ADSL over ISDN, DAML, and Long Loops

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As new technologies evolve, new challenges arise for telephone companies. Some of these challenges include deploying asymmetric digital subscriber line (ADSL) over integrated services digital network (ISDN) and digitally added main line (DAML). Others include extending the reach of ADSL over loops longer then 15,000 feet. In this paper, we will examine those challenges and offer solutions to telephone companies deploying ADSL.

Evolution of Telephony

Telephony has come a long way since Alexander Graham Bell's system of the 1800s. Today, there are 800 million telephone lines deployed worldwide, and telephone companies are aware that those lines represent a significant investment that can be successfully leveraged. The system that Alexander Graham Bell invented used a telephone set and a telephone exchange. The one aspect of telephony that has not changed is that the subscriber end still has a standard telephone set, although it has evolved over several generations (see *Figure 1*). The exchange, however, has undergone dramatic changes ever since the introduction of Mr. Bell's "electrical speech machine." One major change is the addition of digital subscriber loop access multiplexers (DSLAMs) and splitter shelves to the traditional Clas-5 switches and main distribution frames (MDFs) in the telephone exchange.

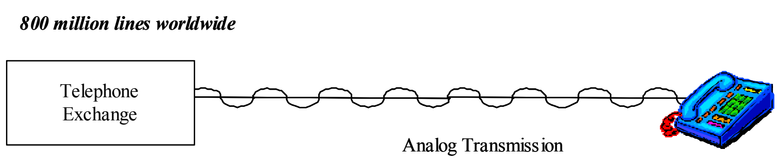
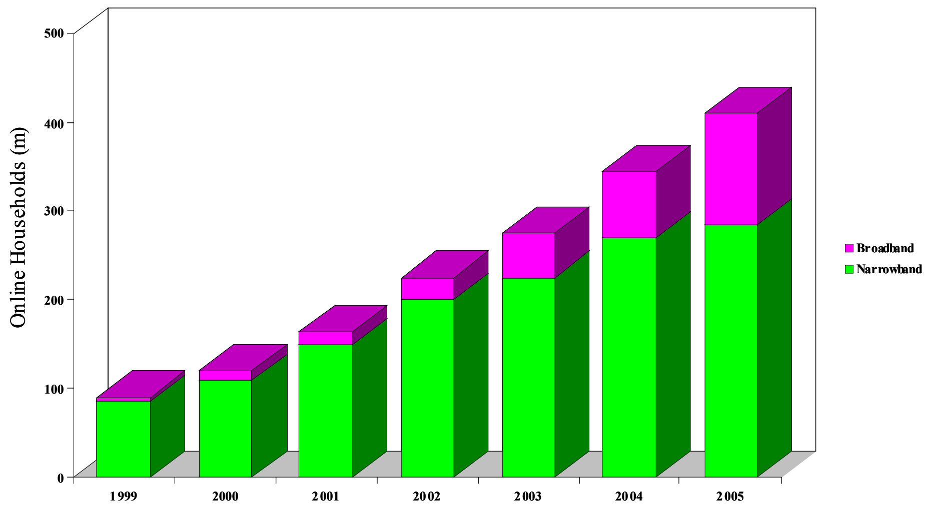


Figure 1: *Twisted Pair Transmission*

For more than a hundred years, millions of telephones connected to telephone exchanges around the world have relied on baseband analog transmission limited to the frequency range from 300 to 3,400 hertz (Hz). The plain old telephone service (POTS) has survived and even flourished over the years as new technologies such as ISDN, DAML, and ADSL were introduced in the local loop by telephone companies. The evolution of the local loop continues, with new technologies such as the symmetric high–bit-rate digital subscriber line (G.shdsl) and high-speed digital subscriber line (HDSL, HDSL2, and 4-Wire HDSL, called HDSL4) being introduced by telephone companies.

Today's ADSL Telephony

Of all these loop technologies, ADSL is the only one that delivers additional bandwidth to a subscriber over a single copper pair without any impact to the POTS service, and it has received a tremendous response from subscribers as well as service providers. The phenomenal success of the World Wide Web (WWW) concept of the Internet has contributed to the significant increase in the number of households that have online access. Whereas POTS and basic rate integrated services digital network (BRI) support narrowband (144 kilobits per second or less), ADSL and other DSL technologies, including primary rate interface (PRI) with an integrated services digital network, support broadband (384 kbps or higher). Broadband has been growing rapidly. Narrowband, which is in standard modems, still dominates in terms of Internet connections, but the yearly growth rate for broadband has been significantly higher and represents the future of digital subscriber line (see *Figure 2*).



Source: DSL Forum

***Figure 2**: Growth of Broadband*

Today's DSL market has two main segments—residential and business DSL—and the requirements and issues that arise for providers are different for each segment. The residential market is high volume and low margin. The business market is high margin with a strong demand for value-added services. The total DSL deployment for both residential and businesses is expected to more than triple by the year 2004 (see *Figure 3*). ADSL technology is expected to continue to dominate the residential DSL segment because most subscribers in this category mostly *receive* information downloads. The business DSL segment will continue to be dominated by symmetric DSL technologies such as SDSL, HDSL, HDSL2, and G.shdsl (G.991.2) because most businesses need to *transmit* as well as *receive* data at high speeds.

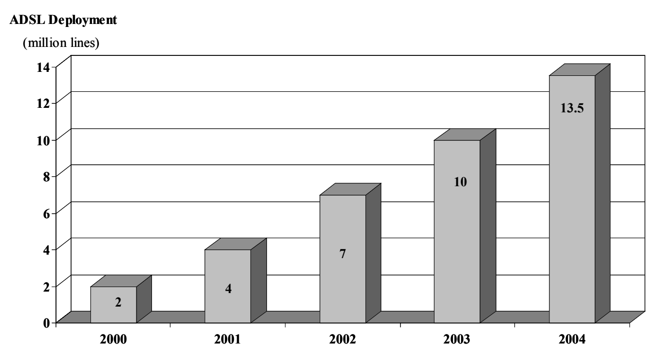


***Figure 3**: ADSL Deployment*

Fundamentals of DSL

The basic concept of DSL is relatively new, yet simple. A central-office terminal (COT) is placed in the telephone exchange (central office) and a remote terminal (RT) is placed either inside or outside the subscriber's premises. The COT and RT use digital transceivers at each end of the copper wire, converting it to a digital pipe (see *Figure 4*).

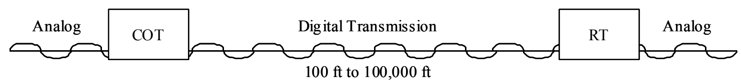


***Figure 4**: Converting "Analog Copper" to "Digital Copper"*

This concept of digital transmission over existing copper pairs was first commercially deployed in the ISDN to provide voice and data services at rates up to 144 kbps to subscribers worldwide. The objective of ADSL is to provide significantly higher data rates, as high as 8,000 kbps downstream and 600 kbps upstream to meet the growing demand for bandwidth.

POTS Splitter Model for ADSL
Figure 5 shows a typical POTS subscriber served by a Class-5 switch. A network interface device (NID) is typically used by the telephone companies at the point of demarcation between inside wiring on the premises and the network link to the premises. A typical NID also contains protection devices to protect against lightning strikes and other hazardous potentials.

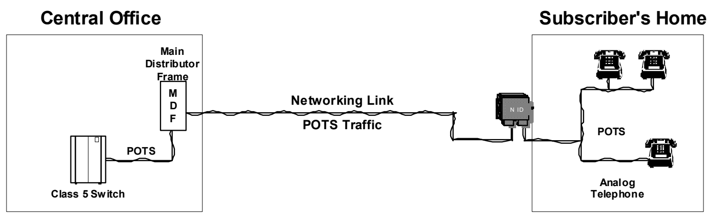


Figure 5*: A Typical POTS Installation*

The telephone subscriber in *Figure 5* can be offered ADSL service by using POTS splitters (these also function as combiners) to transmit ADSL and POTS over a single copper pair. Instead of the voice line going directly from the Class-5 switch at the CO to a subscriber's telephone, two POTS splitters are inserted, one between the Class-5 switch and the main distribution frame (MDF) and the other at the subscriber's home (see *Figure 6*).

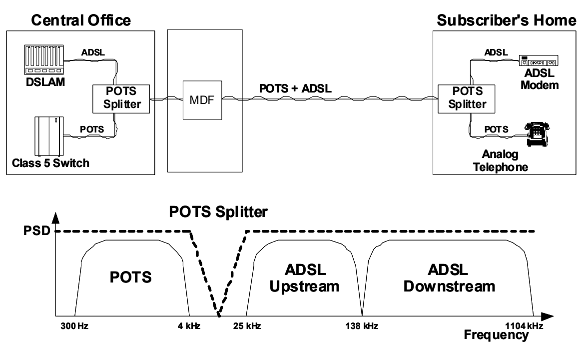


Figure 6*: Today's ADSL and Telephony*

A POTS splitter enables the data and voice signals to be combined and transported to the subscriber over a single twisted pair. At the subscriber location, a split is made into the POTS line and the ADSL line. The POTS splitter can be installed either in the NID or inside the subscriber premises based on a telephone company's installation guidelines.

Using the ADSL technology on that same copper pair, another signal would be sent in two parts, the ADSL upstream and ADSL downstream. On the same line there could be bi-directional transmission or frequency multiplexing. *Figure 6* shows a frequency-division model in which the ADSL upstream and ADSL downstream are separated. In actual implementation, upstream and downstream signal could be intermixed.

POTS Filter Model for ADSL Self-Installation Kits

Telephone companies would prefer to service or add as many subscribers as possible without any trucks rolls. The installation of a POTS splitter in the NID as shown in *Figure 6* required a truck roll and resulted in a slow start for ADSL deployments. An alternative to the POTS splitter is to install an in-line filter for all telephones in the house and to include the POTS splitter as an integral part of the ADSL modem (see *Figure 7*). A telephone company can mail an ADSL “self install” kit to its subscribers containing filters and an ADSL modem. The basic principle is that no POTS splitter needs to be installed in the NID. However, every phone or fax machine on the premises must be connected to the telephone jack on the wall through a small POTS filter. The POTS filter blocks the ADSL signal from interfering with the telephone-set operation. This eliminates the need for a truck roll in as many as 80 percent of installations, as reported by major telephone companies in the United States.

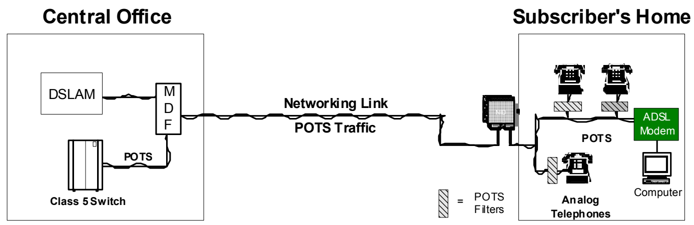


Figure 7*: POTS Filter Model for ADSL*

Line-Sharing Requirement

During the early phase of DSL deployments, the incumbent local exchange carriers (ILECs) limited the availability of unused copper pairs to the competitive local exchange carriers (CLECs). The legal disputes between ILECs and the CLECs led the Federal Communications Commission (FCC) to mandate line sharing, allowing a CLEC to offer ADSL service to an ILEC subscriber by sharing the existing copper wire instead of requesting a new pair. As shown in *Figures 6* and *7*, the use of POTS splitters or filters allows the mixing of POTS and ADSL signals. That lets a CLEC provide ADSL service to new subscribers even while they stay connected to the ILEC for their voice service. It is important to note that of all the DSL technologies mentioned in this paper, ADSL offers the most convenient solution for line sharing. Technologies such as G.shdsl or ISDN incorporate base band (300 to 3400 Hz) frequencies as a subset of the overall transmission range, and that makes it impossible to separate POTS using filters or splitters. A telephone subscriber who is served by ISDN or DAML technologies does not, therefore, qualify for FCC–mandated line sharing.

ADSL Conflict with BRI–ISDN

The POTS splitter/filter model of ADSL as described in previous sections conflicts with the basic rate interface (BRI) of ISDN deployments in many parts of the world. With BRI–ISDN, a subscriber receives two voice channels and a signaling data channel instead of the standard POTS connection. Whereas the POTS signal was limited to a maximum frequency of 4 KHz, the BRI–ISDN signals range from 300 Hz to 80 KHz. The lower end of the ADSL signal range (from 25 KHz to 1104 KHz) conflicts with the higher end of the BRI–ISDN signal (see *Figure 8*). This conflict makes it impossible for a POTS splitter/filter-based ADSL to coexist with ISDN–BRI. In the United States and other parts of the world where there is little ISDN deployment, this conflict has not proved a major obstacle to ADSL deployment.

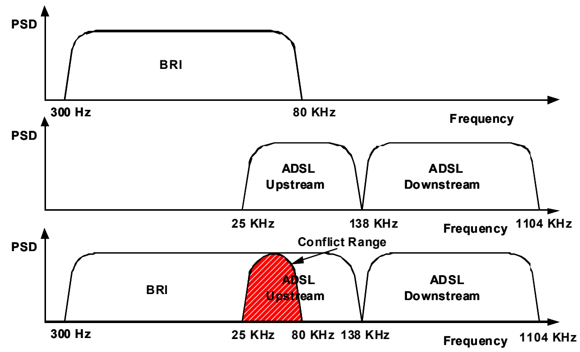


Figure 8*: ADSL Conflict with ISDN*

One potential solution is to change the POTS filters and splitters to BRI splitters, allowing the ADSL transceivers to operate over BRI–ISDN lines. To eliminate a frequency conflict, however, the bandwidths must also be changed (see *Figure 9*), enabling both technologies to coexist on the same line. Germany, which uses BRI splitters, has adopted this solution. Companies selling ADSL equipment in Germany have adjusted frequencies by moving the lowest ADSL frequency beyond the highest BRI–ISDN frequency, so that the ADSL upstream and downstream bandwidth can be separated from the BRI spectrum, just as POTS splitters in the United States separate the POTS from the ADSL.

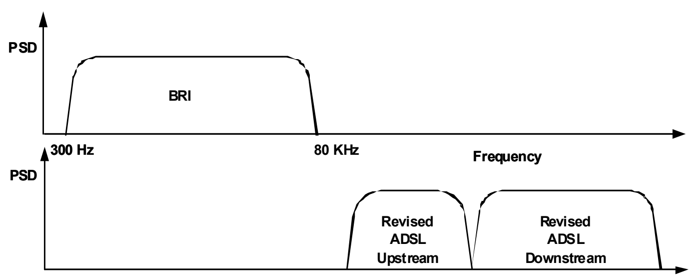


Figure 9*: Power Spectral Densities (PSD) for BRI and ADSL*

But the BRI splitter solution is not without its own problems. After adjustment, the bandwidth reserved for BRI is the spectrum from 300 Hz to 80 KHz, which reduces and significantly limits ADSL data rates. Increased noise caused by the use of higher frequencies on the copper pairs is another problem created by the adjusted bandwidths, because disturbance increases at higher frequencies. The use of BRI splitter/filters further reduces the reach of the ADSL because attenuation of a signal is proportional to its frequency.

Another solution that avoids the use of BRI splitters relies on multiplexing BRI–ISDN signals and ADSL data on the same copper pair at the central office and demultiplexing these two at the subscriber's premises (see *Figure 10*). The ADSL data is usually in the form of asynchronous transfer mode (ATM) packets of Internet protocol (IP) packets. The IP packets are most conveniently transported over 10/100BaseT Ethernet links. This would be a viable solution in Europe, where the BRI lines come out of the NID, and it would be the solution for deploying ISDN equipment.

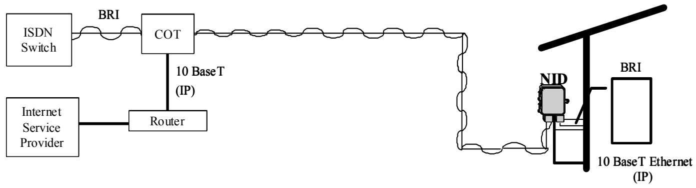


***Figure 10**: Derived BRI and 10BaseT Ethernet*

The standard ISDN terminal inside the subscriber's premises still connects to the ISDN at the NID. To effectively transport BRI–ISDN and 10BaseT over a single copper pair, the RT and COT equipment in *Figure 10* needs HDSL, HDSL2, or G.shdsl transceivers.

ADSL Conflict with DAML Installations

Increasing numbers of residential subscribers request a second phone line, in order to connect their modems and fax machines while keeping the main line available for voice calls. The limited availability of copper pairs forced the telephone companies to use DAML equipment to multiplex two POTS lines in the central office and demultiplex them in a NID at the subscriber's premises to allow two voice circuits to be provisioned over a single copper pair (see *Figure 11*).

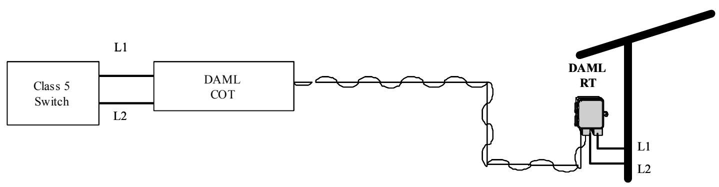


***Figure 11**: DAML for Two POTS on One Copper Pair*

The two-line DAML equipment relies on BRI–ISDN transceivers in the COTs and RTs to establish a digital transport mechanism to create the bandwidth needed to transport two voice channels over a single copper pair. In recent years, the DAML technology has evolved to 4, 6, 8, and 12 voice lines over a single copper pair using HDSL transceivers in the COTs and RTs.

Approximately three million copper pairs in the United States are connected to DAML equipment for delivery of voice lines. If a subscriber currently served through DAML equipment requests an ADSL connection, that subscriber's request has to be turned down unless an unused copper pair is available from the central office to that subscriber's premises. This has become a major obstacle in the deployment of ADSL because marketing studies have shown that a typical second line subscriber (likely to be served by DAML equipment) is more likely to be a potential ADSL subscriber. ADSL cannot coexist with DAML on the same copper pair for the same reason it cannot coexist with BRI–ISDN (or HDSL for similar reasons) as explained earlier.

Studies have indicated that subscribers often choose to keep their second line even when they request an ADSL connection. There are many ways of accomplishing this. One way to solve the ADSL problem with the DAML installations is to derive the POTS lines at the RT and then offer a 10BaseT link at the RT (see *Figure 12*). Instead of actual ADSL, transceivers that emulate ADSL service are included in both the COT and the RT. Data service is provided using 10BaseT Ethernet for the Internet connection and coexistent with POTS lines on the same copper pair.

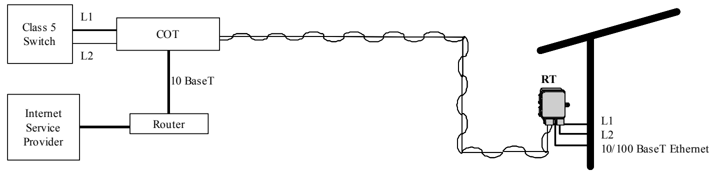


***Figure 12**: Derived POTS and 10/100BaseT Data*

Limited Reach of ADSL (Conflict with Long Loops)

The ADSL technology was invented primarily for the video-on-demand (VoD) application and was considered to have the promise to deliver bandwidth as high as 6 to 8 Mbps over existing telephone lines. One of the limitations of ADSL is that reliable communication between an ADSL COT (ATU–C) and an ADSL RT (ATU–R) is rarely possible over loops longer than 12,000 to 14,000 feet. Subscribers at about 18 kilofeet (kft) from the central office can only get rates comparable to BRI–ISDN. This problem has significantly impeded ubiquitous deployment of ADSL. Subscribers that have to be turned away because they live more than 15,000 feet from the central office are likely to sign up for cable-modem service, resulting in significant lost revenue for the telephone companies.

There are two solutions for resolving ADSL distance limitations:

1. Use of ADSL mid-span repeaters
2. Derived ADSL using COTs and RTs.

The first solution is relatively simple (see *Figure 13*).

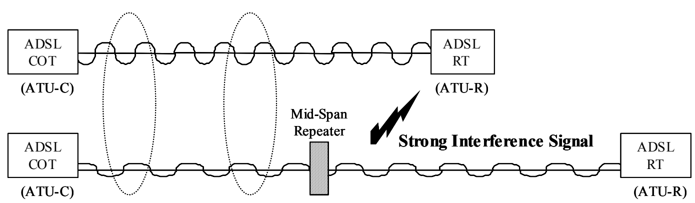


***Figure 13**: Extending ADSL Range Using Repeaters*

The telephone companies generally prefer to avoid mid-span repeaters because of the increased installation cost and the increased noise on the line. A mid-span repeater, even if it is on a different line, can produce disturbance in the cable bundle. A repeater produces a strong signal at the midpoint, which can interfere with signals that are fairly weak because they have been traversing the same cable bundle to that point. As a result, the interference can be significant.

An alternative to using the mid-span ADSL repeater is to use derived ADSL (see *Figure 14*). This is similar to the techniques for using derived POTS and derived BRI described earlier in this paper.

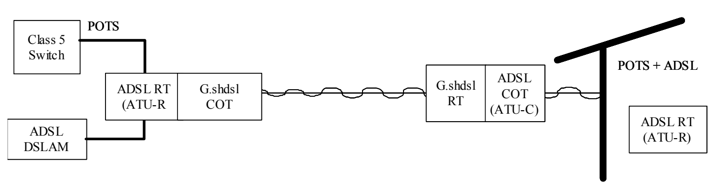


***Figure 14**: Derived ADSL Using G.shdsl*

This is an expensive method by which the range of the standard ADSL technology can be expanded. However, it is a viable solution because tens of thousands of subscribers, who already have standard

ADSL interfaces built into their personal computers (PC), want the telephone companies to provide a standard ADSL interface. The telephone company can now provide those subscribers with ADSL service, even if the long length of the loop would otherwise preclude an ADSL service.

Field trials of derived ADSL using G.shdsl have shown that 20,000 feet can be spanned without a repeater. Over longer distances, an optional repeater can double that reach. Multiple repeaters can be put on a line for even longer range.

Summary

Initially, ADSL equipment was not readily available, although there were many requests for it from subscribers. Telephone companies chose to serve those subscribers who could be serviced without a problem, generally where loops were not long, and most notably within their carrier serving area (CSA) loops. That early subscriber demand is still growing, albeit at a slower pace, and telephone companies are now addressing the requests of subscribers who live a bit further from the central office, especially in the suburbs. Suburban subscribers tend to have a high take rate for services. In general, they are homeowners, have a tendency to have multiple lines, need and will pay for high speed Internet service, and represent additional revenue opportunities to the telephone companies.

Telephone companies need to take an active role in solving DSL problems so that they can avoid losing subscribers to the cable companies. The ISDN, DAML, and long-loop challenges to ADSL deployment can be solved. The solutions lie in emulating the ADSL, the voice, or the BRI–ISDN services by using multiplexing equipment in the form of COTs and RTs. In addition, longer reach can be achieved by using a line-powered mid-span repeater between the COT and the corresponding RT.

If telephone companies do not provide the requested DSL service, then subscribers will switch to cable modems. Once subscribers have successfully completed a learning curve with cable modem, and their service performs reliably, they will tend to keep that service, and it will be very difficult to convince them to switch to DSL.