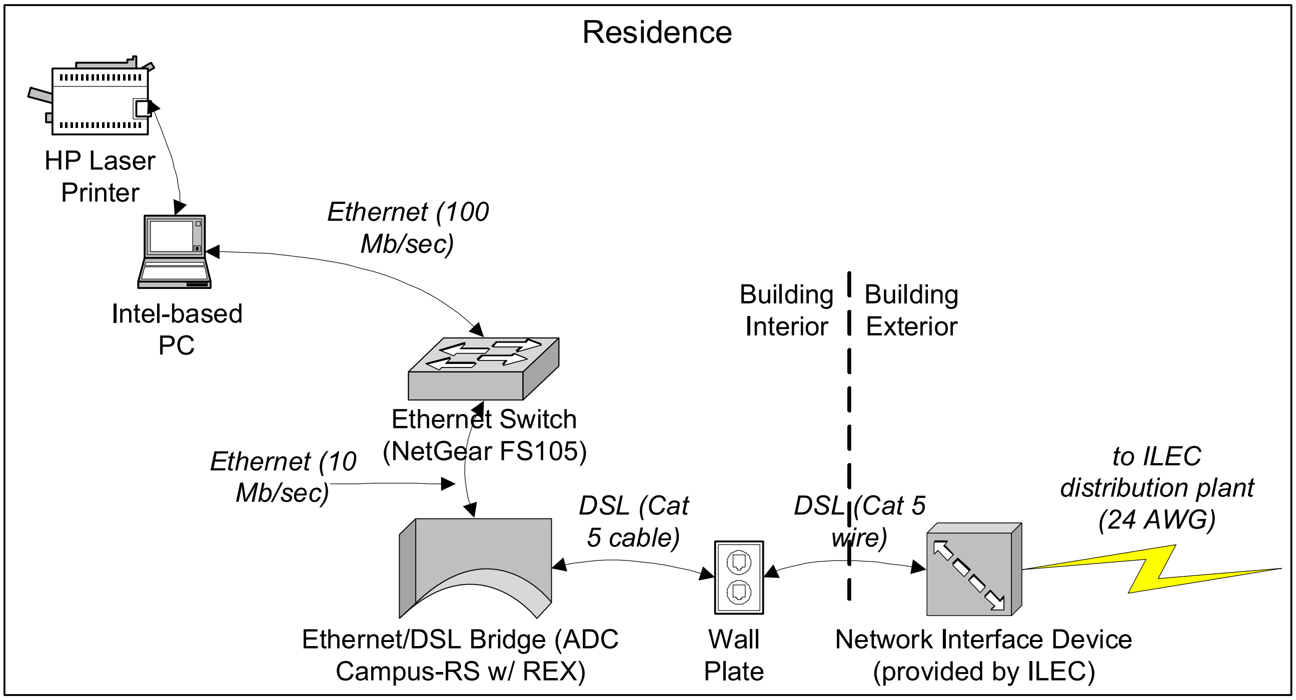

Figure 2. Network Architecture Detail - Residence

cross-subsidies and strategic alliances, it may be difficult to determine, for example, the degree of coupling (which is one element needed for formulating longer-term strategies) between *E1* and *E2*, much less whether, in general, $E1 \rightarrow E2$ or $E2 \rightarrow E1$. *R1* is probably related to *E1* and possibly *T1*. But proving whether $R1 \rightarrow T1 \rightarrow E1$ (the regulator's view), $\{E1, E2\} \rightarrow T1$ (the capitalist's view), or $\{T1, T3\} \rightarrow \{E1, E2\}$ (the technologist's view) is the dominant paradigm is non-trivial. Yet, some answers are necessary at a moderate level of detail *ex ante* if only to avoid an expensive implementation failure. Acquiring permission to perform some physical action or obtain some logical service, especially for an advanced function, in a precise, coordinated, and operationally tested manner is difficult in an organization of any size and complexity. Due to potential communication misunderstandings, varying cost and manageability concerns, and multiple unit- and institution-level strategic initiatives and goals, *01* does not imply *02*, *02* does not imply 03, and *03* does not imply 04. More specifically, even at this level of detail, the direction of the organizational *permission* may be different than direction of the organizational *implementation*.

Finally, note that although *T3* appears last in the sequence of technological *adoption*, it might appear first in a sequence of technological *abandonment*. Although not the central theme in this particular paper, a deeper understanding of these relationships is necessary to inform key decision-makers, including residential end-users configuring networks that traditionally were performed only for businesses, especially for businesses with larger LAN/WAN infrastructures and corresponding deeper pockets. Additional work needs to be done to both identify the key determinants and externalities of each question and discern the directionality, multiplicity, and overall effect of each factor in the decision-making process.

5. System Architecture and Design

Residence (Figure 2). Although my laser printer is Ethernet-enabled, it makes little sense to place it on the network without a specific intervention to limit either the Ethernet frames (e.g., a VLAN switch) or the IP packets (e.g., a router) to a smaller network diameter. Although 100 Mb/sec Ethernet is currently over-provisioned with respect to the speed of the DSL, 100 Mb/sec Ethernet devices for PC's are in widespread use. Further, Gigabit network devices (e.g., Apple Mac PowerBook G4) have been readily available to consumers for at least two years and local electronics stores sell both gigabit switches and Cat Level 6 Level 7 copper patch cables. The 5-port Ethernet (unmanaged) switch permits additional Ethernet devices, specifically other notebooks with other

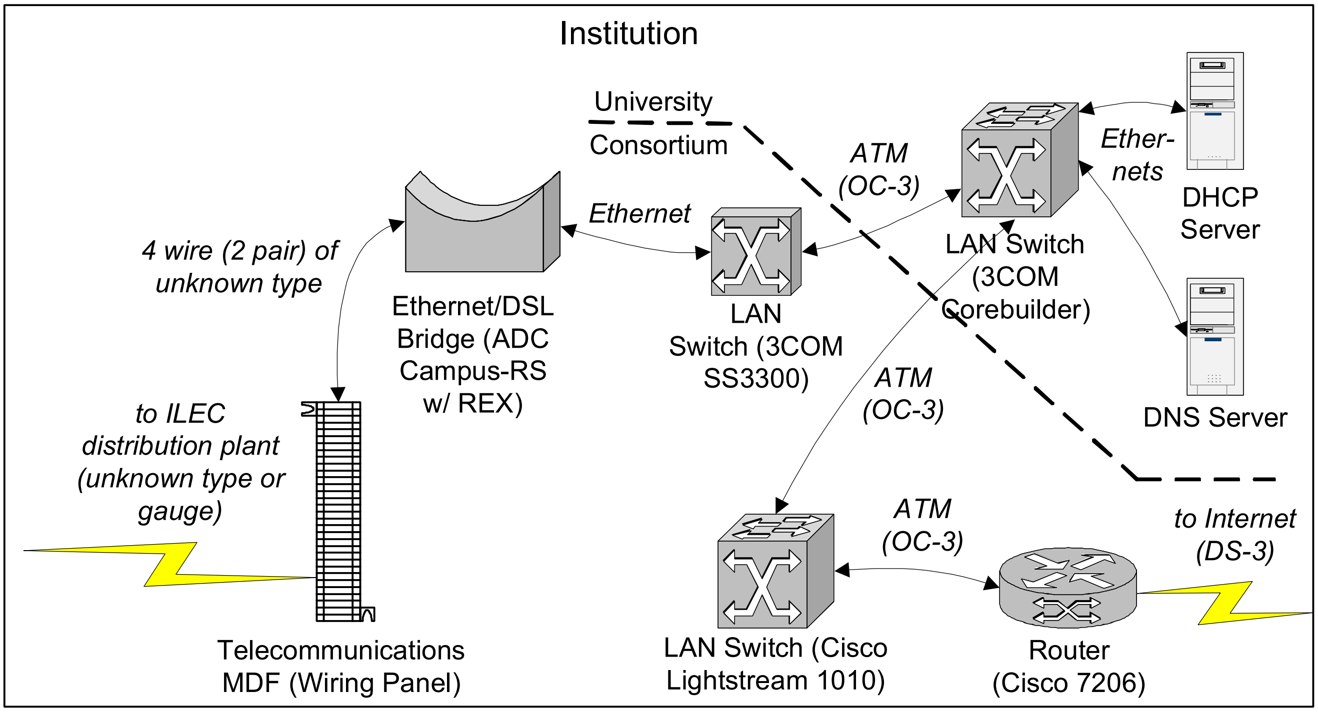

Figure 3. Network Architecture Detail - Institution

configurations, to be attached to the network simultaneously. The Ethernet/DSL bridge requires only minimal configuration as transparent Media Access Control (MAC) forwarding is the default configuration for this device at Link Layer. The ILEC needed to install a new Network Interface Device (NID) on the exterior of my residence. The NID provides better physical access security, ground-fault and lightning protection, and wire management capability.

Institution (Figure 3). The demarcation point for this circuit is a punch block located in the Main Distribution Facility (MDF) managed by the consortium (i.e., multiple Universities) organization at my institution. The Ethernet/DSL bridge located in the MDF requires no site-specific configuration. My co-located bridge, along with approximately six other bridges of an older, but similar type, is attached to a 16-port 3COM (managed) SS3300 switch on the consortium virtual LAN (VLAN). Ethernet frames flow from this device to the primary (there are two others) 3COM Corebuilder enterprise switches via port-based VLAN configuration directives. This switch provides the basic connectivity to servers and hosts providing traditional network functionality, including the two most important for this configuration, Dynamic Host Configuration Protocol (DHCP) and Dynamic Name System (DNS). The Cisco Lightstream is also managed by the consortium and provides inter-campus connectivity. There is not one, but two paths for Internet connectivity. In addition to the existing 45 Mb/sec Internet connection via Quest, an additional connection to high-speed regional (CalREN-2) and national (Internet2) educational backbones via a 20 Mb/sec connection to Los Nettos (managed by the University of Southern California) is scheduled to be implemented in May, 2002.

ILEC (Figure 4). An additional wire pair was run between the NID and first telephone pole in the ILEC distribution plant. Several physical and logical changes were made by ILEC installers in the distribution plant between both my residence and the institution to adequately provision the four-wire loop. In my immediate neighborhood, the distribution plant is generally above-grade and the feeder plant is entirely below-grade. The intermediate subscriber terminal for the connection between the CO and my residence is a box located to the rear of a shopping center. The terminal primarily contains punch blocks for wire cross-connects. I received differing and unconfirmed information from the ILEC technicians as to the precise physical topology between the Central Office and the institution. I am not familiar with the type of equipment that is located in the Central Office to connect the two pairs of wires together to complete the four-wire circuit.

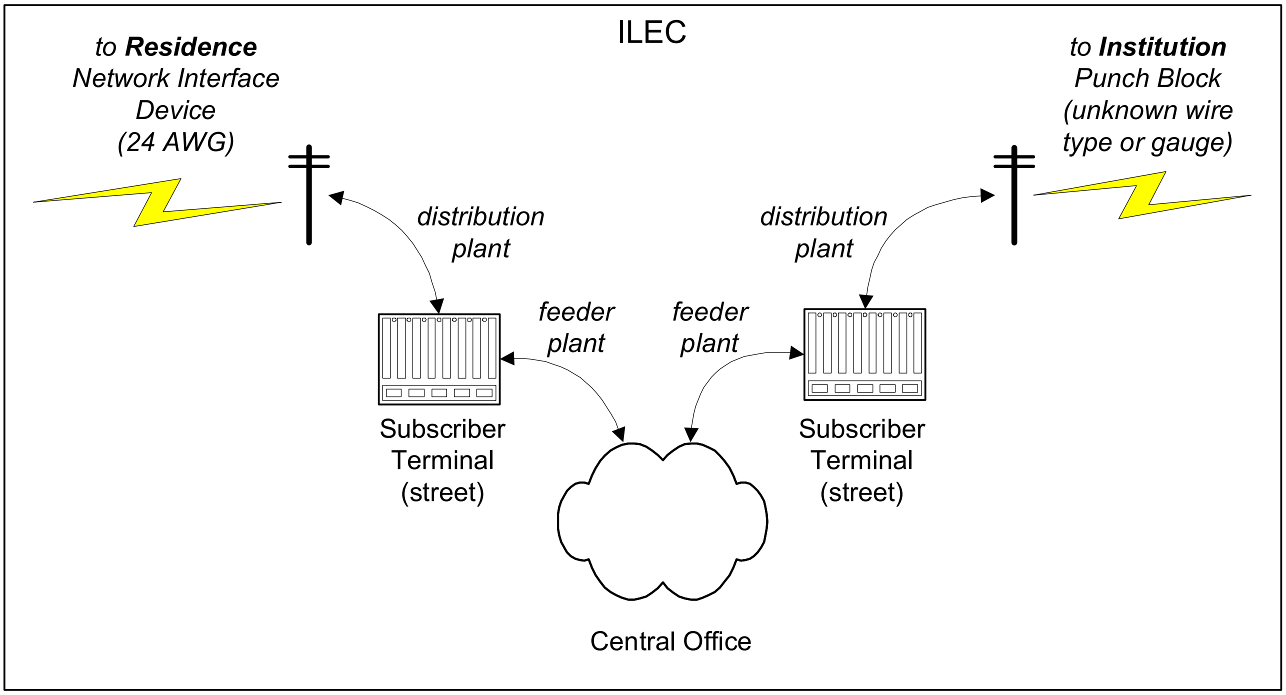

Figure 4. Network Architecture Detail - ILEC

6. Chronology of Implementation

Figure 5 summarizes the key interactions involved in implementing this IP over HDSL strategy. Although not shown explicitly in the diagram, the interaction dialogue occurred using multiple modalities, including in-person (initial approvals and installation testing), telephonic (circuit and equipment orders), and electronic mail (VLAN and IP Service). Note that from the perspective of desired success, some tasks are more suited to one type of modality than another (e.g., email for better historical documentation and in-person for complex, interactive discussion). For some message flows, I simply didn't have a choice as to communication strategy. The first paper transaction in this entire process was the first check that I wrote to the ILEC after the bill came for the initial month of service. The elapsed time of this implementation was August, 2001 to January, 2002.

The "Expose Intent" flow was needed because eventually, irrespective of which physical layer or data-link layer option was implemented (or by whom), I'd need network layer services. I didn't want the network manager to be "blind-sided" by an unilateral, unusual request at a future date (especially after an expensive circuit and/or equipment had been procured). The "Discuss Alternatives" meeting was extremely productive and was the linchpin in the process. We evaluated several options, discussed recommended vendors and equipment specifications, and reviewed the equipment and network topology of similar equipment that was already operational in the telecommunications facility. This provided me with both an organizational precedent and a technological prototype.

Ordering the equipment was relatively straightforward. The only issue was that HDSL equipment is not sold directly in retail stores, so I needed to learn about and work through a sales channel designed primarily for professional telecommunications and networking technicians. My initial order for the circuit, however, was more problematic. The first problem was that the ILEC sales manager didn't know what type of service I was requesting. So I went back to the institutional telecommunications manager and asked for a circuit ID *of the exact same type of circuit that was already in operation at the facility*. I then provided that information to the ILEC and after a few more telephonic exchanges with the ILEC sales and technical managers, the circuit was ordered. The second problem was that there was and extreme wire shortage in my neighborhood. After the circuit was ordered, I waited for my ILEC to find two good wire pairs (i.e., a make a four-wire circuit). After two months, I was notified that they could find one good pair, but not the required *two* good pairs. I'd need to relinquish the *existing* pair to my residence that I was using for POTS voice (and 56Kb/sec dial-up) service. The new pair and the existing pair

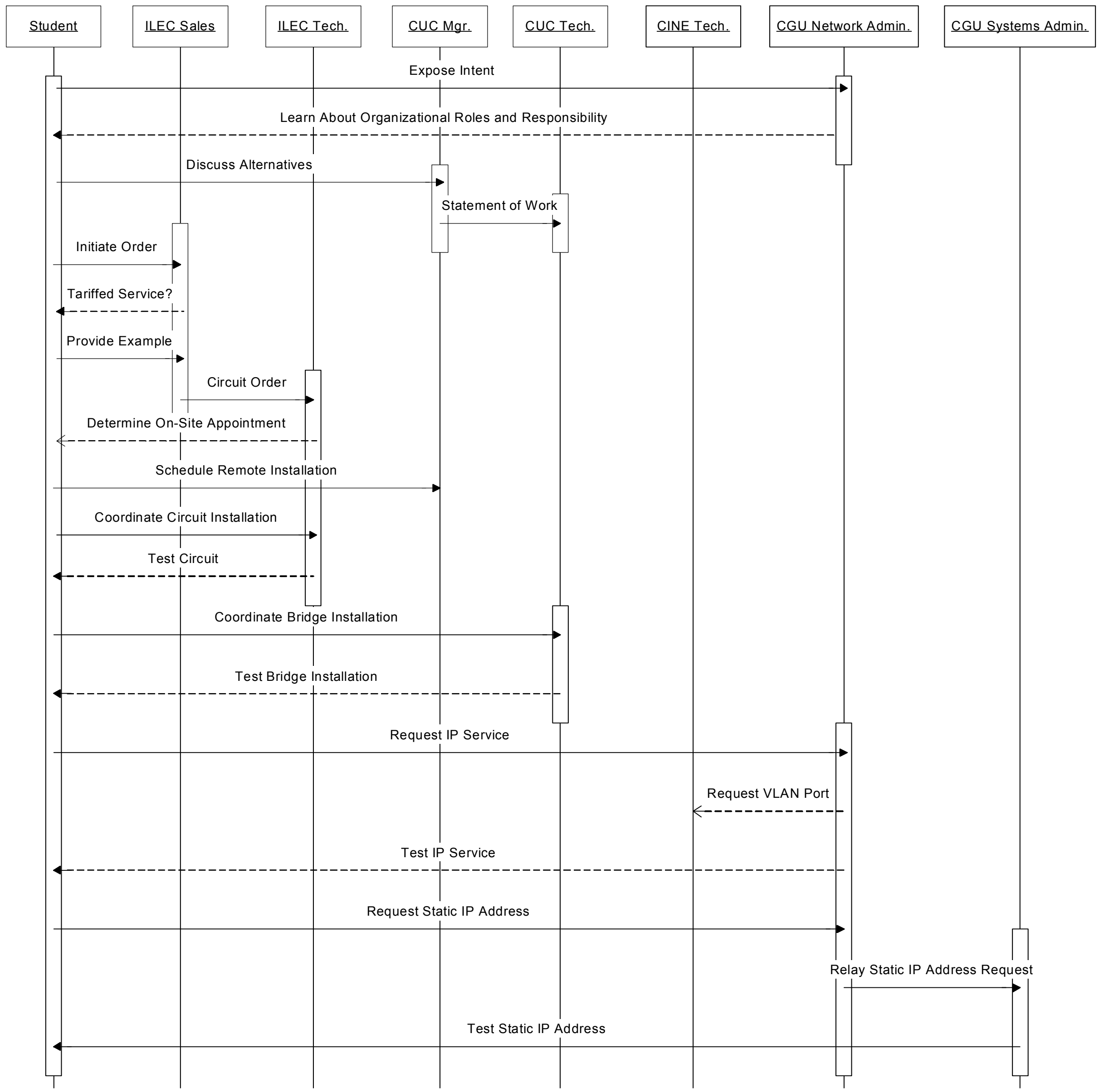

Figure 5. Instance Sequence Diagram - Summary of Interaction Dialogue

could be combined together to complete the necessary circuit. In addition, the new pair ran only as far as the telephone pole closest to my residence. Therefore, the new pair needed to be connected from that pole to my residence with new wiring.

One of the things that I did was to do some background reading on the physical layer requirements for DSL [12]. I came to learn that there 1), is a very wide disparity in loop conditions, 2), testing instruments are occasionally out of calibration, and 3), cable plant records are not necessarily accurate or up-to-date. HDSL circuits have an extremely low tolerance for "loading" or "noise" on the circuit. Partially as a result of this background reading and partially on the advice of the consortium telecommunications manager, I was not only present during the several hours over two days of the circuit installation and testing, I explained to the ILEC technicians what the circuit was going to be used for and asked the technicians to check and double-check their wiring and instrumentation readings. While my existing residential line could be used as one-half of the circuit, the ILEC technicians (one technician needs to be at each of the two locations simultaneously) had to go through two other pairs (the original pair as specified on the order

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did not fully meet the proper loop conditions) before they found a suitable pair. Although this process required an extended amount time, it was the only way to optimally provision the loops adequately. In particular, I asked the primary ILEC technicians to double-check the Tip-to-Ring, Tip-to-Ground, and the Ring-to-Ground load factors as well as the longitudinal balance. The length of one loop was 9,690 feet and the length of the other loop was 12,620 feet. Although it seems counterintuitive that there could be 3,000 feet of "extra" copper between two locations (especially two facilities located near each other and the CO), both the primary ILEC technician and the consortium technician told me that not only that this was indeed common, but in fact, much larger variances exist in the area served by this CO. I also learned that according to the primary ILEC technician, some of the copper distribution plant in my area was more than 50 years old. Compared to the circuit installation, installing and configuring the HDSL equipment and then attaching it to an available Ethernet port on the Ethernet switch was relatively straightforward. The only minor problem was that I discovered was that one wire pair had been inadvertently reversed running from the punch block to the co-located equipment in the consortium telecommunications facility.

I also download the errata sheet for the manuals from the HDSL equipment vendor's (ADC) web page. This described, interestingly, that the maximum speed of this HDSL equipment was 2.304 Mb/sec, not 4.608 Mb/sec. DSL is designed to operate with a Signal-to-Noise (SNR) ratio of 6 dB to achieve a Bit-Error-Rate (BER) no higher than 10^{-7}. Each HDSL unit has an LCD screen that displays the local and remote operating margins above the minimum 6 dB level. These margins are constantly fluctuating and each individual loop varies (due to different loop lengths and impulse noise), but operate as a circuit at approximately 16 dB SNR at a data rate of 1.544 Mb/sec and at approximately 10 dB SNR at a data rate of 2.304 Mb/sec.

IP service was initially tested via the consortium's DHCP server, until the VLAN could be configured to properly switch my Ethernet frames to my own University's DHCP server. Note also from Figure 1 that the request for a static IP address needed to be received by the University *system* administrator from the University *network* administrator (and not from me). The system has remained stable for more than five months. The DSL connection did go down for a day in the fourth month of operation, but neither the personnel at the institution nor the ILEC could determine the root cause (although there was some significant precipitation during that week). To reactivate the connection, I had to cycle the power to the local HDSL equipment. Minor problems have arisen at the network layer, (e.g., the DHCP lease time is a bit too long and reverse DNS is not implemented), but various workarounds exist to address each of the issues.

7. Future Enhancements and Conclusion

The technologies and markets will certainly continue to evolve with respect to residential broadband. A number of infrastructure enhancements and research studies are possible in the future. Each of these options should be evaluated along the same methodological dimensions—organizational, technological, and economic.

Due to the physical geography of the Southern California metropolis (i.e., characterized by both large and mid-size mountains), wireless solutions can be problematic to engineer correctly, but very useful when feasible. For example, the broadcast towers for nearly every one of the TV stations (and a number of FM stations as well) are located on just one mountaintop (Mt. Wilson)--and that site is only of moderate height in the region. A number of possibilities exist for deploying a Broadband Wireless Access (BWA) solution to a large number of constituents using Multichannel Multipoint Distribution Service (MMDS) and to a lesser extent (due to operational range), Local Multipoint Distribution Service (LMDS). A technological overview of LMDS and MMDS can be found in [11]. A technological overview of Fixed Wireless Services (especially satellite) can be found in [1]. In April, 2002, the IEEE published the 802.16 ("WirelessMAN") specification [17]. This specification employs a variety of bands between 11 GHz and 66 GHz and opens the door for high-speed, residential broadband networking connectivity with access contours significantly larger than 802.11b or 802.11a. This could include antennas at various Height Above Average Terrain (HAAT) levels leading to a new physical layer alternative in the competitive "last mile" market space.

The number of DSL providers and their associated service offerings is constantly changing. Naturally, any analysis would need to incorporate both the quantitative and qualitative "switching costs" concomitant with such a systematic change.

My ILEC has a number of options that might be useful in future [16]. Among them are "SONET", "High Capacity DS1 and DS3", and "Transparent LAN Services (TLS). I already have the throughput equivalent of "High Capacity DS1" (1.544 Mb/sec), but I suppose I might be able to utilize the 45 Mb/sec speed of the "High Capacity DS3" (45 Mb/sec) offering in future. This type of service would most likely be deployed via fiber. "Transparent LAN Services (TLS)" eliminates the DSL layer altogether. TLS connects an Ethernet (10 Mb/sec or 100 Mb/sec) or Token-Ring LAN at the main facility and a similar LAN at a remote facility via single-mode fiber and switched at the link (MAC)-layer within the ILEC CO. The necessary technological requirements for "end-to-end", wide-area Ethernet are known and the service is practical today in many regions, particularly large urban environments [9]. It would be useful to explore this service with other network researchers.

Probably the two most productive improvements in the short-run would be to continue using a DSL connection to the institution, but implement newer HDSL2 or Rate Adaptive ADSL (RADSL) technologies. HDSL2 improves upon HDSL by 1), reducing the wiring requirements from a four-wire circuit to a (significantly more common) two-wire circuit and 2) reducing crosstalk in the wire bundle and Trellis-coded modulation to improve channel efficiency (see pp. 35-41 in [12]). In principle, both HDSL2 and RADSL should be feasible on the existing circuit, although only empirical, *in situ* testing can determine that with any degree of precision. Another option would be to simply deploy a traditional ADSL solution, albeit with no access multiplexing.

This paper has described a single implementation of a residential broadband networking strategy. This implementation was unique in that it used the HDSL form of xDSL, and that the terminus of the connection was not located at a traditional ISP or ILEC/CLEC. This implementation was successful, although several obstacles needed to be overcome throughout the process. One important lesson is that even sound and stable technologies cannot be deployed without substantial planning, including attention to subtle details such as the institutional organizational knowledge base and the roles and responsibilities of individual staff professionals.

8. Acknowledgements

The custom IP solution described in this paper would not have been possible without the assistance and guidance of several individuals. In particular, Danny Gmeiner and Don Ho facilitated the provisioning of the telecommunications and equipment co-location, and Darrel Martinez and Andy Davenport facilitated the various VLAN and LAN configurations. Mark Putnam, the primary ILEC installer, expertly installed the four-wire circuit and supplied additional information about the local loop structure and testing instrumentation. I am indebted to them for their time and patience. Dissemination of this research was partially supported by the Center for Management and Organization at California State University, Northridge.

9. References

[1] Barbounakis, I, Stavroulakis, P., and Gardiner, J., G. (2000). General Aspects of Digital Technologies for Wireless Local Loops. *International Journal of Communication Systems*, May, 13(3), 187-206.

[2] The Digital Workforce: Building Digital Skills at the Speed of Innovation, (1999). *U.S. Department of Commerce,* June. <http://www.ta.doc.gov/Reports/itsw/digital.pdf> (accessed on May 18, 2002)

[3] Falling Through the Net: Defining the Digital Divide. (2000). U.S. Department of Commerce, October. <http://www.ntia.doc.gov/ntiahome/digitaldivide/> (accessed on May 18, 2002)

[4] Huff, W. D. (2000). Colleges and Universities: Survival in the Information Age. *Computers and Geosciences*, Pergammon, July, 26(6), 635-640.

[5] Internet2. <http://www.internet2.edu/>

[6] Introduction to The Internet and Higher Education. (1998). Editorial. *The Internet and Higher Education*, Elsevier, 1(1), 1-5.

[7] Ives, B., Loiacono, E., and Piccoli, G. (2001). DSL Provisioning: Redefining "Customer Service". *Communications of the Association of Information Systems*. December, 7(21).

[8] Luker, M. (Ed.) (2000). *Preparing Your Campus for a Networked Future*. Educause Leadership Strategies series. Jossey-Bass.

[9] Minoli, D., Johnson, P., and Minoli, E. (2002). *Ethernet-Based Metro Area Networks: Planning and Providing the Provider Network*. McGraw-Hill.

[10] Rowe, B., (2000). Strategies to Promote Advanced Telecommunications Capabilities. *Federal Communications Law Journal*, School of Law-Bloomington: Indiana University, March, 52(2).

[11] Sari, H. (1999). Broadband Radio Access to Homes and Businesses: MMDS and LMDS. *Computer Networks*, February, 31(4), 379-393.

[12] Starr, T., and Cioffi, J. M., and Silverman, P. J. (1999). *Understanding Digital Subscriber Line Technology*. Prentice-Hall.

[13] Wolcott, P., Press, L., McHenry, W., Goodman, S., and Foster, W. (2001). A Framework for Assessing the Global Diffusion of the Internet. *Journal of the Association for Information Systems*, November, 2(6).

[14] See, for example, Corporation for Educational Network Initiatives in California (CENIC). http://www.cenic.org/

[15] See, for example, <http://www.dslreports.com/>.

[16] See <http://www22.verizon.com/enterprisesolutions/ProdSolns/ProdGroup.jsp?name=Data+Services>

[17] For more information, see <http://grouper.ieee.org/groups/802/16/index.html>.

[18] See, for example, the Telecommunications Deployment Plan (1996) produced by the Southern California Association of Governments (SCAG). <http://www.scag.ca.gov/pub/others/execsum.pdf> (accessed on May 19, 2002)