IPv6: THE NET GROWS UP
By Kevin Werbach

The remarkable growth of the Internet was a surprise to most of those who built it, but their success was not an accident. The Internet works as well as it does because of architectural decisions made during its gestation in the research and academic world. Many of those decisions are reflected in the Internet protocol (IP). Yet after two decades, IP is finally beginning to show its age. Workarounds to accommodate its limitations are themselves creating inefficiencies, bottlenecks and security risks, making the Net increasingly brittle and complicated.

The Internet Engineering Task Force (IETF) has developed a new version of IP, known as version 6 (IPv6), replacing the current IPv4. Partly because IPv6 is a long-term solution for an industry with notoriously short planning horizons, and partly because the limitations of IPv4 are felt most acutely outside the US, this issue has not received the attention it deserves. Yet to a large extent the deployment path of IPv6 will determine how open the Net remains to innovation in the future.

The Net is fast becoming the pervasive platform for all forms of communication. But to fill that promise, it must become more reliable and secure while still flexible and open to novel applications. IPv4 was never designed to scale up to the level of today's Internet, let alone to what the Net may become over the next decade.

The IETF began work on what was then called IP Next Generation (IPng) in 1994. The IPng working group, led by Cisco’s Steve Deering and Nokia's Bob Hinden, gradually converged on a specification. IPv6 became a draft standard in August 1998.

Developers have begun to implement IPv6 stacks, but commercial deployment in routers and networks has not yet occurred. No one claims IPv6 is a bad idea, but its triumph is neither imminent nor certain. Rolling out a new low-level protocol to today's huge Internet population will take years. Moreover, IPv6 implementation will depend on the willingness of vendors and network managers to support the new protocol. Various workarounds have already extended the usefulness of IPv4 and reduced the pressure to upgrade. ===>

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But the move to IPv6 remains critical long-term. The Net may continue to function indefinitely on IPv4, but it would gradually lose its open, all-points-accessible character. Without IPv6, the scaling challenges facing the Net will only become more acute.

A Brief primer on Internet addressing

IPv4 uses 32-bit addresses (e.g. 255.128.92.24). In theory, therefore, IPv4 could handle 232 or over 4.2 billion unique nodes.

If address assignments were wholly arbitrary, routers would have to query a lookup table of 4 billion entries each time they forwarded a packet. To reduce routing-table complexity, IP addresses are aggregated into hierarchical classes. The first part of each address represents a network, and the remainder describes a more specific sub-network and/or host machine. Though each host has a unique address, that address is determined partly by the network to which it is connected. Core routers need only keep track of the larger networks; once a packet reaches the right network it can be routed internally.

IPv4 originally had three primary classes of addresses. In theory there is room for 126 Class A networks, each of which could contain over 16 million hosts; 65,000 Class B networks containing up to 65,534 hosts; and over 2 million Class C addresses containing up to 254 hosts.

However, the original system had significant inefficiencies because the network classes were so coarse-grained. A network with 50 hosts would get a Class C address even though it didn't need over 80 percent of the address space; a network with 5,000 hosts might get a Class B even though that would waste over 60,000 potential addresses. With the Net's rapid growth, projections in the mid-1990s suggested that address exhaust was only a few years away.

Classless inter-domain routing (CIDR), now widely implemented, has reduced significantly the rate of IP address consumption. With CIDR, each address includes an extension that indicates what portion refers to the network as opposed to the individual host within the network (e.g. 127.64.255.18/24). This system in effect creates a more gradual step function for assigned address blocks. The Internet Assigned Numbers Authority (IANA) and regional IP address registries now assign blocks to service providers based on demonstrable need, and require end-users to get their addresses from their upstream service providers.

In the real world, not all Internet-connected hosts have unique IP addresses. Dial-up users typically have temporary addresses dynamically assigned out of a pool for each session. Intranets often use private addresses because of IP number scarcity or perceived security benefits. Firewalls, caches and load-balancing devices also may alter IP addresses en route so that they are not transparent end to end. Network address translators (NATs) between networks make it possible for users with non-globally unique IP numbers to communicate with the rest of the Net. The NAT box converts the local network addresses back and forth to unique Internet addresses by reading the packet payload to determine the correct destination.
IP numbering vs. DNS

IP defines the structure of Internet packets. Its usual companion, the transmission control protocol (TCP), defines how to send those packets across the network reliably. An IP packet includes a payload (the contents being sent) and a header indicating its source and destination address along with other routing information. The most important components are the addresses, and it is here that IPv6 most differs from IPv4.

The Net has two complementary but distinct addressing systems: IP numbering for machines and the domain name system (DNS) for people. Host computers connected directly to the Net have numeric IP addresses. (For more detail, see the box on page 2.) The DNS is essentially a set of lookup tables that map human-friendly alphanumeric domain names to those IP numbers. Uniform resource locators (URLs) extend those domain names to refer to specific files or pages on a server. When you enter a URL or an e-mail address a DNS server converts the address to IP a number, which routers use to send traffic between sites.

DNS is essential for the things humans care about – marketing, branding, easy recollection, trademark protection and so forth. Consequently, in recent years the DNS has gotten all the attention. There have been major controversies as the US government and other organizations have worked to shift DNS policy management to a private international corporation and to introduce competition to the name-registration process. (Disclosure: Esther Dyson is the interim chairman of this new entity, the Internet Corporation for Assigned Names and Numbers (ICANN).)

DNS management issues are extremely important, but without IP addressing there would be no way for a device to find a remote node on the network. Over the long run, Internet architecture will depend to a large extent on how IP addressing issues are handled.

The IPv6 solution

IPv6 is neither a company nor a proprietary technology, so its significance in this era of e-commerce and astronomical Internet stock valuations may be difficult to appreciate. IPv6 was designed by engineers for engineers, to solve a specific set of problems with the existing Internet protocol. But IPv6 also signifies the full emergence of the Net as a platform for business and social interaction. John Patrick, vp of Internet technology at IBM, emphasizes that "the Internet is the new medium. It is not a new medium. It is the new medium. As of today the Internet is not on a path for the scalability needed to support the millions of e-businesses, billions of people, and trillions of devices that will be connected."

IPv6 addresses these existing limitations in four primary areas: address space, quality of service, security and configuration.

Four billion unique addresses sounded pretty expansive in the early days of the Internet, but the network has grown far bigger than anyone envisioned. One problem is that companies don’t necessarily use address space in the most efficient manner. If you think addresses are scarce, you'll try to hoard them. If you were lucky enough to get a class A address back in the pre-commercial days of the Net, you certainly won’t give it back even if...
you aren't using it. And if you live outside the US, chances are your
country's share of IP address space is disproportionately small as a func-
tion of its population.

IPv6 offers a 128-bit address space, divided equally into host and network
components. Thus, IPv6 allows 2^64 or 18,446,744,073,709,551,616 separate
networks, each of which can include 2^64 unique devices. Those are big
numbers, equivalent to 1,5000 addresses per square meter on the planet.
The Net has a way of exceeding expectations, but it's hard to imagine the
IPv6 address space being exhausted in the foreseeable future.

IPv6 also offers several security enhancements. All IPv6-capable routers
must support IPSec, a network-layer end-to-end security specification.
IPv6 headers also include an authentication extension so that a receiving
site can verify where a packet came from. This capability addresses the
increasingly common practice of spoofing return addresses, a major element
in denial-of-service and other attacks against service providers. IPSec
and authentication are options under IPv4, but they are not required.

IPv6 also supports more robust quality of service (QOS) management. As
we've described before (see Release 1.0, 6-98), there is no magic bullet
for QOS, and QOS approaches such as differentiated services can be used
under IPv4. IPv6 adds a header field that makes it easier to segregate
traffic flows so that routers can apply different traffic-handling policies
to them. Effective end-to-end QOS will still require sufficient bandwidth
and higher-level management systems such as the ones from Cisco,
Orchestream (in which Esther Dyson is an investor) and IP Highway.

Finally, IPv6 includes automatic configuration features to simplify the
assignment of addresses to networks and devices. IPv4 devices originally
had to be manually configured each time they were connected to a new net-
work. This is why, for example, it was so difficult to use an Ethernet
connection from a hotel. Today most networks employ dynamic host configu-
ration protocol (DHCP) servers that automate this process to some extent,
but the DHCP servers themselves add complexity to network management. IPv6
also supports serverless configuration, which allows a host or router to
configure its address by reference to neighboring routers without a dedi-
cated configuration server. Ideally, a network could be completely renum-
bered (for example, to switch ISPs) without users even realizing it,
although it's not clear whether all the DNS-related issues can be resolved
to make this possible.

The end of end-to-end?

The real significance of IPv6 lies at a broader level. As we've discussed
recently, the two most significant elements of the next-generation Net are
always-on high-speed connectivity and pervasive networked devices (see
Release 1.0, 12-98, 2-99 and 4-99). IPv6 is an important enabler for both
these developments.

Addressing, arcane though it seems, has a direct relationship to network
architecture. If every network host has a unique logical address, it's
possible to send packets across the network without any changes en route.
Every router knows where a packet is going by its destination address,
because that address refers to only one point on the network.
Consequently, intermediate networks and routers need not understand the payload of a packet. New applications can be deployed at the edges of the network, because those are the only points that examine packet content. In other words, networks don't have to be optimized for particular services.

This is the essence of the Internet. Internet Architecture Board (IAB) chairman Brian Carpenter points out that transparent transmission of packets dates back to the origins of the Internet in 1973. The endpoints define the applications and cope with other complexities such as error detection, leaving the middle of the network free to get packets to their destination in the most efficient way. The classic 1984 paper by Jerry Saltzer, David Clark and David Reed, "End-to-End Arguments in System Design," delineated the value of this approach. Carpenter, who emphasizes that the IAB and IETF are still debating these issues, is drafting a discussion paper that outlines the implications for today’s Net (see Resources section for references to both papers).

End-to-end transparency falls apart without sufficient address space. If Al wants to send a message to Ethel but Ethel doesn’t have a unique address, the packets will have to be modified somewhere en route. For example, a network address translator might connect Ethel’s network to the rest of the Internet. But if a NAT encounters a traffic from an unfamiliar application, it may have difficulty distinguishing the destination address from the packet payload. At that point the application breaks. NATs and similar devices such as firewalls also create performance bottlenecks, security risks and single points of failure.

Engineers disagree vehemently both within companies and within organizations such as the IETF about how big a threat NATs pose. While some view NATs as the death of the Net, others such as Scott Bradner, a technical consultant at Harvard and trustee of the Internet Society, have urged a more measured assessment. Application protocols can generally be designed to avoid breaking when they pass through NATs, but the mere fact that protocols must take such intermediate network elements into account runs contrary to the Internet's end-to-end philosophy.

The IETF has established a NAT working group to identify the specific architectural issues NATs raise. Whether or not NATs should be used, they are increasingly common in the real world. For example, high-speed service providers such as @Home typically use NATs so that several always-on users can share a single IP address. Even under optimistic scenarios of IPv6 deployment, NATs won’t go away – some networks will still prefer private address space. The question is whether NATs become more and more prevalent throughout the Net, ultimately between and even within ISP networks.

A better model

Globally unique addresses are the only way to avoid spiraling complexity of the Net. New services like real-time streaming video will require scalable quality of service management and the flexibility to add new application functions that the existing network was never designed for. That means a true end-to-end system such as IPv6. Shortcuts may seem appealing at first, but so long as they break the open end-to-end model they will be less effective than long-term solutions. (This is similar to the objections we raised to high-speed cable Internet access services, see
As IBM's Patrick asks rhetorically, "If better routing of air traffic were devised, would that mean we don't need a new air traffic control system?"

Over the long run, band-aids such as NATs create as many problems as they solve. Continuing under IPv4 means never-ending workarounds, creating more and more headaches for ISPs and network managers. As Carpenter explains, "complexity equals cost, in particular operational cost." Some costs are less than obvious. For example, current restrictive IP number assignment policies may have staved off address exhaust, but they have also generated new inequities. Many companies and organizations received IP address allocations far beyond their internal needs before address space became scarce. Others received large address blocks because they were part of the old boys' network that built the Net. Thus @Home, with fewer than 500,000 subscribers, has fifteen times more IP address space than all of China.

ICANN is in the process of establishing an address supporting organization to develop policy recommendations for IP address allocation. The existing system may be improved, but problems and ugly work-arounds will persist as long as addresses remain scarce.

The limitations of IPv4 become most severe in the context of mobile devices. The proliferation of handheld and wearable networked devices (see Release 1.0, 4-99) will create even more demand for addresses. Furthermore, mobile devices must often be assigned temporary addresses when they physically move from one network to another. The lack of built-in auto-configuration in IPv4 makes this process even more difficult.

Perhaps the biggest problem with IPv4-based workarounds is that they reduce the space for innovation. The further we get from the notion of end-to-end transparency, the harder it is to deploy new, unplanned protocols and applications. "One wonders whether, if the Net was built with NAT boxes eight years ago, the Web wouldn't have happened," speculates IPv6 working group co-chair Bob Hinden.

Transition issues

Despite the long-term advantages of IPv6, it's still far from certain that IPv6 will be widely deployed in the next several years. "I don't think this has ever been done before — this kind of transition in such a large-scale deployment," notes Hinden. He says he's "fairly confident" about widespread IPv6 deployment, but admits that it's impossible to predict the timing. Patrick of IBM is also cautiously optimistic: "I believe the net present value of the costs to step up to the problem will soon be viewed as less expensive than continuing to pay the costs of the 'kludges'."

Pete Loshin, author of IPv6 Clearly Explained, found in a survey published last October that 53 percent of respondents were aware of IPv6, 24 percent had specific plans in their organizations to test and deploy IPv6, and six percent were actually testing it. While acknowledging that most ISPs and North American users don't yet feel any urgency about IPv6 deployment, Loshin sees the glass as half full: "If you graphed the growth of the IPv6 effort since the first RFCs were published in 1994, it would probably track pretty close to the IPv4 growth curve starting around 1981. Ultimately, it will probably reach critical mass much more quickly than IPv4 did."
Some of the necessary pieces are missing. Although IPv6 stacks are being developed on all major platforms, they still are not sufficiently robust and commercially available in routers. IPv6 uses the DNS differently than IPv4, necessitating technical modifications that are not yet fully resolved. An IETF working group is now working to address the DNS issues.

There are also integration and implementation issues that will arise once IPv6 is deployed. For example, authentication support and the new addressing structure will both impose additional computational requirements on network devices, but whether that will affect real-world performance remains to be seen. Virtual networks such as the 6bone (an experimental testbed that grew out of the IETF's IPv6 transition group) and the 6ren (a similar network for research and educational sites) that allow organizations to try out IPv6-enabled equipment will help in this regard.

There is a chicken and egg problem here: No one will deploy IPv6-enabled network equipment until there is a critical mass of users with IPv6 stacks, but users won’t move to IPv6 until networks support it. As Cisco’s Fred Baker, the chairman of the IETF, observes, “Service providers and corporate networks are not coming to their vendors and pounding the doors down looking for IP6.” IPv4 workarounds such as CIDR and NATs have relieved much of the perceived pressure to deploy IPv6. The IETF isn’t a marketing organization; Latif Ladid of Telebit is working to create an IPv6 Forum that would take on this evangelism role.

One key element is the desktop. Microsoft has made positive noises about IPv6, and about a year ago a group in Microsoft Research posted a test version of an IPv6 stack compatible with Windows NT 4.0 and Windows 2000 on the Microsoft Website. The shipping version of Windows 2000, however, will not include IPv6 support.

Fortunately, IPv6 and IPv4 networks can coexist. IPv6 packets can “tunnel” inside IPv4 networks, allowing new IPv6-only networks and devices to communicate with one another even if the intervening infrastructure has not been upgraded. Machines can also run IPv4 and IPv6 stacks simultaneously, or networks can use protocol-translating NATs between the two address spaces. Using NATs mitigates the end-to-end transparency benefits, but at least it allows networks to take advantage of the greater address space and other advances in IPv6 before widespread deployment occurs elsewhere.

Likely scenarios

We suspect that significant rollouts of IPv6 will initially take place at the edges of the Internet, in particular cases where the need is greatest. Widespread deployment will depend on the right alignment of incentives. There is no appreciable opposition to IPv6, but many vendors and companies simply don’t see the benefit yet of upgrading. There may be greater demand for IPv6 in Europe and Asia, which have been allocated a much smaller fraction of IPv4 address space relative to their populations than the US. These countries also tend to have less-developed existing IP infrastructures, which makes it easier to jump to the new protocol. For example, China would have a difficult time providing Internet connectivity at penetration levels comparable to the US without using IPv6.
Baker notes that "there is only 'no problem' [with the current address space] if current Internet usage demographics hold — if the People's Republic of China, the Indian sub-continent, South America, and Africa remain isolated and disconnected." He continues, "each of these considers Third-world status unacceptable and are working very hard on changing their status." Thus, drawing straight-line predictions from current Internet demographics may be dangerous.

Hinden, who works for wireless equipment vendor Nokia, sees wireless data networks as another major driver for IPv6 deployment. "It's much harder to do mobility if you don't have global addresses," he says, because the necessary database lookups are more complex when the physical location of the originating device is moveable.

As we described last month, every wireless phone will have an IP stack in a few years, and many mobile devices such as personal digital assistants (PDAs) will come with always-on wireless connections (see Release 1.0, 4-99). Pervasive network connections to billions of devices are only viable with enough address space to go around. The big issue is whether these devices primarily connect through dedicated gateways or on a peer-to-peer basis in the traditional Internet model. Bradner notes, "If [the peer-to-peer model] is remotely successful, you can have an awful lot of machines suddenly on the Net," and it's unclear how such devices could be supported without IPv6.

IPv6 is a long-term solution. Then again, we have little doubt that the Net will be with us for a long time to come. The business case for IPv6 may be less obvious in the short term, but the same could be said about the Net itself in its early days. It's important that vendors, network managers and service providers begin thinking about IPv6 and how they will implement it, lest the Net fall victim to its own success.
DEEP IMPACT: The net swallows the phone network

The twin asteroids of technology and competition are hurtling towards the nearly $1-trillion global telecommunications industry. The surprising thing so far is how little has changed in the face of the visible threats. Traditional players such as the Baby Bell local phone companies in the US still capture the vast majority of revenue flows. Voice phone service looks much as it did a decade ago; a bit cheaper and with a few more features, perhaps, but the same product. New competitors mostly cherry-pick large business customers or focus on wholesale capacity, rather than confront incumbents directly.

Bits are bits. When the long twilight struggle between voice and data concludes, data will surely emerge victorious. Conventional voice service will morph into a set of applications delivered over the Internet platform. Flexible, open, decentralized technologies will replace today's centralized proprietary systems, transforming not just the communications industry but Internet services as well.

Technologies such as packetized voice over digital subscriber line and Internet protocol PBXs are the early precursors of this shift. Like the mammals scurrying around the feet of the dinosaurs, they may appear insignificant at first, but they will chip away at the foundations of the telecom world order...even as the dinosaurs continue to lay dinosaur eggs.

Telephone switches are just big computers, subject to the performance curve of Moore's law. Fiber-optic transmission capacity has been increasing even faster. So why is it that today's $1,000 PC makes last decade's $10,000 workstation look like a toy, and Internet backbone networks run 40,000 times faster, while telecommunications services have improved only incrementally over the same period?

The answer involves both technology market dynamics. (For more detail, see the appendix in Release 1.0, 6-98.) Delivering reliable, high-quality voice service to millions of people is a significant challenge. Existing networks are designed to do this well. Even if a "green field" IP network could do better, there are hundreds of billions of dollars of infrastructure already in the ground, only partly depreciated. Because laying new wires is so expensive, competitors must interconnect with and lease portions of the existing network. But the current pricing structures for both those wholesale services and their retail counterparts are based on the analog, monopoly-controlled telecom world of the past.

Invasion of the bit snatchers

A year ago, we described how Internet-based technologies are changing the core of the communications network (see Release 1.0, 6-98). Similar advances are now beginning at the edge. These new IP-based services address niche markets today, but they give new competitors – and smart incumbents – the ability to do everything the traditional infrastructure does, only better.

The Internet and the voice phone network generally run over the same transmission facilities, but they operate in very different ways. Circuit-switched connections tie up a 64-kbps channel in each direction for the
duration of every call, while Internet traffic is generated only when information is sent. End-users, however, don't care about technical details; they care about services. Voice is the same service regardless of whether it is transmitted as circuit-switched analog sound waves or as digital packets. Because packet networks are so much more efficient, an increasing share of voice traffic will be packet-based over time.

Voice service is more than a commodity. Customers have come to expect a certain (high) level of reliability and a set of ancillary services from the phone network. For IP-based services to compete, they must match that quality and feature set. The first generation of voice-over-IP equipment failed to meet those criteria, but a new set of companies is looking to capture the value of existing telecommunications services rather than simply the traffic.

At the edge of the network, there are two primary barriers in the way of the IP onslaught: the last mile and office phone systems. Both are now being eroded. *(Note to readers: We're entering the telecom milieu, so prepare yourselves for acronym overload.)*

**Packetized voice in the last mile**

Voice over IP creates a viable arbitrage opportunity where rates are heavily inflated today, such as international service and domestic service in many countries outside the US. Although several providers including Qwest and IDT offer domestic long-distance voice-over-IP service in the US, these services have had little effect on the market. With nationwide long-distance service routinely available at 10 cents per minute from major carriers, voice over IP can rarely compete on cost. The problem isn't that voice over IP can't match the quality or reliability of circuit switching. Even if it could, there would be little reason for service providers to switch to a new technology. There must be some significant advantage, analogous to the price advantage internationally.

Equipment vendors are now creating such an opportunity by marrying packet voice technology with high-speed access. Long-haul voice-over-IP services save costs by compressing the voice channel and multiplexing more conversations over a common pipe. But bandwidth costs are a relatively small component of end-user prices.

In the local network, however, allocation of bandwidth is critical. Incumbent local exchange carriers (ILECs) own the lines running into homes and businesses, which makes it difficult or expensive for competitive local exchange carriers (CLECs) to enter. The Telecommunications Act of 1996 in the US required that incumbents lease these local loops to competitors, but the process has been extremely messy. Even if new entrants are able to lease unbundled loops, they are forced to replicate the architecture of the incumbent networks. They may be able to compete on price or service, but they are subject to most of the same economic assumptions as the traditional carriers. So-called data CLECs such as Covad, NorthPoint and Rhythms NetConnections which offer high-speed data connections using digital subscriber line (DSL) technology can compete successfully only because the traditional alternative — T-1 service — is so expensive.
Voice over DSL changes those assumptions. A twisted-pair copper loop traditionally handles one 64-kbps voice channel, whereas DSL allows that same loop to carry 1.5 mbps or more of data. Voice-over-DSL gear breaks that data capacity up into multiple derived voice channels, effectively turning one loop into many. But unlike traditional pair-gain systems, voice-over-DSL solutions are flexible and compatible with other services. In effect, the DSL modem on the customer premises becomes a gateway that supports a range of networked voice and data connections and applications.

Three companies — CopperCom, Jetstream and TollBridge — are developing voice-over-DSL equipment. They attack similar opportunities, the main technical distinction being TollBridge's use of voice over IP technology. Jetstream had a head start, though CopperCom has grabbed most of the recent headlines and all three currently claim similar rollout schedules.

**CopperCom**

CopperCom, based in Santa Clara, CA, was founded by ceo Cynthia Ringo, cto Martin Taylor and vp of marketing Jennifer Stagnaro. The three had worked together over nearly a decade in various combinations at enterprise networking vendor Madge Networks, voice-over-IP gateway provider Vienna Systems and data-warehousing pioneer Red Brick.

“We were looking for an opportunity where we could actually try out something that we believed was a different model for how you start a high-tech company,” Ringo says. Rather than starting with technology, they first identified a market opportunity and figured out how to serve it. The opportunity began with DSL, Ringo continues. “We started off basically looking at, from a market perspective, what would it do to the competitive landscape for carriers if you could cost-effectively deliver voice over DSL in the local loop?” The founders talked to over 60 service providers and gradually developed a product road map and business model.

The result is CopperCom. CopperCom's hardware allows carriers to provision up to 16 voice channels, in addition to high-speed data, over a single phone line. The gear supports toll-quality voice service, including all the standard features such as call waiting, as well as fax and dial-up modems, with carrier-class reliability and scalability on the back end.

The company focuses on the small-business and upscale residence market segment, which Ringo calls “the last bastion of monopoly” for the incumbent carriers. Using CopperCom's equipment, a data CLEC could lease one unbundled loop from an incumbent for roughly $20 per month and sell the end-user up to 16 lines of voice service plus high-speed Internet access. Because the CLEC can charge for all of these separately, the economic case is compelling.

“If you’re deploying DSL, voice is an application,” Ringo says. Carriers offering data-only DSL may face competition from cable modem services that would force them to lower their rates (although so far such head-to-head competition is limited and cable is not available in most business areas, as we discussed in Release 1.0, 2-99). Currently, small businesses spend 10 times as much for voice services as for data, so using DSL solely for data leaves a significant amount of money on the table.
Ringo believes that CLECs will be the best market for voice-over-DSL technology in the near term because they move more quickly than incumbents, but she believes ILECs will ultimately be a bigger customer market. “From the very beginning, we have structured our business to be able to address incumbents as well as new-entrant carriers.” For example, CopperCom supports the TL-1 management language which is common in incumbent networks but not widely used by new entrants. The company says its gear works with DSL central office equipment based on both frame relay and ATM.

CopperCom has begun limited trials with potential customers, and expects to have significant trials in the next 60 days with CLECs, ILECs and interexchange carriers (IXCs), with product availability in the third quarter. Ringo says that although CopperCom's products run over DSL, the technology can relatively easily be adapted to cable or wireless networks.

CopperCom's investors include Hambrecht & Quist, Texas Instruments, Intel, Patricof & Co. and Unterberg Towbin. Ringo sees the TI and Intel investments as particularly strategic. Because CopperCom's equipment runs on its own software and is designed to be flexible and extensible, Ringo believes the company will be able to improve features and lower cost rapidly as the performance of digital signal processors (DSPs) increases.

Jetstream

We mentioned Jetstream Communications briefly in our article on the Net and small business last year (see Release 1.0, 7/8-98). As we noted, the company shifted its development efforts from small office PBXs to integrated voice and data solutions for service providers.

Ceo Sundi Sundaresh says Jetstream's management decided to build voice-over-DSL products in late 1997. “Our initial belief was that this was a huge opportunity for the competitive service provider,” he says. “Any competitive carrier that had a desire to reach smaller line-size customers would see this as a valuable opportunity.”

As the company developed its product, however, it realized that voice-over-DSL technology would also appeal to IXCs interested in offering local service. In addition to saving on unbundled loop costs, IXCs could backhaul traffic to central switching points rather than deploy equipment at every central office. ILECs can benefit from the technology as well, Sundaresh says, because it allows them to offer bundled services and to deploy additional lines in areas where they do not have sufficient copper loops in place. The incumbents are more likely to use voice over DSL to serve high-end residential customers, whereas the CLECs and IXCs will tend to focus on small to medium business. Although the new entrants will move aggressively at first, Sundaresh expects that the three groups will represent roughly equal markets in three to four years.

Sundaresh believes that the cost-saving case for voice over DSL is only the beginning. “The opportunities to provide different compelling service offerings is limited only by the imagination of the service providers,” he says. By adding functionality to the basic voice/data bundle, service providers will be able to maintain good margins even as competition and technology erode the price of connectivity.
Jetstream successfully demonstrated its Unity architecture in the lab at the end of last year, and it is now running four trials with potential service provider customers. The company is targeting general availability for the third quarter of this year. Sundaresh sees the breadth of Jetstream's partnerships as an important advantage. Jetstream has worked to ensure that its equipment inter-operates with existing DSL multiplexer equipment deployed by carriers, and also supports a range of different customer premises equipment.

The 40-person company raised $10 million last month from Canaan Partners, Crosspoint Venture Partners, the Mayfield Fund and Mohr, Davidow.

TollBridge

TollBridge Technologies, based in Sunnyvale, CA, focuses on competitive local exchange carriers (CLECs) that have purchased end-office “Class 5” switches. The company has raised $17 million from investors including WorldView Technology Partners, Sutter Hill Ventures, Communications Venture Partners and Matrix Partners. TollBridge cto Asher Waldfogel served as a consultant to a number of networking startups including RedBack, Sentient and Copper Mountain. He saw an opportunity for DSL technology to open up new opportunities for CLECs, but all the existing DSL products were designed solely for data. TollBridge was founded in March 1998; co-founder and ceo Gary Tauss comes from small-office router vendor Ramp Networks.

Like its competitors, TollBridge views small business as the most significant opportunity. While regulators protect residential customers and large enterprises have the clout to negotiate discounts, Tauss says, “the guys in the middle, the small businesses, have nobody representing them and therefore they are paying a lot of money for these services.” CLECs today only have limited ability to reach this market, however, because it's generally too expensive for them to deploy switches at all incumbent central offices (COs).

TollBridge’s solution is to use data CLECs as wholesale bandwidth providers that can connect customers to voice CLECs’ switches. “We say anywhere there's broadband service, you can bring those customers back into a single Class 5 switch without worrying about where you’re connected,” Tauss explains. The data CLEC would provision the high-speed line over an unbundled loop to the customer, and the voice CLEC would take the traffic off the data network at a convenient point and connect it to a switch.

While CopperCom and Jetstream run packetized voice over asynchronous transfer mode (ATM), TollBridge uses voice over IP. ATM has built-in quality-of-service mechanisms but is more complex than IP. CopperCom and Jetstream say IP is not yet mature enough for voice service, but TollBridge believes it can offer toll-quality voice over DSL without ATM. The strategy is risky, but if it can deliver and can convince service providers that ATM is unnecessary, TollBridge could have an important advantage. The company has successfully tested Class 5 switch interoperability with a major CLEC and will announce rollout details later this month.

TollBridge has designed its equipment to run over any kind of network and any flavor of DSL. Carriers need not buy different equipment depending on whether they use frame relay or ATM, for example. TollBridge’s narrow
focus on CLECs also distinguishes it from its competitors, who have
designed their products to appeal to ILECs as well.

Although the near-term business case is to expand the reach of voice CLEC
services, Tauss acknowledges that voice over DSL has broader potential.
"It brings us a little bit closer to voice and data convergence, because
now you've got partners working together who really know both sides of the
world," Tauss says. "It creates all kinds of new partnerships between
traditional class 5-owning CLECs who know about voice, and new aggressive
data-focused CLECs like NorthPoint, Rhythms and Covad."

Bundled services to the home

CopperCom, Jetstream and TollBridge all focus initially on service
providers selling to small businesses rather than residential markets.

The same hybrid voice/data technology could be the bridge between high-
speed Internet access services and home networks (see Release 1.0, 12-98).
DSL or cable modems could turn into the mythical residential gateways that
support both external voice and data connectivity and internal LAN applica-
tions. 2Wire, a startup in Milpitas, CA founded by former Polycom ceo
Brian Hinman, wants to make this vision a reality. "Sharing the DSL pipe
for both voice and data applications follows from basic economics, whether
it is for business or residential use," says Hinman. The company won't go
public with details until it launches later this year, but it bears watch-
ing. Superline, jointly developed by Paradyne and Lucent subsidiary AG
Communications, also shows promise for this market.

The IP PBX

Businesses today have a choice for their phone systems between Centrex
service and private branch exchange (PBX) equipment. Centrex is hosted at
the local phone company and priced on a monthly basis, while a PBX is
installed at the customer premises. Because Centrex involves a recurring
charge for each user, PBXs are typically cheaper except for very small
companies. PBXs also tend to offer more sophisticated features. But the
traditional PBX is closed, proprietary hardware, leaving the customer
dependent on the vendor for upgrades and new services.

A number of companies have begun building equipment that offers PBX func-
tionality over IP connections. With a standards-based platform, the PBX
suddenly becomes as flexible as a Web server. Vendors and customers can
take advantage of best-of-breed hardware and can add features through stan-
dard interfaces. Moreover, the IP PBX complements voice-over-IP services.
Companies don't just buy basic dialtone phone service; they expect addi-
tional features such as conferencing, call forwarding, voice mail and
directories.

The real efficiencies of the IP infrastructure occur when all those servic-
es run over the same platform. Want computer telephony integration (CTI)
features such as address lookups from your contact manager, or call-center
functions such as advanced queueing and incoming call information popping
up on your computer screen? Just add software modules.
That will require effective quality-of-service (QOS) management so that voice quality remains good. The levels of reliability and scalability that customers expect appear to be at least a year off, perhaps longer, but getting there will not require any great technological leap. Because IP PBXs can use off-the-shelf hardware components, it should be relatively easy to extend them to enterprise-class redundancy. End-to-end policy management systems will help ensure QOS across network links (see Release 1.0, 6-98).

One company that clearly understands this vision is Cisco. Last October, Cisco acquired IP PBX vendor Selsius Systems for $145 million. Selsius had developed a complete IP-based office phone system consisting of telephone handsets, call processing software, and a voice-over-IP gateway. The Selsius phones look like ordinary office telephones, but with an Ethernet port instead of a standard RJ-11 connector on the back. Voice traffic inside the enterprise runs over the corporate LAN/WAN infrastructure rather than the voice network. Cisco is converting its own in-house phone system to the new architecture to prove that it can deliver scalable, reliable performance and significant cost savings.

Several other companies such as Altigen, Vertical Networks, Shoreline Teleworks and NBX (acquired in February by 3Com) have begun to offer IP-based boxes that take the place of the traditional PBX. Ultimately, though, a PBX is just a set of software applications. That intelligence belongs at the edges of the network, but it need not reside on the customer premises. Companies are increasingly outsourcing important functions to application service providers (see Release 1.0, 9-98) to free themselves of IT costs. The same model works for telephony applications.

Hosted IP PBXs will allow service providers to offer reliable, scalable telephony services to their customers, because the PBX server is managed as part of the carrier network. At the same time, because they use open Internet standards, hosted IP PBXs can take advantage of best-of-breed components, can integrate with other hosted or local applications and can offer Web-based self-provisioning. It's Centrex, but without the limitations of the older systems, just as voice-over-DSL technologies allow carriers to offer the same end-user value as circuit-switched voice while leveraging the benefits of packet-switching.

Odisei

Odisei is building a next-generation hosted IP PBX solution. CEO Frederic Artru was formerly an engineer at Apple, where he was involved with the Versit consortium that developed the vCard and vCalendar standards for exchanging personal information online. Specifically, he co-authored Versit's CTI encyclopedia, which described how to make a PBX compatible with computer-telephony-integration systems. Based on this knowledge about how to model a PBX in software, he founded Odisei in February 1998. The 12-person company is headquartered in Palo Alto, CA, with R&D based in Sophia Antipolis, France.

Odisei's IntraSwitch is a Java-based telephony server that offers traditional PBX features and can serve as a control point for LAN-based telephony products throughout a company. Odisei plans to sell IntraSwitch to service providers such as ISPs and CLECs, who would then use it to offer
Centrex-like services over packet-switched networks. The company is now lining up sites to test its software, and it plans general availability for IntraSwitch early next year.

"The original model was to use this technology in similar fashion to most of the IP PBXs deployed today: as on-premises equipment on a server and driving either IP phones or phone gateways," says vp of marketing Dominique Pitteloud. With the emergence of centrally-provisioned voice over packet technology, however, Odisei's founders saw a new opportunity. Service providers are looking for ways to offer value-added services beyond base-line Internet connectivity. Voice is one of those applications, but once voice is routed over the data pipe it becomes possible to offer additional services that previously required specialized equipment.

The benefit of this approach is flexibility. As a Java-based application, IntraSwitch can run on standard carrier-grade Sun Netra servers, and a single server can host multiple virtual PBXs for different customers. The servers can be located virtually anywhere in a service provider's network, whereas circuit-switched equipment is closely tied to the physical infrastructure. Customers can log into the device remotely over the Web, and can self-provision administrative functions such as adding users that require telephone-company service technicians on a Centrex system.

Because IntraSwitch talks standard protocols, it can easily support different access networks and customer-premises devices. For example, Odisei announced a partnership last month with hardware vendor 8x8, which recently introduced a four-port IP-telephony gateway called Symphony for the small office/home office market. It has also partnered with Calista, which makes gateways to allow legacy business telephones to interoperate with IP-based PBXs. At the software level, IntraSwitch allows common desktop applications such as ACT! and Outlook to integrate with the company phone system, because everything is running on the same platform. Or a company's e-commerce site could offer click-to-talk functionality routed to the appropriate customer service representative, without an expensive new call center infrastructure.

On May 12, Odisei agreed to be acquired by 8x8. Pitteloud says the merger won't change Odisei's fundamental story, but will provide additional resources to bring IntraSwitch to market and to couple it with 8x8's end-user hardware for faster development and better reliability.

Hollowing out the communications industry

Inexorably, the Net is swallowing the phone network. Qwest's purchase of LCI last year and Global Crossing's pending acquisition of Frontier demonstrate that bandwidth is the most valuable currency at the core of the network. AT&T recently announced that it would stop buying circuit switches and would migrate over time to a packet-based architecture. Most of the industry's revenue remains voice-centric, but that will change as voice-over-packet solutions mature. Groups such as the International Softswitch Consortium, formed last week to develop interoperability standards for voice and IP networks, will help the process along.

Once the dike breaks the communications industry may change quickly. The software world is just getting accustomed to packaged products turning into
hosted services (see Release 1.0, 9-98). In telecom some applications are moving in the other direction. As IP infrastructure migrates all the way out to the customer, it becomes more cost-effective to build value-added services at the edges of the network. On one level, connectivity itself will become more of a commodity. Traditional circuit-switched carriers and their hardware vendors can leverage control over proprietary systems and interfaces, but in the IP world the pipes are separate markets from the applications that run on top of them. On the other hand, the converged world provides new opportunities for service providers.

The holy grail of the communications world is one-stop shopping. Service providers are convinced they can generate greater margins and retain customers by offering a bundle of local, long-distance and wireless voice services and applications along with Internet connectivity. This vision animates both AT&T in its acquisition of cable operators to provide local phone service, and local companies such as Bell Atlantic seeking approval to enter the long-distance market.

One thing this vision misses, though, is that the pipes are the commodity piece of the one-stop shopping environment. Wholesalers such as Qwest and Level 3 can thrive in a commodity environment because they have so much bandwidth to sell, but at the retail level, price competition will gradually squeeze the margins from any competitive service. The challenge is to move up the value chain. Service providers' real assets will be their experience and customer relationships.

The hidden value of connectivity

Connectivity is the true portal. Before you reach Yahoo! or Amazon.com, you need to get online. Companies that provide voice and Internet connections will be in the best possible position to offer customers hosted applications or other add-on services. The margin might come from e-commerce-enabling legacy databases or video programming, or it might come from a flat monthly service-integration fee with everything else offered at cost. So long as the wires themselves are open to sufficient competition, service providers will have to innovate and offer the packages that customers demand.

Such offerings will be most compelling for residential consumers, and for small to medium businesses. Large enterprises already can turn to systems integrators such as EDS and IBM which combine applications with networks. But a small business still typically calls on different providers to install its phone system and to handle its applications (payroll, human resources and so forth) and e-commerce site. Different companies will still develop and host those applications, but in the emerging IP world, communications service providers will be an important channel to bring them to customers.

Today's incumbent carriers aren't necessarily the dinosaurs in this scenario, though they certainly have the most to lose. If a voice bit is really the same as a data bit, prices for traditional communications services are bound to plunge. Any company that acknowledges this can position itself for the future.
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For further reading:

Jerry Saltzer, David Reed, and David Clark, “End-to-End Arguments in
   System Design,” ACM Transactions on Computer Systems, Vol. 2, No. 4 at
   277-288 (November 1984)

Brian Carpenter, “Internet Transparency,” (unfinished draft), available
   at www.ietf.org/internet-drafts/draft-carpenter-transparency-01.txt

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  please let us know.)
**Release 1.0 Calendar**

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**June 3**

5th Human Factors and the Web conference - Gaithersberg, MD. Hosted by the National Institute of Standards and Technology. Contact Sharon Laskowski, (301) 975-4535; fax, (301) 975-5287; hfweb@nist.gov; www.nist.gov/hfweb.

**June 14-17**

GigaWorld IT Forum '99 - Scottsdale, Arizona. For info contact Adrienne Kennedy, (781) 792-2643; fax, (781) 982-1724; a.kennedy@gigaweb.com; www.gigaweb.com/events.

**June 22-24**

PC Expo - New York, NY. Over 100,000 corporate technology buyers in search of new toys. Sponsored by Miller Freeman; keynote speakers include Bob Herbold and Chuck Geschke. For information, call (800) 829-3976; www.pcexpo.com.

**June 22-25**

*INET '99* - San Jose, CA. The Internet Society's annual conference. For information e-mail inet99-register@isoc.org; www.isoc.org/inet99/. ED speaking

**July 14-17**

Genetic and Evolutionary Computation Conference - Orlando, FL. Joint meeting of the 8th International Conference on Genetic Algorithms and the 4th annual Genetic Programming Conference. For information call (650) 328-3123; fax, (650) 321-4457; e-mail gecco@aaai.org; www-illigal.ge.uiuc.edu/gecco/.

**July 15-17**

The Wizards of OS: Operating Systems and Social Systems - Berlin. Examines the meaning of operating systems as the foundation of the contemporary information society. Contact Volker Grassmuck, 49 (30) 313-2795 or 49 (30) 2093-3180; vgrass@rz.hu-berlin.de.

**September 25-27**

#Telecommunications Policy Roundtable Conference - Alexandria, VA. The premier event for policy wonks interested in telecom-related technology issues. For information, contact Dawn Higgins, (202) 452-9033; e-mail tpcc@ei.com; www.si.umich.edu/~prie/tpcc/.

**October 10-17**

Telecom 99 / Inter@ctive 99 - Geneva, Switzerland. The International Telecommunications Union's massive telecom conference and trade show. Call 41 (22) 730-6161; fax, 41 (22) 730-6444; e-mail telecom99@itu.int; www.itu.int/telecom.

**October 24-26**

**EDventure's Tenth Annual High-Tech Forum** - Budapest, Hungary. Call Daphne Kis, (212) 924-8800; fax, (212) 924-0240; daphne@edventure.com; www.edventure.com.

* Events Esther plans to attend.
# Events Kevin plans to attend.

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