

ISDN

Integrated Services Digital Network Tutorial

With ISDN you can transmit large amounts of data, voice, and video signals over a single telephone line, at higher *speeds-and* **lower** *cost-than* any analog modem.

ARC Electronics

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Integrated Services Digital Network (ISDN)

is a high-speed digital data service typically provided by your telephone company. With ISDN you can transmit large amounts of data, voice, and video signals over a single telephone line, at higher speeds-and lower cost-than with any other digital service or analog modem - because it's a digital service, ISDN offers near-perfect line quality that's far superior to analog lines. Now line conditions will never force you to fall back to a slower speed because they engineer your line to the met the the requirements of the 2B1Q modulation they use for the basic line (2B & 1D). The local phone company will bill you for an install of the ISDN line. If they would engineer your analog phone line to specs we might go faster too - but not all lines met the specs for modems (but then again they are leasing you a Voice line not a Modem line).

There are two types of ISDN lines. The basic rate line is an ISDN user-to-network interface made up of three communications channels-two B-channels (which can bonded) for voice, data, etc. and one D-channel for signaling. The primary rate line is an ISDN-to-user network interface made up of 23 B-channels and one D-channel.

• Typical ISDN Applications

ISDN is *the perfect choice for* any number of high-volume datacomm applications where faster data rates, lower prices, and guaranteed data integrity are required:

- * Internet Access and On-Line Service
- * Telecommuting
- * Remote Office Routing
- * Videoconferencing

- * PC-to-PC Screen-Sharing and Collaboration
- * Disaster Recovery

ISDN connections are made almost instantly-typically less than a second-unlike analog modems and analog lines which can require 30 to 60 seconds before any data can be transmitted.

Also consider ISDN service when you need...

- * Datacomm service to more than one location.
- * Datacomm lines for just a few hours a day.
- * Simultaneous voice and data communications.
- * A high-speed backup line.

Is ISDN Affordable?

Absolutely! In fact, tariffed rates are *still falling!* And with ISDN already available throughout more than 70% of the U.S., strong growth and continued tumbling prices are expected well into the next century. Compare the costs of ISDN and other high-speed services, using the chart below.

Three Main Reasons to Consider ISDN:

- 1 . ISDN is a switched service. That means data connections are temporary, and the ISDN link is active only when you use it. The benefit After a small monthly fee, you pay only for ISDN calls you make. Dedicated high-speed services such as T1 charge a high monthly rate even if you don't use them.
2. ISDN supports flexible connections to multiple sites. Just like a regular telephone line, ISDN lets you dial any ISDN location-anywhere in the world! Services like DDS or T1 provide a fixed point-to-point connection, with no flexibility to dial other locations. ISDN gives you fast, flexible communications for a much lower price!
3. All-digital transmission means high performance. High-speed analog modems

A single BRI line can accommodate up to 128 Kbps over two virtual 64-Kbps Bearer (B) channels. Each B channel can simultaneously transmit digital data and fax signals, along with digitized voice and video traffic. A single 16-Kbps Delta (D) channel is allocated to support system "overhead" functions such as signaling the telecomm switching system to initiate a call

(also referred to as a 2B+D line).

What makes ISDN unique is that each B channel is a separate communication circuit. That means that just one ISDN line can support simultaneous two-way communication for two devices, such as a computer and a telephone, or a computer and a video camera for teleconferencing.

Additionally, if you need to send more data than one 64-Kbps B channel can handle, ISDN also supports the de facto **BONDING** standard for **inverse multiplexing**. This links the two B channels into a single logical circuit that can support data rates up to 128 Kbps. In fact, using ISDN multiplexors, you can now merge multiple ISDN lines for maximum data rates as high as *512 Kbps!*

Why ISDN?

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If you've used some of the newer Internet facilities -- such as graphical World Wide Web browsers or CU-SeeMe video conferencing -- over a modem connection, you realize that accessing the Internet at current modem data rates provides barely adequate performance. As applications become more sophisticated and require more bandwidth, this situation will only worsen. And if you're putting an entire corporate LAN on the Internet, a modem connection becomes a serious bottleneck. Unfortunately, the current crop of high-speed modems, running at 28.8 Kbps, are about as fast as modems will ever get. That's because a physical speed barrier exists at 30 Kbps -- a barrier that can't be broken without abandoning the modem's analog signaling for something completely different (see see The Truth About High-Speed Modems).

That "completely different" something is digital signaling, in the form of Integrated Services Digital Network (ISDN). Using the same copper phone lines that modems use, ISDN delivers a five-fold speed improvement (up to 128 Kbps) and provides essentially perfect transmission reliability. And ISDN can mesh into other digital technologies, such as Frame Relay and ATM, making possible future speeds several times higher even than 128 Kbps.

The "Integrated" part of ISDN's name refers to the combining of voice and data services over the same wires (so computers can connect directly to the telephone network without first converting their signals to an analog audio signal, as modems do). This integration brings with it a host of new capabilities combining voice, data, fax, and sophisticated switching. And because ISDN uses the existing local telephone wiring, it's equally available to home and business customers. Most important for Internet users, however, is that ISDN provides a huge improvement in access speed at only a fractional increase in cost.

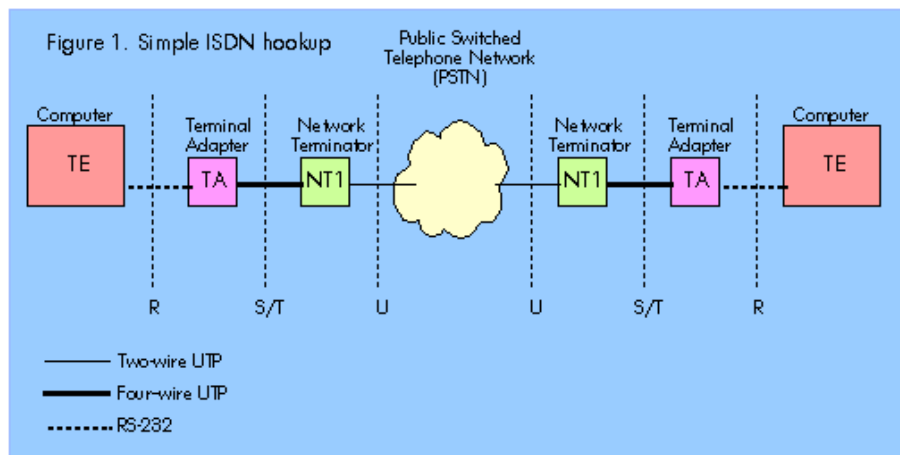
ISDN service is available today in most major metropolitan areas and probably will be completely deployed throughout the U.S. by the end of 1995. Many Internet Service Providers (ISPs) now sell ISDN access -- some for little more than you'd currently pay for modem access (about \$1/hr). To find out if ISDN will work for you, you need to understand the capabilities ISDN offers, how it delivers them, and what it all costs in equipment and fees.

The Basics

ISDN provides a raw data rate of 144 Kbps on a single telephone company (called telco in the business)

twisted pair. To better suit voice applications, this 144 Kbps channel is partitioned into subchannels: two 64 Kbps B (for bearer) channels and one 16 Kbps D (for data) channel. Each B channel can carry a separate telephone call and usually has its own telephone number, called a Directory Number (DN). You can combine the two B channels together to form a single 128 Kbps data channel through a process called bonding (more on that later).

Figure 1 shows a minimal ISDN setup connecting two computers. The incoming twisted pair enters a telco-provided box called the network terminator (NT1), which breaks the 144 Kbps channel into the two B and single D subchannels. (If you're wondering how ISDN squeezes 144 Kbps out of the same twisted pair that modems struggle with at 28.8 Kbps, read see How ISDN Does It).



The B channels carry customer voice or data signals. The D channel carries signals between your ISDN equipment and the phone company's central office. The two bearer plus one data channel is called the Basic Rate Interface (BRI) in telco lingo, or sometimes just 2B+D for short. You also can buy ISDN in bulk: 23 B channels with a single 64 Kbps D channel. This service, called the Primary Rate Interface (PRI), inherits most of the capabilities and limitations of BRI, so what you learn about 2B+D applies to PRI's 23B+D service, as well.

Continuing with Figure 1, a single four-wire cable carries the 2B+D channels to another box called the Terminal Adapter (TA). Unlike the NT1, which provides only a single function (creating the 2B+D channels), the TA can do many things. Its job is to connect any and all of your Terminal Equipment (TE) -- computers, fax machines, LANs, or telephone sets -- to one or both of the B channels. Depending on the variety of terminal equipment you want to connect, the TA might be cheap or expensive, simple or complex. In this example, the TA is shown as a separate unit, but it could easily be contained within the computer (as an add-in card or integrated feature) or integrated with the NT1 into a single box as a modem replacement or stand-alone TCP/IP router. ISDN's current popularity is stimulating the introduction of new TAs regularly.

Figure 1 also shows the external ISDN reference points, labeled R, S/T, and U. (Don't strain yourself trying to deduce what R, S, T, and U stand for -- they are simply consecutive letters of the alphabet, chosen by the ITU -- The International Telegraphic Union, a standards-setting body -- as the next available designations from the entire set of ITU standards.) Each interface point requires an electrically different device connection and cabling. The U reference point is the incoming unshielded twisted pair (UTP); the S/T reference point is a four-wire UTP cable.

A typical TA for data-only applications might simply emulate a pair of ordinary (albeit very fast) Hayes-compatible modems, translating standard modem setup and dialing commands into ISDN call-setup commands. You connect your computer to this kind of TA with a normal RS-232 cable and use your usual modem or fax software set to 64 Kbps (or as high as you can go). The TA provides automatic rate adaptation to match whatever data rate your computer supports with ISDN's 64 Kbps channel, so that if your computer can't communicate faster than, say, 38.4 Kbps, it will still work fine under ISDN (and even connect properly to a remote computer operating at some other speed). An example of a more sophisticated TA is the ISDN router, which connects to an ISDN line on one side and your office or home LAN on the other. An ISDN router can carry your network traffic -- AppleTalk, IPX, TCP/IP -- either down the street to your main office or around the world on the Internet. The advantage of an ISDN router over the simpler modem-replacement TA is the ability to support many different kinds of computers without special ISDN software; the router contains all the intelligence necessary to move traffic over an ISDN link, literally moving your local LAN to the far-away destination of your choice.

"But wait!" you cry. "All you've done so far is replace modems with a lot of extra boxes and wires. If this is all ISDN offers, what good is it?" Remember, the example in Figure 1 is a minimal ISDN setup. Even with this bare-bones configuration, though, you're getting the equivalent of two 64 Kbps modems, two telephone lines, and virtually guaranteed reliable data transport. This last item is an important advantage over analog modems, which suffer from all kinds of maladies ranging from intermittent line noise to speed mismatches and protocol conflicts.

Because ISDN is purely digital, the telco can more easily deliver data intact from end to end, largely eliminating the effects of noise. And because the 64 Kbps channel is essentially a pure "bit pipe," with no rate negotiation or handshaking involved, there are no modem speed or protocol differences to cause conflicts. In fact, because the negotiation phase with ISDN is so simple, ISDN takes only a second or two to dial and establish a connection (modems may take as long as a minute to accomplish the same thing). These benefits alone are worth the cost of two high-speed modems, which is about what a bare-bones TA costs.

In an Internet-access application, your computer treats the basic TA just as it would a modem, using the PPP (Point-to-Point) serial line protocol to carry your Internet traffic. From your point of view, then, the ISDN connection setup is identical to the setup a PPP modem Internet connection. Although you could technically run the popular SLIP (Serial Line Internet Protocol) over ISDN, PPP is the ISDN transport protocol of choice for several reasons. First, PPP is built into a number of ISDN-capable routers on the market, and your ISP will likely be using one of these routers to provide ISDN dialup service. Second, a variant of PPP, called MPP (for Multichannel Point-to-Point Protocol) lets you combine the two 64 Kbps D channels to create one 128 Kbps bonded channel. This is also called inverse multiplexing, and is usually set up to provide bandwidth on demand -- only adding the second channel when network traffic warrants. Bandwidth-on-demand is a cost-saving feature. Each D-channel ISDN connection is treated as a separate phone call, so having two channels up costs twice as much as one if your ISDN connection has per-minute usage fees associated with it. For flat-rate ISDN calls, you can permanently bond the D channels.

Getting Clever

Beyond a basic ISDN setup, you can set up ISDN to simulate the features of an office PBX, using advanced TAs or direct computer-integrated ISDN hardware. If you're using an ISDN connection for telecommuting or branch offices, for instance, you may want to take advantage of ISDN voice features. ISDN offers a number of flexible options for mixing voice and data traffic. For example, although a 2B+D interface provides only two bearer channels, you're only limited to two devices using those channels at any one time. Up to eight

devices can share access to the channels using a feature of ISDN called passive bus. Passive bus uses a second kind of network terminator, called an NT2, to let up to eight separate TAs share a single 2B+D circuit. TAs that support passive bus have a port labeled S/T, to indicate that you're making the connection at the S/T ISDN reference point.

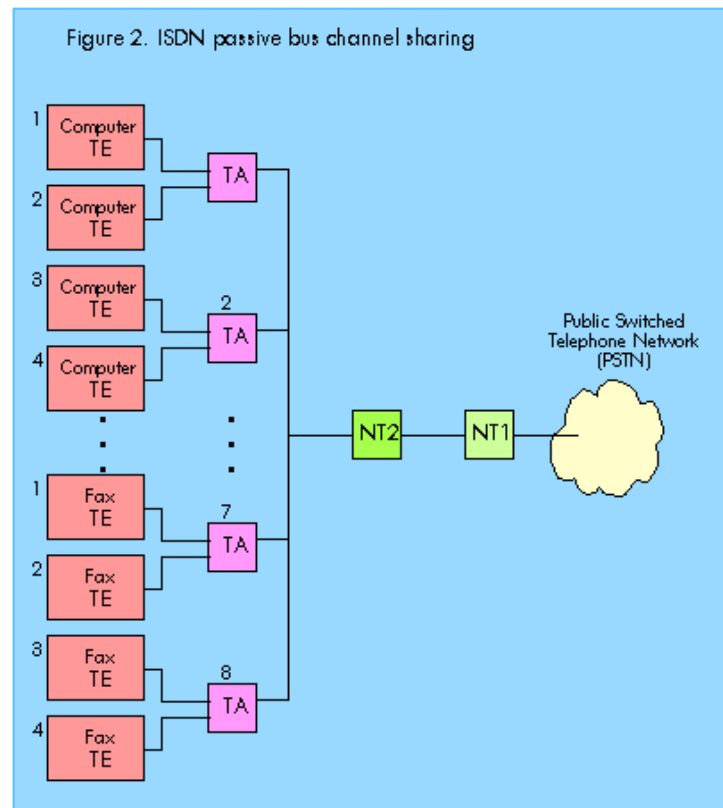


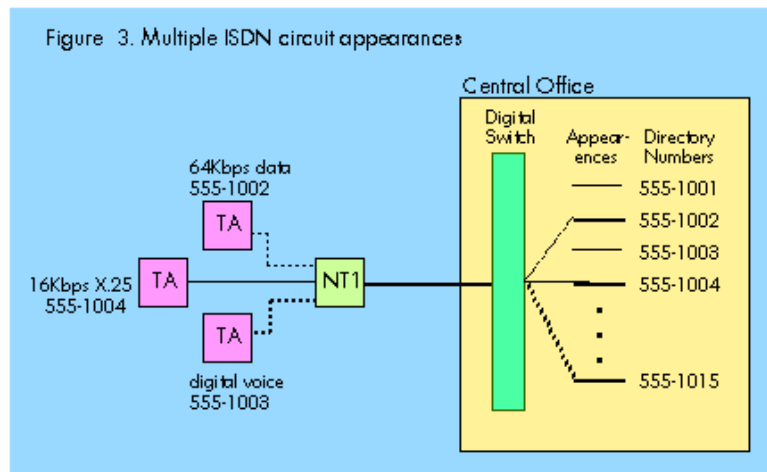
Figure 2 shows a passive bus with a dozen computers and four fax machines sharing an ISDN circuit. You need one TA for every two pieces of terminal equipment. Whenever a computer or fax machine wants to use a B channel, its associated TA checks to see if a channel is available, and, if so, dedicates it to the requesting TE. The example shows maximum device sharing, but the cost of additional 2B+D circuits is low enough that you'll likely have fewer devices on a single bus.

An alternative to using an external TA is to connect your computer to ISDN directly. You can get adapters for PC, Mac, and RISC systems providing direct ISDN connectivity, and some systems, such as the Sun Sparcstation, have integrated ISDN built in. Along with the adapter, you need software supporting ISDN's call control protocols. Most integrated ISDN products include basic software providing the equivalent of "dumb" TA functionality. You can add options for fax, image, and even video conferencing features. In isolation, these capabilities may not seem useful, but combined with another ISDN feature -- call appearances -- they let you construct sophisticated integrated voice/data applications.

Now Appearing

You're already familiar with the call appearance concept, although you may not know it. The traditional Plain Old Telephone Service (POTS) call waiting and three-way calling features, which let you put a call "on hold"

while taking or making a second call, provide two call appearances -- the call you're talking on and the call on hold. ISDN expands that capability to up to 15 separate calls (Figure 3).



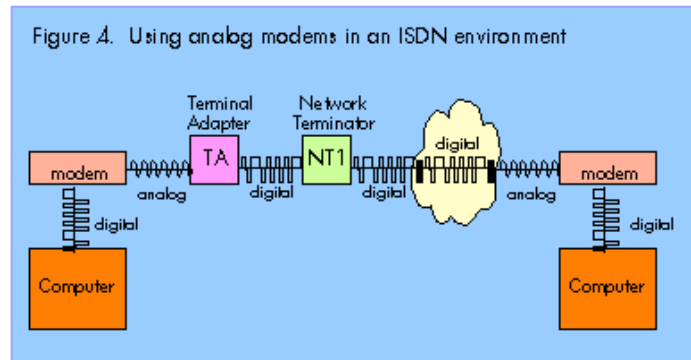
For incoming ISDN calls, the telco's Central Office (CO) sends a call setup message to the TA via the D channel, indicating that a call is available to be picked up (if multiple TAs are connected via passive bus, any TA can pick up the call). The TA can answer the call and assign it to an available B channel, or, if both B channels are in use, it can free a channel by placing an active call on hold and making the new call active. These calls can be either data or voice, in any combination. Thus, a single TA could have as many as 15 simultaneous calls in progress, with any two of those calls active (i.e., actually communicating).

If the TA is a personal computer, it can act as a sort of mini-PBX, making possible all sorts of sophisticated call-handling applications. You can transfer calls from one B channel to another (or among 23 B channels on ISDN PRI service), join two or more calls together in a conference, hold active calls, resume held calls, retrieve calling-number identification data, even forward calls to a completely unrelated telephone number (which might not be an ISDN circuit). In practice, multiple call appearances are more useful for voice than data calls, and most data-capable ISDN TAs only support multiple appearances if they also support voice features. Still, the call appearance concept is important in bandwidth-on-demand applications, where one TA might combine both B channels to obtain a 128 Kbps data pipe but relinquish one B channel to answer an incoming call from another location.

All Dressed Up. But Now, Who to Call?

So who will you call with your brand new ISDN connectivity? The obvious first answer is your Internet Service Provider (ISP). Many ISPs are recognizing the performance and reliability improvements of ISDN over modems and are rolling out ISDN services. You can also call other ISDN users, which could be remote sites in your own IS organization, public BBSs, customer sites for EDI or transaction processing, or commercial online services such as CompuServe.

The data applications of ISDN shown so far all require that both parties in the connection have ISDN or packet data service. What if you need to connect with somebody that isn't ISDN capable? The answer is that you use your good ol' analog modem (you didn't throw away your modems yet, did you?) and a TA that supports analog voice connections, or POTS (Figure 4).



This kind of TA accepts an ordinary voice or modem audio signal through a standard RJ11 modular jack and digitizes it for transport across the ISDN interface. It interprets the touch-tone dialing signals put out by your telephone set or modem and generates the required ISDN call-setup signals. If the number you're calling isn't an ISDN POP, the telco equipment at the remote end automatically translates the digitized audio back to analog audio, where the destination modem (or human being) hears what it's always heard before ISDN came along.

This might seem like a terribly roundabout way of maintaining backwards compatibility. It is. But even if ISDN achieves its goal of 95% deployment by the end of 1995, there still will be hundreds of thousands of U.S. modem/fax users, not to mention overseas modems and fax machines. In fact, some ISDN TAs include built-in analog modems (sometimes anomalously called "digital modems") just to provide compatibility with existing analog fax and data devices. So plan on keeping your modems around at least until the end of the decade; you'll still need them occasionally. Fortunately, many TAs provide POTS ports without much additional cost, so this is a painless necessity.

Paying the Data Piper

So what does ISDN cost? That depends on your local telephone company, equipment budget, and ISP. An Internet ISDN connection consists of three components: the ISDN line itself, the equipment (an ISDN TA and possibly an NT1), and the ISP's fees.

Many telcos are pricing ISDN similarly to a normal business telephone line, with measured service charges for the time you're actually using the circuit (plus normal long-distance charges when they apply). The cheapest service (PacBell's) runs \$30 per month for local access plus message-unit charges of four cents for the first minute and one cent for each additional minute. If the call is long distance, you'll also pay long-distance digital charges, which can be two to three times higher than voice long-distance calls (although competition is rapidly bringing these costs down). Even the most expensive ISDN providers have monthly rates below \$100, and many have options that eliminate message-unit charges. For example, PacBell's "Home ISDN" package charges message units only between 8am and 5pm on non-holiday weekdays.

The NT1 costs between \$100 and \$200, but often you can find TAs with the NT1 device built in. ISDN TAs range in price from as little as \$300 for data-only units providing Hayes-compatible modem emulation to \$1,500 or more for ISDN-capable routers that can interconnect LANs over ISDN. Standalone TAs often cost less than bus-specific plug-in cards and are usable across a wider range of computer systems. And ISDN routers, which don't depend on your host computer's serial port capabilities, are even more flexible than stand-alone TAs. Unless you have a tightly-coupled ISDN application that requires a plug-in card, you're

better off with standalone devices. And unless you're certain you'll never need to connect more than a single computer to the Internet, an ISDN router is a better investment than a serial-port TA that requires host-specific software to operate.

The Right Choice

There seems little doubt that ISDN is in the Internet's future as an entry level connection path. While some critics complain about ISDN's limitations and push alternative solutions (see The Last Mile), the fact is that ISDN is here, and the others aren't. Now that you understand how ISDN works and what it's good for, you can look into using it as an Internet connection alternative. Keep an eye on ISDN technology; prices are coming down and capabilities are expanding.

The Truth About High Speed Modems

Modem manufacturers like to advertise apparent speed, regardless of how fast their products actually pump data. When encountering these claims, keep in mind the following fact: for dial up modems, the fastest practical speed is about 28,000 bps. The 28,000 bps limit is a function of the public switched telephone network's (PSTN) signal-to-noise (S/N) ratio. (The laws of information theory -- first proven mathematically by Claude Shannon in 1948 -- determine how much information can pass through an analog channel with a given S/N ratio.) Most of the U.S. PSTN has an S/N ratio of about 1000:1 for voice-grade lines, which (according to Shannon's law) yields a maximum data rate of about 30,000 bps. How, then, does one explain the 38,400, 57,600, and even 112,000 bps claims made by vendors? The answer is Data compression.

The ITU recommendation for 28,000 bps modems, called V.34, specifies a signaling standard designed to work reliably on most PSTN voice-grade lines. The operative word in that standard is most: There are still many local phone companies in the U.S. where V.34 won't operate or where the overall quality of a long-distance connection is too poor for V.34. In such cases, V.32 can fall back to a slower speed -- 20,000, 14,400, 9600, 4800, or even 2400 bps.

A separate recommendation, V.42, defines an error detection and correction protocol for modems that lets the modems themselves ensure reliable, error-free data transport. A modem with both V.34 and V.42 capabilities is a handy thing because it removes from the attached computers the responsibility of routine error handling. Given that error-correcting modems provide guaranteed data transport, CCITT decided that the modem was also a good place to perform data compression and released the V.42bis (from the Latin bis for second) recommendation in 1990. The data compression algorithm used in V.42bis modems has the potential for achieving as much as a four-fold decrease in data volume. In real life, though, compression depends on the data; only in rare cases does it ever reach even 50 percent, and then only with plain-text data. The more forthright vendors report their 28,800 bps modems as running at 28,800 bps. Other vendors go for the gusto, multiplying 28,800 bps times two or four to get 56,000 or 112,000 bps.

There is another reason to look upon modem compression with jaundiced eye: It turns out that the modem wasn't such a good place to put compression, after all. It seemed like a good idea back when computer users ignored security and plain text was most often the data of choice. Now, however, users are turning to host-based encryption and compression to both protect their data and get better data reduction. Host-based compression algorithms have advanced beyond the original V.42bis recommendation and generally give higher compression ratios than modems. Also, to save space in online archives, users want to store files that are already compressed.

Thus, most file transfers today are encrypted or compressed (or both) by the host and cannot be compressed any further by the modem. In fact, modem compression actually increases the amount of data when you send a previously compressed file! For most modem users, onboard compression is becoming a nuisance they want to turn off. Finally, keep in mind that (when appropriate) ISDN TAs can perform compression, too. Many ISDN-capable routers provide compression because LAN data is often compressible. If you're getting confused by all the speed and compression variables in the modem world today, remember that it all goes away with ISDN.

How ISDN Does It

You might be asking: "If ISDN can squeeze 144 Kbps out of my phone line, why can't a modem do the same thing?" The answer lies in the evolution of the telephone network. A given pair of wires connecting two parties for communication can carry electrical signals in one of two forms: analog or digital. An analog signal changes gradually through an infinite number of values, while a digital signal changes instantly (in theory) between just two values. The human voice and a musical instrument are examples of analog signals -- both produce complex variations in frequency and amplitude. A light switch typifies a digital signal -- it can be either on or off.

An analog signal's infinite number of variations makes it impossible to reproduce exactly. An analog signal will go only so far in copper wire; to go further the signal must be regenerated electronically with a device called a repeater. The repeater converts the weak input signal to a stronger output signal, unavoidably distorting it in the process. Each regeneration degrades the signal a bit more (in the same way that photocopies of photocopies get worse at each iteration). In a large telephone network, the "copy of a copy" problem becomes very expensive to solve, requiring sophisticated equipment and costly cabling.

Digital signals, on the other hand, are easy to regenerate precisely. Because there are only two possible states for the signal, even a heavily degraded signal can be regenerated into an exact copy of the original. What's more, the cost (and complexity) of equipment to regenerate digital signals is trivial compared with that for analog. Not surprisingly, telephone companies recognized this cost advantage a long time ago and have since converted all long distance transmission to digital signaling. When a subscriber makes a long-distance call, the central office (CO) converts the analog signal to digital using a technique called sampling (see "Analog-to-Digital Conversion Diagram"), in which the state of the analog signal is captured about 8,000 times per second. Each state is converted to an 8-bit binary number, and the resulting string of binary numbers becomes a digital data stream at 64 Kbps. This digital stream is routed along the long-distance network, being regenerated as needed. Each regeneration produces an exact copy of the original digital data stream, so no information is lost. When the destination CO receives the digital data stream, it reverses the sampling process and transmits the resulting analog signal to the receiving subscriber. (On a side note, many local telephone companies are converting to digital switching, even for local calls).

A modem can't get 64 Kbps out of an analog line because the CO's signal sampling, at 8,000 times per second, limits the bandwidth of the analog signal to about 3 kHz, which in turn invokes Shannon's Law (see "The Truth About High-Speed Modems") setting the practical speed limit for such a channel to about 30 Kbps. To get higher analog speeds requires higher fidelity in the audio signal, dictating faster sampling in the CO's analog-to-digital conversion, which would result in a digital data stream faster than 64 Kbps. Telco's aren't about to change out all their voice digitizers for faster versions or upgrade all their digital circuits to carry channels faster than 64 Kbps. So the probability of the phone system ever supporting faster analog signaling rates is zero.

This is where ISDN steps in. ISDN cuts out the middleman by eliminating the need for voice digitizers in the CO. ISDN carries through the 64 Kbps digital signal from the CO right to the subscriber, and the subscriber can use it for voice or data as required. Advances in electronics make it practical to do voice digitizing right in the subscriber's phone, and direct digital attachment of computers eliminates the need for modems.

The Last Mile

ISDN has its detractors, most of whom rally behind other methods for going digital directly to the subscriber. The alternatives include existing copper-wire digital services, such as T1 (at 1.544 Mbps), Frame Relay (FR, at 56 Kbps to 1.544 Mbps) Asynchronous Transfer Mode (ATM, at 25 Mbps to 100 Mbps), and Switched Multimegabit Data Service (SMDS, at 35 Mbps). Most of these services cost several hundred to several thousand dollars per month, pricing them out of reach for many small-scale users.

Another alternative is to replace copper wire with fiber optic cabling, which would reach out and touch every subscriber with essentially unlimited bandwidth. There is a single overriding problem with all these alternatives: They suffer from an inability to conquer a physical barrier that telephone companies euphemistically call "The Last Mile."

The Last Mile, also called the local loop, is telco talk for the twisted wire pair between the CO and the subscriber. This part of the telephone network is virtually unchanged since Alexander Graham Bell. Each telephone user requires a dedicated pair of copper wires. The length is usually more than a mile but fewer than 20 miles and averages about five miles in metropolitan areas. Faster digital services (such as T1, fractional T1, ATM and SMDS) require digital repeaters at least once per mile. But normal copper pairs -- buried perhaps 50 years ago -- don't have such repeaters. What's worse, they often have analog conditioning equipment that actually impedes digital signals! If you want high-speed digital service, your telco will cheerfully run conditioned lines to your office -- for a hefty fee.

What about just replacing all the copper with fiber optics, as the Fiber-to-the-Home (FTTH) proponents suggest? The 130 million phone lines in the U.S. use 650 million miles of copper pairs. Considering that planet Earth is only about 93 million miles from the sun, this is a hefty amount of wire in anybody's book. According to a 1987 Bellcore study, the cost to replace all the existing copper with fiber would be \$250 billion (and several decades of labor). This is about ten times what it would cost to replace every telephone switch in the U.S. with digital equipment and lines!

What about replacing just the business lines, or metropolitan area lines, with fiber? Indeed, this is what will probably happen. But even such limited deployment won't be cheap or fast (about \$10,000 per subscriber -- and still requiring decades to complete). All the while, information technology will continue to decentralize the workplace, increasing the demand for faster communications.

ISDN can serve users until FTTH (or some other technology) is ready for prime time. ISDN isn't as fast as everyone would like, but it's a heck of a lot faster and cheaper than what we've got. And it's being delivered today.

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