

The Future of the Internet and Broadband ...and How to Enable It

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Overview

The ITIF is pleased to have the opportunity to offer our viewpoint on this very important issue, and pleased that the United States' expert agency on telecommunications is making a concerted effort to gaze into the crystal ball in order to divine the contours of events that none of us can really foresee. It's a useful exercise that should stimulate some creative thinking, whatever the immediate outcome.

Let's review how we got here, at least with regard to the Internet. The Internet as we know it today is the culmination of a 50 year experiment with packet switching that began in the mind of a young engineer named Paul Baran. Baran set out to devise a method of building communications networks that could survive nuclear attack, and Internet is a side-effect of that project. His work inspired the designers of the ARPANET, which fostered the education of a team of engineers who in turn helped design the CYCLADES network in France. CYCLADES engineers in turn provided the conceptual framework for the modern Internet. The Internet now serves 1.5 billion people connected to 65,000 autonomous systems, which meet in 300 Internet Exchange Points where they share 300,000 routes.

The theme we draw from the past is a pattern of global cooperation in research; independent investment; ever-increasing utility, performance, and power; and ongoing collaboration in research, engineering, and operations.

We use this system today for e-mail, social networking, telephony, video-conferencing, and publishing prepared content in many forms, and will continue to use these traditional applications for some time. In the not-too-distant future, we're going to make greater use of rich audio-visual media for a variety of applications such as home monitoring and control, the maintenance of the smart grid, interpersonal communication in rich forms all the way up to holograms, and encompassing wider circles of participation. Distance learning, distance conferencing, and entertainment experiences from near and far will be routine. Libraries, encompassing written as well as audio-visual content will of course be easily searchable, and if we're too tired or restless to read a book, we'll have it read to us or performed on a nearby screen by real or virtual characters, and we'll chat with friends (or strangers if we prefer) while we watch or simply immerse in a 3D sound field.

More than eight billion new CPUs will be sold this year, but only a small number will be networked. Both of these numbers will grow. Our computers will be embedded in our cars, homes, workstations, glasses, and clothing, and we won't have to login or out as we move around because they'll know who we are, where we are, where we're going and what we intend to do when we get there, and they'll know how to share this information with each other while keeping it private from prying eyes. We'll interact with our machines more by gesture and speech than by keyboards and mice, but they'll anticipate a lot of our wants, wishes, and whims.

We'll need a network with several orders of magnitude more power, reach, and scale than the ones we have today to make this future come to pass, of course. This will mean continued advancements in processing power, storage, and transmission. With regard to the Internet itself it will also mean that the Internet of the Present will not become the Internet of Future: there is no migration path. Rather, it will be one of the networks that will form parts of this new Mega-Internet; probably an appendage that we utilize for passing stored content. It will be like the AlohaNet in Hawaii was when it was attached to the ARPANET through a gateway: a limited, but still vital, system.

Internet Architecture

It's been known for some time that the Internet architecture is challenged. The system has grown far beyond the scope of its original design, and currently suffers from a number of ailments related to its addressing and routing scheme, the structure of its protocols, and the method of its financing and operation. The Internet Architecture Board's (IAB) Workshop on Routing and Addressing declared as much in 2006:

The clear, highest-priority takeaway from the workshop is the need to devise a scalable routing and addressing system, one that is scalable in the face of multihoming¹, and that facilitates a wide spectrum of traffic engineering (TE) requirements.²

The Internet's addressing problem began when TCP and IP were separated. There was only one address, and IP got it. IP turned what had been a computer address into the address of a wire, which would have been fine if the computer had then got an address of its own. This didn't happen, hence issues with mobility, scalability, and routing

redundancy arose because routes and wires had addresses but end systems didn't. The Internet is thus an end-to-end system in which "ends" aren't directly addressable.

The Internet engineering community has tried to work around this fundamental design flaw with systems such as Classless Inter-Domain Routing (CIDR) and Locator/ID Separation (LISP)³, but these modifications simply delay the inevitable routing overload.

So it's clear that a new architecture is needed, and some of the best minds in the research community have been trying to devise one for some time now, using a variety of testbeds funded in by the National Science Foundation such as GENI and Stanford's Clean Slate.

We need to make sure that the Internet's new architecture doesn't suffer from the "Second System Effect" that Fred Brooks taught us about.⁴ We don't want bloat, but we do need a somewhat richer set of transport services than the current system provides: the one-size-fits-all model of transport and billing also inhibits growth. There is a very important reason to emphasize this requirement.

We have seen that most of the innovation the Internet has fostered takes place at the edge of the network. This is by design. But we have also seen an interaction between the capabilities of the network and the range of applications that it can support. When TCP/IP was originally deployed on the ARPANET infrastructure, the fastest link between any two routers was 56 kilobits per second. At that speed, video streaming was not a practical application. Most uses emphasized stored content and limited interactivity, such as the remote logins that were the major use of the ARPANET before TCP/IP.

As the link speeds have increased (all the way up to 100 gigabits per second in some cases,) the range of practical applications has broadened and now we take it for granted that we can do one-on-one video conferencing in standard definition and transfer entire DVDs worth of files, but not always at the same time and not always as often as we might like. We can now access the Internet from mobile devices, despite the evident shortcomings of a system of addressing that's distinctly hostile to mobility, thanks to a number of clever tricks inside the mobile networks, but the handoffs from sub-network to sub-network aren't always as fast as they should be. Capability has improved, but we're not yet in a position to utilize a fully pervasive system of universal connectivity, nor will we ever be in such a position given the constraints of the current architecture.

The Internet of the future has to support multi-homing, multi-tasking, and rapid mobility. The economics of this system need to be rational, with a proportionate ratio of cost and price for various uses and a high capital efficiency ratio. Currently, we have to increase the speed of a core link by 5 megabits per second to realize a 1 megabit per second apparent increase in throughput, and the ratio should be closer to 1:1.⁵ And it has to be secure and resilient to failures, although most of the security will continue to be provided in end-systems and their network gateways rather than in the transport system.

Internet R&D

There's no guarantee that the Internet of the future will be designed in the United States. The world of the Internet is flat, and many of the brightest engineering minds live and work outside our borders. In fact, we can be confident that a many of the innovations we will come to accept on the Internet of the Future will be created outside our borders, and that the fundamental architecture may be as well; the architecture of the current Internet was largely developed in France, after all. We're constrained by establishment thinking here, and often fail to appreciate how thoroughly wedded we are to conventional wisdom and sacred cows. And in contrast to some other nations, we have not made Internet R&D as much of a priority in recent years.

With regard to the particular area of network architecture research, it doesn't take large teams with enormous budgets to make fundamental advances. Paul Baran worked with a very small team, as did Louis Pouzin, the inventor of the framework for end-to-end networks that informs the Internet of today (as well as the four other major packet networks created during the same period as the Internet.) These gentlemen and their teams had a willingness to construct the problem differently than their predecessors had, with no commitment to the preservation of a status quo, and the ability to produce spare, elegant designs that could scale into extremely large systems with no loss of capability or runaway increase in overhead.

The Internet of the Future will start with a very simple architecture which combines the functions we now know such a network needs to have in a different conceptual model. The model will probably be "recursive," one in which large pieces are built out of small pieces whose structure resembles that of the larger ones, and so on. A small bit of work in this direction has been done by Joe Touch of the Information Sciences Institute at USC, and a much more comprehensive effort is underway at Boston University behind the leadership of John Day building on an Inter-Process Communication framework.

The fourth generation wireless networks specified by the 3GPP Working Group are explicitly "Next Generation Networks" which combine existing elements of Internet protocols with new wireless capabilities in ways that have not been possible in the past. LTE uses Internet Standards such as RSVP and Integrated Services, for example. Such efforts don't depend on the invention of new transport protocols, they're primarily different ways of combining many of the elements of network technology we use today, but in different ways and through different interface functions. That being said, TCP is overdue for replacement.

We needn't design the new Internet in this workshop, but we must emphasize that fundamental re-conceptualizations of the networking problem need to be an important research focus, and these efforts need to be explicitly driven by the requirement to support innovation by the network's ultimate users even better than we have in the past.

Broadband and Telecommunications

The Internet runs on telecommunications networks, and increasingly on wired and wireless broadband networks and these support end-use devices that rely on semiconductor processing. That system, and the companies that provide the hardware, software and services that enable it, has been driven by research and innovation. Innovation beyond the Internet itself is a different and more wide-ranging challenge, in part because the scale of the problem and the resource needed for progress are much bigger.

Historically, the United States became the world leader in computing and telecommunications because we had institutions that made large and visionary investments in early stage research which was then widely shared. A core component of this innovation ecosystem was Bell Labs. Since its founding in 1925, Bell Labs has made seminal scientific discoveries, created powerful new technologies, and built the world's most advanced and reliable networks. These innovations included data networking, the transistor, cellular telephone technology, operating systems, the laser, digital transmission, and digital signal processors. Because so much of the results of this research “spilled” over to other firms (not just AT&T) and industries, the incentive to do this kind of foundational, generic research was based on the fact that AT&T had significant market power and was a regulated monopoly. When the costs of research could be included quietly in the rates paid by U.S. telephone customers, it was much easier to support the optimal level of telecom research. But with the introduction of competition to the telecommunications industry, Bell Labs has been restructured to focus more on incremental technology improvements with a shorter-term payoff. But while the downsizing and restructuring of Bell Labs is just one example, it is reflective of an overall shift in corporate R&D, with companies in the U.S. expanding their investments in development much more quickly than their investments in research. Indeed, the decline of the U.S. long-range industrial research infrastructure is troubling for the future of broadband technology, and importantly for the competitive position of U.S. telecommunications equipment suppliers.

The Bell Labs experience is emblematic, albeit more dramatic, of what has happened in corporate support for R&D, including in IT and telecommunications. Overall, corporate R&D support in the United States has shifted away from more exploratory research toward more short-term projects with more certain results. And in some segments of the IT industry, corporate R&D has declined. For example, from 2001 to 2007, corporate R&D in the United States in the communications equipment sector has fallen almost by half (declining 45%) as a share of GDP.

As such, if the United States is to maintain its role as an innovation leader in this area, the federal government needs to step in and help create the incentives for the conduct of more exploratory and risky research in these areas. Unfortunately, in some areas the federal government is going in the wrong direction.

For example, another major player historically in the development of the Internet and telecommunications has been DARPA. DARPA played a key role in supporting the

development of computer science as an academic discipline through large sustained investments at universities like Carnegie Mellon, MIT, and Stanford. But like Bell Labs and many private sector R&D supporters, DARPA too has shifted its focus in the last decade away from more exploratory research toward more short-term projects with more certain results.⁶

In contrast, other nations have focused more extensively on broadband and telecommunications R&D. There are a wide range of examples. Finland's TIVIT program seeks to create new ICT-based business ecosystems aimed at enabling a real-time information society. Tekes (the Finnish innovation agency) will provide €50M (\$71M) of funding in 2009-2010 for research into Future Internet, Flexible Services, Devices and Interoperability, and Cooperative Traffic ICT. A separate program, Value-Added Mobile Solutions (VAMOS) 2005-2010, is funded at €16.4M (\$23.5M) annually for R&D into how mobile devices, networks, and component technologies can be used in commercial applications by Finnish industry. If the U.S. were to match this on a per-GDP basis, it would have to invest \$6.8 billion per year.

Sweden invested SEK 909M (\$128M) in 2008 and will invest SEK 1,445B (\$204M) in 2009 for government-funded R&D aimed at transportation and telecommunications industries. A joint partnership between Vinnova (the Swedish innovation agency) and the Chinese Ministry of Science and Technology will invest €4M (\$5.7M) in seven joint projects focused on mobile technologies.

The Dutch government provided \$155 million funding for research into high-speed networks, including the GigaPort Next Generation Network, a national infrastructure research network permanently at the disposal of the government, the IT industry, educational and research institutes; the Virtual lab e-science (VLE) for collaboration and testing new technologies; and Freeband Knowledge Impulse, a joint initiative of the government, industry, and academia to increase knowledge of fourth generation telecommunications⁷

The UK government is investing £1 million to help companies and universities carry out initial research and feasibility studies into technologies that will be needed for the next generation of broadband beyond that currently available, so called Ultra Fast Broadband. The funds and projects are being channeled through the UK's Technology Strategy Board.

At the EU level, the European Union's 6th Framework Programme prioritized €3.6B (\$5.1B) of funding for information society technologies (IST) research. The EU Member States have earmarked a total of €9.1 billion for funding ICT over the duration of FP7.

Asian broadband leaders are also investing heavily in IT R&D. Japan funds advanced telecommunications research through, among other agencies, NEDO (New Energy and Industrial Technology Development Organization). For example, they are investing 1.04 billion yen (\$11 million) in the Development of Next-generation High-efficiency Network Device Technology. In South Korea, the Electronic & Telecommunications

Research Institute (ETRI) receives over \$350 million annually for electronics and telecommunications research. The government is also supporting research on ubiquitous sensor networks, aimed at letting smart machines and products communicate with each other.

Policy Issues

We're in a period of transition between the Internet of the Past and the Internet of the Future, and consequently are caught in the middle of several tugs-of-war and innovation tensions, many of them not visible to the general public except in their side-effects. We don't know which elements of the Internet of Today will survive the transition and which ones will be upgraded, but we need to be able to ensure that the networks we use in ten years time will support the applications we want. A core challenge for moving forward will be the development of a more robust Broadband and Internet research program.

This should start with an increase in government support for research in these areas. There are a number of programs at the federal level to support research in this area. The major one, the NSF's Directorate for Computer and Information Science and Engineering, supports research in these areas. The program supports investigator initiated research in all areas of computer and information science and engineering and helps develop and maintain cutting-edge national computing and information infrastructure for research and education generally. In FY2008, it received \$535 million, with an approximately \$235 million in addition through the ARRA. However, not counting the one-time ARRA funding, CISE funding has barely increased – just 7 percent as a share of GDP from 1995 to 2008.⁸ And overall U.S. government R&D to computer science increased at a slower rate (30 percent) from 2000 to 2005 than did overall federal government support for R&D (40 percent) and has barely budged as a share of GDP.⁹ If we are to maintain the kinds of innovations we need in the future in these areas, we will need to increase federal support for research in this area.

There have been efforts that recognize we need to do more here. The Advanced Information and Communications Technology Research Act (S.1493) was introduced in 2007 to among other things establish a Telecommunications Standards and Technology Acceleration Research Program at NIST to support and promote innovation in the United States through high-risk, high-reward telecommunications research. In addition, it would establish a program of basic research in advanced information and communications technologies focused on enhancing or facilitating the availability and affordability of advanced communications services to all Americans. However, the legislation was not passed.

It is time to build on these efforts in several ways. First, we should expand federal support for these initiatives. This would include increasing support for networking R&D by at least \$50 million per year at NSF, with additional increases at Department of Energy and DARPA. In addition, NSF should fund a major upgrade of "campus cyberinfrastructure," (including high performance computing, data centers, local area networks, and external connections to advanced backbones).¹⁰

But it's not just enough to increase research support; the federal government should also spur more inter-firm and industry-university collaborative research in these areas. We have some successful experience with this to date. For example, 12 wireless communications companies have formed a research consortium with the University of California-San Diego Engineering School to work on advanced research related to their industry.¹¹ The Semiconductor Research Corporation (SRC) – a nonprofit research consortium of 36 companies and federal government agencies – plans, invests in, and manages a low-overhead, industry-driven, pre-competitive Global Research Center program that addresses the short-term needs identified in the Semiconductor Industry Association's International Technology Roadmap for Semiconductors. The Microelectronics Advanced Research Corporation, a subsidiary of SRC, operates a Focus Center Research Program that funds multi-university research centers to address broad, long-range technological challenges identified in the Roadmap. Semiconductor and related firms and the Department of Defense jointly fund the Focus Centers.¹²

The federal government should create a process to allow more industry-university collaborative research efforts to be formed in other related areas. For example, as discussed above, the Finnish government supports an active research consortium in wireless technologies. The idea would be to offer competitive grants to industry consortia to conduct research at universities. These competitive Industry Research Alliance Challenge Grants would match funding from consortia of businesses, businesses and universities, or businesses and national labs. These grants would resemble those that the current NIST Technology Innovation Partnership program (TIP) and the NSF innovation programs (Partnerships for Innovation, Industry-University Cooperative Research Centers, and Engineering Research Centers) offer. However, these grants ideally would have an even greater focus on broad sectoral consortia and would allow large firms as well as small and mid-sized ones to participate.

But in addition to funding these kinds of consortia, we also need to fund small team efforts, outside the research establishment. This is particularly important in helping to create the new architecture and give them access to the research testbeds and opportunities to confer. The DARPA SBIR process is instructive.

With respect to the Internet itself, there are several steps to take. First, we should abandon the idea that there's a seamless path to the future. There may be one, but we don't need to assume we know where it is.

Second, network engineers often express fears of fragmentation and stress uniform solutions. That may not be the most productive path, as it leads not to a "network of networks" but to "one large network" with a common set of limitations. A multiplicity of separately designed and managed networks with common data interchange formats may be a more productive approach.

Third, it is important to clarify the rules on permitted and non-permitted forms of network management. Relying on vague, service-stifling generalities, overly

prescriptive minutiae or outright bans as some legislation proposes will limit needed research and innovation in the network.

Fourth, it is important to develop rules for unlicensed and secondary use of spectrum that recognize the nature of digital packet networks and build on our experience with such systems in the past five years. Related to this is the importance of providing an expedited means of resolving disputes over spectrum use that conforms to a legal doctrine of spectrum rights and doesn't require lengthy court battles. Problems arising over particular secondary uses need to be resolvable in minutes, for example.

Conclusion

The Internet of the Future will come about with or without action by the Commission, the Congress, or the research community in the United States. This is because networking is now a global concern and much of the work that will build this network is already underway around the world. But without U.S. leadership, progress will be slower than desirable. Moreover, if the United States wishes to provide leadership in this effort, let alone participate in it, we'll need to actively support research and deployment efforts.

The Internet that we use today was designed for research purposes and pressed into service to meet user needs for a global system before it was sufficiently well-developed for the purpose. Moore's Law, massive investment, and the heroic efforts of a global team of professional administrators working around the clock have enabled it to come this far, but we can't count on it to grow much larger. Fortunately, we've learned enough along the way to be able to devise a system that will serve us for the next 35 years. The trick is to tap into the intelligence of the network engineering community around the world, extract the best ideas, test them in parallel, and synthesize.

Endnotes:

¹ Multi-homing provides multiple network paths to a system or service.

² David Meyer, Lixia Zhang, and Kevin Fall, eds., "Report from the IAB Workshop on Routing and Addressing," RFC 4984 <<http://www.ietf.org/rfc/rfc4984.txt>>

³ David Meyer and Darrel Lewis, "Architectural Implications of Locator/ID Separation," Internet Draft <<http://tools.ietf.org/pdf/draft-meyer-loc-id-implications-01.pdf>> (accessed September 27, 2009).

⁴ Fred Brooks, *The Mythical Man-Month: Essays on Software Engineering (Anniversary Edition)*, Addison-Wesley, 1995.

⁵ The inability of the Internet core to saturate links is a consequence of the congestion control algorithm employed by TCP.

⁶ Erica Fuchs, "The Role of DARPA in Seeding and Encouraging New Technology Trajectories: Integrated Photonics, Microelectronics, and Moore's Law." Invited Chapter in *Swimming Against the Current: The Rise of a Hidden Development State in the United States*. Ed. by. Fred Block, 2007 forthcoming.

⁷ Ministry of Economic Affairs, “Broadband and Grids Technology in the Netherlands,” *Innovation*, (The Netherlands: Ministry of Economic Affairs, 2005), <<http://www.ez.nl/content.jsp?objectid=143637&rid=142410>>.

⁸ National Science Foundation, *NSF Budget Request to Congress and Annual Appropriations, 1995-2008* (Washington, D.C.: NSF), <<http://www.nsf.gov/about/budget/>>.

⁹ The National Science Foundation, *National Patterns of R&D Resources, 2009* <<http://www.nsf.gov/statistics/natlpatterns/>>.

¹⁰ The federal government has also provided minimal funding (around \$1 million per year over the last five years) to Internet2, a consortium the research and education community, which promotes the missions of its members by providing both leading-edge network capabilities and unique partnership opportunities that together facilitate the development, deployment and use of revolutionary Internet technologies.

¹¹ Center for Wireless Communications Web site, <<http://www-cwc.ucsd.edu/members.php>>.

¹² See Focus Center Research Program Web site, <<http://fcrp.src.org/member/about/fcrpqa.asp>>.