FEATURED ARTICLE

HISTORY OF THE INTERNET AND ITS FLEXIBLE FUTURE

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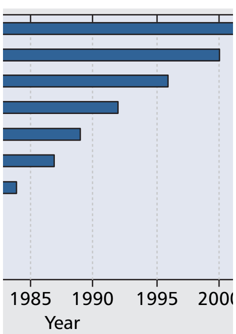

The author relates the history of wireless communications to the history of the Internet. A vision of where the Internet is heading is presented A network with extreme mobility, ubiquity, personalization, adaptivity, video addiction, and surprising applications, as yet unimagined is foreseen.

ABSTRACT

This article relates the history of wireless communications to the history of the Internet. The early work on packet switching is traced, and then a brief description of the critical events in the growth of the Internet is provided. Then, a vision of where the Internet is heading is presented, with a focus on where user participation, flexible applications and services, and innovation are appearing. A network with extreme mobility, ubiquity, personalization, adaptivity, video addiction, and surprising applications, as yet unimagined is foreseen.

INTRODUCTION

TODAY'S INTERNET

The applications of communication technologies that serve the needs of our industry and of society have undergone significant shifts since the beginnings of telecommunication a century ago. The wireless and wireline digital infrastructure we currently enjoy, which serves a vast worldwide community of users, has seen the merging of analog and digital technologies and of voice, data, video, text, image, fax, graphics, and streaming media. The Internet is the current manifestation of these many developments and the vortex around which an accelerating wave of change and improvement is taking place, not only in the infrastructure, but also in the applications, users, services, and innovations of the technology.

The Internet is leading the way into a twenty-first century information society. It has penetrated our institutions and has changed our behavior and attitudes in fundamental ways. More than one billion people on this planet use the Internet today. The younger generation cannot conceive of a time when they could not share their photos, chat with friends, stream video, or shop online. We can never turn the clock back to the pre-Internet world.

The secret of the power of the Internet lies in the fact that it embraces and encourages everyone to contribute their creative ideas, knowledge, and works and make them available to others interactively on the Internet. The Internet founding philosophy of openness and community provided the environment that spawned its tremendous growth in its early years.

The Internet has a flexible future, and the form it takes depends upon how we and circumstances shape it. Certainly it is safe to say that it will be a network with *extreme mobility*, *personalization*, *video addiction*, and *surprising applications as yet unimagined*.

Yet, as we race forward into this world of always connected people, devices, applications, and services, it is helpful to glimpse the past and see the forces and the pioneers that helped bring about these wonders. Too often we forget that many of the advanced technologies we enjoy in the present were conceived of, developed, and deployed many years ago by heroes of yesteryear. Let us review the past and explore the heritage of the technology with which we are endowed before we launch into a vision of where we are heading.

WHAT THEY WERE SAYING BACK THEN . . .

Who said the following and when?

"It will be possible for a business man in New York to dictate instructions, and have them instantly appear in type at his office in London or elsewhere. He will be able to call up, from his desk, and talk to any telephone subscriber on the globe. . . . An inexpensive instrument, not bigger than a watch, will enable its bearer to hear anywhere, on sea or land, music or song, the speech of a political leader, the address of an eminent man of science, or the sermon of an eloquent clergyman, delivered in some other place, however distant. In the same manner any picture, character, drawing, or print can be transferred from one to another place.[1]"

In reading this quote, one can't help imagining that this person is talking about a vision of the Internet. He is discussing worldwide connection among a vast number of users, instantaneous communication, and the transmission of voice, image, and data — with the use of a truly small access device. Amazingly, this is a quote from 100 years ago (1908) and was written by the famous Nicola Tesla, one of technology's unsung heroes, whose contributions to communications, power generation, and much more, were enormous. His insight and vision were prescient.

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Not everyone in those days got it right. Witness, for example, a quote by the great Heinrich Hertz, who created radio waves in a controlled laboratory environment: "I do not think that the wireless waves I have discovered will have any practical application." This quote goes down in history along with many other famous "misses" by technology leaders, such as: "This 'telephone' has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us." (Western Union internal memo, 1876); "That's an amazing invention, but who would ever want to use one of them?" (President Rutherford B. Hayes to Alexander Graham Bell in 1876 on viewing the telephone for the first time); "Heavier-than-air flying machines are impossible." (Lord Kelvin, president, Royal Society, 1895); "Everything that can be invented has been invented." (Charles H. Duell, Commissioner, U.S. Office of Patents, 1899); "I think there is a world market for maybe five computers." (Thomas Watson, chairman of IBM, 1943); "There is no reason anyone would want a computer in their home." (Ken Olson, president, chairman, and founder of Digital Equipment Corp., 1977). I remember being subjected to the same kind of narrow-minded and failed thinking in the early 1960s when my development of packet switching was dismissed by the top management of what was then the world's largest networking company, AT&T; they commented that packet switching would not work, and even if it did, they wanted nothing to do with it.

Much to his credit, Guglielmo Marconi, one of radio's pioneers, said later in his life, "Have I done the world good, or have I added a menace?" One could argue that Marconi was among the first to anticipate the dark side of global communications; for as we know, today we are menaced by spam, viruses, denial of service, identity theft, fraud, botnets, pornography, and so on.

Some of these early pioneers set the stage for the wireless revolution in the midst of which we find ourselves today, and that revolution is an integral, if not major force in the Internet and its flexible future. If we are to do a proper job of tracing the origins and history of the Internet, then we must present at least a brief history of wireless.

A Brief History of Wireless

Wireless has a long history. Its origins are to be found in the early literature involving the relationship between electricity and magnetism (notably, the widely known experiment conducted in 1820 by Hans Christian Orsted in which he demonstrated that a wire carrying a current could deflect a magnetized compass needle). In this article, we will not pursue that discussion; rather, we will briefly discuss the radio timeline and how it pointed the way to packet radio and today's mobile networking, which is such a strong and growing component of the Internet.

A landmark event occurred in 1864 when James Clerk Maxwell mathematically predicted the existence of radio waves. This was a stunning piece of work in which he was able to anticipate the radiation of radio waves (i.e., that electromagnetic fields spread in the form of polarized waves and with the speed of light) from the mathematics itself. Einstein offered the following laudatory comment in reference to Maxwell's work: "The special theory of relativity owes its origins to Maxwell's equations of the electromagnetic field." Unfortunately, Maxwell died in 1879 before his prediction was experimentally verified.

The experimental evidence would come just around and after the time of Maxwell's death. In 1878, David E. Hughes was able to send and receive Morse code, discovering radio waves in their first application. Later in 1888, Heinrich Hertz proved the existence of radio waves using a primitive transmitter and receiver.

It was in 1893 that the innovative Nicola Tesla demonstrated "wireless telegraphy" for the first time. In 1894, Alexander Popov built his first radio receiver in Russia, demonstrating it publicly in 1895, and subsequently developing the first non-laboratory radio service. By 1894, Oliver Lodge transmitted radio signals at Oxford University (based on a device known as a "coherer," which itself was based on a discovery made in 1890 by French physicist, Édouard Branly); but note that this was one year after Tesla and one year before Marconi himself had done so. Also in 1894, Jagadish Chandra Bose demonstrated a short-range radio transmission in Calcutta, India, using millimeter range wavelength microwaves. His research of remote wireless signaling was the first to use a semiconductor junction to detect radio waves and anticipated the existence of P-type and N-type semiconductors.

In 1895, Guglielmo Marconi transmitted wireless signals a distance of about one mile from the laboratory in his home outside of Bologna, Italy. That began a sequence of demonstrations of transmitting radio over longer and longer distances: in 1896, Tesla transmitted wireless signals over distances of up to 30 miles; in 1898, Popov effected ship-to-shore communication over a distance of six miles and then, over 30 miles in 1899; Marconi conducted a number of distance experiments for radio transmission with an 1897 link between the Isle of Wight and Bournemouth, England, some 13 miles away; a link across the English Channel (using a Tesla oscillator) in 1899; and then finally, in 1901, Marconi transmitted the first trans-Atlantic radio signal over a distance of 2200 miles.

In 1897 Marconi was granted a British patent (filed in 1896) for wireless telegraphy and established the world's first radio station and what later became the Marconi Wireless Telegraph Company. It was in 1900 that Nicola Tesla was granted his U.S. patents revealing the basic techniques for greatly improving radio transmitter performance; these had been filed in 1897. Marconi's U.S. patent application was turned down in 1900 and repeatedly for the next three years. However, in 1904, the U.S. patent office reversed its decision and awarded the patent to Marconi. Later yet, in 1943, the U.S. Supreme Court reversed the ruling once again and upheld Tesla's patent.

In 1900, Reginald Fessenden succeeded in transmitting voice over radio. In 1906, Lee de

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Forest invented the Audion, now known as the vacuum-tube triode, an essential component for radio systems. Then in1909, Marconi won the Nobel Prize in physics for his contributions to radio.

It is interesting to observe the interplay among these pioneers as they generated their own ideas and approaches to advancing wireless technology. They had a collective synchronicity of independent creativity and invention that spanned geographies across several continents.

These early developments caused radio to reach across the globe in a ubiquitous deployment. However, it was not until the digital age in the latter part of the twentieth century that we began to see wireless technology branch out in a number of important directions, including digital cellular telephony, mobile ad hoc networks, packet radio, wireless network access, hand-held wireless platforms, and so on, all of which contribute to today's Internet. Let us now review the history of the Internet.

A Brief History of the Internet

The Role of ARPA

One of the precursors of the Internet was an event that captured the world's attention and aroused a deep sense of concern in the United States. That event was the launching of the Soviet Union's Sputnik, the first man-made object to orbit our planet. It occurred on October 4, 1957, as part of the International Geophysical Year. It caught the United States by surprise and generated an awareness that we had fallen badly behind in science and technology. In response to this, in February 1958, President Eisenhower created the Advanced Research Projects Agency (ARPA), designed to promote research that would ensure that the Communists would never again beat America in any technological race.

One of ARPA's offices was the Information Processing Techniques Office (IPTO), which funded research in computer science and was highly successful in its early days, making great strides in the areas of time sharing, networking (spawning the Internet), packet satellite networking, packet radio networking, artificial intelligence, digital signal processing, high performance computing, hypertext, and much more. J.C.R. Licklider of the Massachusetts Institute of Technology (MIT) became the first head of IPTO in October 1962; this was shortly after he articulated his visionary ideas for a Galactic Network [2]. He had envisioned a series of connected computers linking everyone to a universe of information. This vision expanded his related concept (in 1960) of man-computer symbiosis [3] in which humans and computers would work together, exploiting the strengths of each in a symbiotic fashion. Although Licklider conceived of a Galactic Network, he did not offer a plan to implement such a system.

In 1963, Licklider left IPTO and ultimately returned to MIT. He was succeeded as director of IPTO by Ivan Sutherland, formerly of MIT, who held that position from 1964 until 1966. During his tenure at ARPA, Ivan visited the University of California Los Angles (UCLA) and suggested that a three-node network be created on campus to connect three IBM computers, all in different departments; sadly, the political issues involved with such a cooperative network were too much to overcome, and the network effort was disbanded. Nevertheless, the idea of implementing a computer network was already taking form within ARPA. Indeed, in 1965, Sutherland gave Larry Roberts of MIT an ARPA contract to create a dial-up 1200 bps data connection across the country between the TX-2 computer at MIT Lincoln Laboratory and a Q-32 computer at System Development Corporation in Santa Monica, California [4]. The connection worked, but it established how difficult computer-to-computer connection was and that there was a need for a more sophisticated network with the proper protocols to support such connections. With Licklider's encouragement, Ivan recruited Robert Taylor of the National Aeronautics and Space Administration (NASA), to become Associate Director of IPTO in1965, and Taylor succeeded Ivan as director in 1966. While there, Taylor also recognized the need for a network, this time to connect the many different computers that were being supported by ARPA so that they could share their hardware, software, and applications. To manage this effort — which was soon to become the ARPANET — in 1966, Taylor brought in the aforementioned Larry Roberts, to be Chief Scientist at IPTO. We shall return to this shortly.

Merging Threads of Inquiry

Like the early wireless pioneers, who had a synchronicity in their ideas, there was a similar phenomenon at work in the research community that generated the underpinnings of the Internet technology. Across continents, similar early networking ideas were being generated on the east coast in Cambridge, on the west coast in Santa Monica, and across the Atlantic in the United Kingdom. We refer to these three as the following: the MIT thread; the RAND thread; and the National Physical Laboratory (NPL) thread.

The MIT Thread — I came to MIT in 1957 to pursue a master's degree in electrical engineering. I had no intention of ever getting a Ph.D., no plan to go into academia, and little confidence that I was cut out to do truly advanced research (I did not realize that much of the innovative research work was actually done by graduate students). Although my plan was to take a job at MIT Lincoln Laboratory upon completing my degree, my M.S. supervisor, Professor Frank Reintjes, convinced me to stay at MIT and pursue a Ph.D. degree. I decided I would only do so if I were to find a research topic whose solution would have an impact. So I contacted the legendary MIT professor, Claude Shannon, who had created information theory and asked to work with him; to my delight, he agreed. However, when I looked around at my classmates, I found that most of them were working in the area of information theory, the area in which Shannon had solved most of the critical problems. This was not for me, because I judged that the remaining problems were both hard and of relatively little consequence. At the same time, having worked at Lincoln Laboratory and MIT, where I found myself surrounded by computers, I realized that sooner or later, these computers would need to communicate with each other. I also realized that the existing telephone network was woefully inadequate for such communication and that what was needed was a new network technology. Around that time, I found myself talking to Professor Ed Arthurs, who had been consulting on a classified project, about which he could reveal nothing except that it involved the problems facing computer-to-computer communications. I recognized that providing an effective solution to these problems was a fascinating challenge and one that I hoped would have a significant impact on technology and computers. The challenge and possible impact appealed to me, and so in 1959 I went forward on my Ph.D. research in this area.

By 1962, I completed my Ph.D. dissertation [5] in which I created a mathematical theory of packet networks, the technology underlying today's Internet. My results turned out to be well suited for realizing Licklider's vision. I published my dissertation research as a book [6] in 1964. In my research, I addressed the issues of scalability, performance evaluation, large network design, distributed adaptive control, hierarchical routing, shared resources, demand access, packetization of messages, and the advantages of large shared systems; additionally, I uncovered the underlying principles for the behavior of these networks. In an April 1962 publication [7], I was the first to introduce the idea of chopping messages into fixed-length blocks (later to be called "packets"). Much of this early work is summarized in a recent paper [8]. One of my main goals was to develop a design methodology that would scale to very large networks, and the only way to accomplish that was to introduce the concept of distributed control, wherein the responsibility for controlling the network routing would be shared among all the nodes, and therefore, no node would be unduly tasked; this resulted in robust networks. I was pleased to see this design methodology scale to the billion nodes in today's Internet.

Licklider and I, though both having conducted our research at MIT, did not know of each other's work; ironically, the combination of our work had laid the foundation for the technology and application of the Internet — something that would not be realized until years later.

The RAND Thread — Paul Baran of the RAND Corporation in Santa Monica was busy working on military communications during the period from 1960 to 1964 with the goal of using redundancy and digital technology to design a robust communications network. His early efforts in 1960 were devoted to the application of redundancy to maintain reliable multilateral communications in a network made up of unreliable links [9]. In September 1962, he published a paper [10] in which he extended those results and also introduced the use of standard-size addressed message blocks and adaptive alternate routing procedures with distributed control. His "hot potato" routing was innovative. In August 1964, he produced a set of 11 important reports [11] in which he elaborated on many details of the design. This work was done independently of the work that I had done at MIT and in many ways, the results we achieved in addressing the problem of packet networks were complementary.

The NPL Thread — Donald Davies, of the NPL in the United Kingdom, began thinking about packet networks in 1965 and coined the term "packet" that year. In a privately circulated paper [12], dated June 1966, he described his design for a data network and used my earlier theory to calculate its performance. Davies lectured to a public audience in March 1967, recommending the use of his technology for the design of a public-switched data network, and published an October 1967 paper [13] with his NPL group in which details of the design were first described in an open publication. This led to the NPL Data Communications Network, a one-node network, which first became operational in 1970, and whose further design details are described in a 1969 paper by Roger Scantlebury [14]. Those design documents included the basic elements of what we now find in packet-switched networks. Unfortunately, at that time, the U.K. government did not see fit to fund a full effort in this direction.

These were the three key threads of research, each of which developed elements of the technology of packet switching independently: the MIT thread (Kleinrock), the RAND thread (Baran), and the NPL thread (Davies). To my knowledge, the three threads seemed to be unaware of each other although, as mentioned previously, Davies quoted my book [6] in his early paper [12]. In the background, ARPA was poised to catalyze this work into a deployed network that evolved into the Internet.

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How the Threads Merged

The MIT and ARPA threads merged in 1963–64 when Licklider and I became aware of each other's work; by that time, I had accepted a faculty position at UCLA. However, no plans to implement a network had yet been conceived. The MIT/ARPA link strengthened in 1966 when Bob Taylor of ARPA recognized the need to create the net, and as mentioned previously, brought in MIT's Larry Roberts to run the project (Roberts became Director of IPTO in 1969). Roberts was well aware of my early MIT research (we were classmates there, as was Sutherland). He was convinced by my results that a packet network would work and that packets would not fall on the ground with overflowing buffers. In fact, in his own words [15], *"In order to plan to spend millions of dollars and stake my reputation, I needed to understand that it would work. Without Kleinrock's work of Networks and Queuing Theory, I could never have taken such a radical step."*

Roberts organized an ARPANET design meeting for a number of the ARPA principal investigators in April 1967 to discuss the concept of creating an ARPANET and decide on the key aspects of its design. Wesley Clark, of MIT Lincoln Laboratory, proposed the idea of a separate computer to sit in front of each node as a gateway to the network and offload most of the net-

As researchers and developers, we were driven by a strong sense of community in which the ideas and the products of our research were to be shared freely among all. The gratification for us was not one of proprietary ownership, but rather was the broad use of our creative works by others.

working functions from the attached host computers. The separate computer took on the name of interface message processor (IMP), and each of these would be (nearly) identical across the network. Herb Baskin from UC Berkeley insisted that a network connecting (time-shared) computer could sustain a maximum round-trip response time of no more than one-half second if it were to provide interactive performance. So we decided to specify a maximum of one-half second response time for short messages. We felt that reliability was a key issue and also realized that the four nines specification for reliability in telephone networks was not appropriate for data networks. Instead, we simply required that the network not fail if any single switch or link went down — this amounted to what is known as a two-connected topology. I insisted that if this was to be an experimental network, then we must definitely include tools in its design to allow measurements to take place throughout the net; this led to a requirement for the switches to contain hooks in the network to allow trace packets to be generated, for artificial traffic generators to be included, for measurements to be collected and forwarded, and so on. Having proposed these tools, and having laid out the theoretical foundation for these networks, ARPA decided that my laboratory at UCLA would be the first node of the network and also would become the Network Measurement Center [16] and conduct a variety of stress-testing experiments on the running network.

Based on the deliberations at this April 1967 meeting, Roberts then prepared an ARPANET design paper [17] and presented it at the ACM Symposium on Operating System Principles in October 1967. Scantlebury also was there presenting the NPL paper, [13] coauthored by Davies, *et al*. It was through a conversation at that meeting with Scantlebury that Roberts first became aware [18] of Davies's packet-switching ideas and of Baran's work. In June 1968, Roberts wrote an ARPA plan [19] in which he proposed that ARPA build a working network that would permit researchers to log on to each other's computers over the network and gain access to the many resources of each computer. This plan was by approved by Taylor in less than three weeks. Almost immediately, Roberts began drafting the request for proposal (RFP) [20] to build the proposed network and sent it out to 140 potential contractors in mid-1968. The contract was awarded to a Cambridge, Massachusetts firm — Bolt, Beranek, and Newman (BBN) — in January 1969.

The Project Manager for the BBN team was Frank Heart. He collected a team consisting of Dave Walden, Bernie Cosell, Severo Ornstein, Ben Barker, Will Crowther, and Bob Kahn to modify and program the Honeywell DDP-516 minicomputer they had selected to serve as the IMP. The BBN team produced an elegant design that met the specifications laid out in the ARPA RFP. This design was reported in the Host-to-IMP Report 1822 written by Bob Kahn who was in charge of the system design at BBN. Because UCLA was to be the first node of the ARPANET, BBN was tasked with delivering to UCLA the first IMP on Labor Day, 1969, only eight months from the time BBN was awarded the contract.

At UCLA, I assembled: a research team of computer science graduate students (Jack Zeigler, Gerry Cole, Carl Hsu, Al Dobieski, Gary Fultz, and Mario Gerla) to carry out analytic, design, and measurement studies for the forthcoming network; a software team (led by Steve Crocker and consisting of Jon Postel, Vint Cerf, Charlie Kline, and Bill Naylor) to design and implement advanced network protocols; and a hardware engineer (Mike Wingfield) to implement the Host-to-IMP interface; there were many others on the team as well. Basically, it was our job to prepare for connection as the first node on the ARPANET.

Other groups across the research community formed in similar ways. One should note that the culture of those early days of the ARPANET community was one of open research, shared ideas and works, no overbearing control structure, and trust in the members of the community. This culture came largely from the enlightened ARPA management (Roberts and Taylor), who allowed considerable freedom and flexibility in our research efforts; they imposed minimum requirements in terms of progress reports, meetings, site visits, oversight, and so on. As principal investigators, we delegated the further development and implementation of the protocols and software to a group of researchers and graduate students distributed across the country that self-organized themselves into a cooperating team that was extremely effective in producing results.

We felt strongly that control of the network should be vested in all the people who were using the net and not in the carriers, the providers, or the corporate world. As researchers and developers, we were driven by a strong sense of community in which the ideas and the products of our research were to be shared freely among all. The gratification for us was not one of proprietary ownership, but rather was the broad use of our creative works by others.

On July 3,1969, two months before the Internet came to life, UCLA put out a press release [21] announcing the imminent deployment of the ARPANET. In that release, I described what the network would look like, and what would be a typical application. I am quoted in the final paragraph as saying: "As of now, computer networks are still in their infancy, but as they grow up and become more sophisticated, we will probably see the spread of 'computer utilities,' which, like present electric and telephone utilities, will service individual homes and offices across the country." I am pleasantly surprised at how the computer utilities comment anticipated the emergence of Web-based IP services, how the electric and telephone utilities comment anticipated the ability to plug in anywhere to an always on and "invisible" network, and how the individual homes and offices comment anticipated ubiquitous access. What I clearly missed was the fact that my 99-year-old mother (now deceased) would be on the Internet; that is, I did not foresee the powerful community side of the Internet and its impact on every aspect of our society. We will return to this future vision later. For now, let us continue to trace the history.

1969 was a special year. In that year, a number of notable events occurred. The United States put a man on the moon. The Woodstock festival took place on a farm in New York State. The New York Mets won the World Series. Charles Manson went on a killing spree in Los Angeles. And, the Internet was born. Each of these events was widely publicized across the globe, except for the Internet — its birth was unheralded — no tape recorder, no camera, no media coverage, and so on. However, the impact of this event is now being felt in every aspect of our lives.

A major milestone was reached on September 2, 1969 when the newly arrived IMP at UCLA was connected to the UCLA host computer, an SDS Sigma-7 machine, thus establishing the first node of the fledgling network. It was on that day that the infant Internet took its first breath of life. In October, a second IMP was delivered by BBN to Stanford Research Institute (SRI) in Menlo Park, California, after which the first high-speed link of the Internet was connected and linked those two IMPs at 50 kb/s (this was considered blazing speed at that time). Later in October, SRI connected its DEC 940 host computer to its IMP.

The next milestone occurred when the first host-to-host message ever to be sent over the Internet was launched from UCLA and caused the infant Internet to utter its first words. This took place at 10:30 p.m. on October 29, 1969 when one of my programmers, Charlie Kline, and I proceeded to log in to the SRI host from the UCLA host. The procedure was for us to type "log" with the system at SRI set up to be clever enough to complete the rest of the command, namely, to add "in" and thus create the word "login." Charlie and Bill Duvall, the programmer at the SRI end, each had a telephone headset so they could communicate by voice as the message was transmitted. At the UCLA end, we typed in the "l" and asked SRI if they received it; "Got the l," came the voice reply. We typed in the "o" and asked if they got it and received "Got the o." UCLA then typed in the "g" and asked if they got it, and the system crashed! This was quite a beginning. However, on the second attempt, it worked fine! So, the first message on the Internet was a crash, but more accurately, was the prescient word "lo" (as in "lo and behold!").

The Growth and Development of the Internet

This section consists of brief entries, showing the year of an event, a comment regarding the event and the personalities, as appropriate.

- 1969: The first four nodes of the ARPANET are deployed. In order, they come up at UCLA, SRI, University of California at Santa Barbara, and the University of Utah.
- 1969: Howard Frank assists ARPA in the network topology design.
- 1969: Steve Crocker establishes the Request For Comments (RFC) series and authors the first RFC [22] entitled "Host Protocol."
- 1970: The ARPANET spans the United States with a connection from UCLA to BBN.
- 1970: The Network Working Group (NWG) releases the first host-to-host protocol called the Network Control Program (NCP) [23]. It was the first transport layer protocol of the ARPANET, later to be succeeded by TCP.
- 1970: A series of documents are published at a major conference describing the ARPANET technology [24].
- 1970: Norm Abramson develops Alohanet in Hawaii, a 9600-bps packet radio net based on the ALOHA multi-access technique of random access.
- 1971: BBN introduces the terminal interface processor to allow a terminal to connect to the ARPANET without connecting through a host.
- 1972: Ray Tomlinson of BBN introduces network email and the @ sign.
- 1972: First public demonstration of the ARPANET at the ICCC conference in Washington, D.C., organized by Bob Kahn.
- 1972: Norm Abramson's Alohanet connected to the ARPANET. This eventually led to the Packet Radio Net (PRNET) and was the first additional network connected to the ARPANET.
- 1973: The Packet Satellite Net (SATNET) is attached to the ARPANET, based on a shared 64-kb/s Intelsat IV channel. This is the first international connection and initially connects the United States and the United Kingdom. There are now three networks interconnected.
- 1973: Detailed performance analysis of slotted Aloha is published [25] and shows that it is fundamentally unstable without suitable dynamic control.
- 1973: Motivated by the three interconnected networks, Bob Kahn and Vint Cerf conceive of the Transmission Control Protocol (TCP) and publish the idea formally in 1974 [26]. This architecture would allow packet networks of different kinds to interconnect and machines to communicate across interconnected networks.
- 1973: Bob Metcalfe invents Ethernet when he proposes the technology in a memo circulated at the Xerox Research Center in Palo Alto.
- 1975: I publish a memo on the optimal transmission range for packet radios [27].
- 1975: Management of the ARPANET is transferred to the Defense Communications Agency (DCA).
- 1976: X.25 protocols developed for public packet networking.
- 1977: TCP is used to connect three networks (ARPANET, PRNET, and SATNET) in an intercontinental demonstration.
- 1978: TCP splits into TCP over IP. This effort was driven by Danny Cohen, David Reed, and John Schoch to support real-time traffic and enabled the creation of the User Datagram Protocol (UDP) over IP.
- 1979: Usenet is created, precursor to the bulletin boards and Internet forums of today.
- 1979: CSNET is conceived as a result of a meeting convened by Larry Landweber. The National Science Foundation (NSF) funds it in early 1981. This enabled the connection of many more computer science researchers to the growing Internet.

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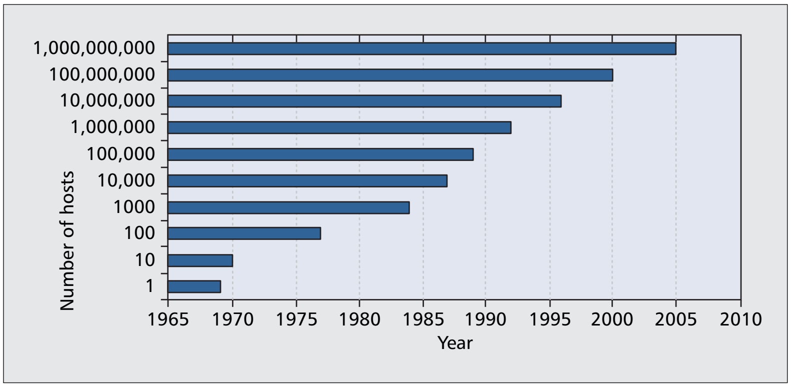

Figure 1. *The growth of Internet hosts.*

- 1980: Ethernet goes commercial through 3-Com and other vendors.
- 1981: IBM introduces their first personal computer (PC).
- 1983: TCP/IP becomes the official standard for the ARPANET.
- 1983: DCA splits MILNET from the ARPANET.
- 1984: The Domain Name System (DNS) is designed by Paul Mockapetris.
- 1986: NSFNET goes online at 56 kb/s. It is upgraded to 1.5 Mb/s in 1988 and to 45 Mb/s in 1991.
- 1988: The NRC Computer Science and Telecommunications Board produces its first report [28] proposing a National Research Network. This has a strong impact on Senator Al Gore.
- 1988: Robert Morris unleashes the first Internet worm. This is the commencement of the dark side of the Internet.
- 1989: Twentieth anniversary of the Internet celebration hosted by UCLA.
- 1989: Tim Berners-Lee proposes a global hypertext project, to be known as the World Wide Web (WWW).
- 1989: ARPANET backbone replaced by NSFNET.
- 1991: The High Performance Computing and Communication Act is enacted by the U.S. Congress and championed by Al Gore.
- 1991: Tim Berners-Lee makes the first Web site available on the Internet.
- 1991: NSF acceptable use policies are changed to allow commercial traffic on the Internet.
- 1992: Internet Society is formed.
- 1992: The number of Internet hosts passes the one million mark.
- 1993: The Mosaic browser is released by Marc Andreessen and Eric Bina of the National Center for Supercomputer Applications (NCSA) at the University of Illinois, Urbana-Champaign.
- 1994: Lawrence Canter and Martha Siegel launch the first deliberate mass posting of spam email [29] on the Internet. The very first spam email [30] occurred much earlier, in 1978, but did not spawn the spam deluge to which we are subjected today.
- 1994: Netscape browser is released.
- 1994: Twenty-fifth anniversary of the Internet celebration hosted by BBN.
- 1995: Netscape goes public and the dot com boom starts with the faith that a “new economy” is beginning.
- 1995: Bill Gates issues “The Internet Tidal Wave” [31] memo within Microsoft.
- 1996: The Telecom Act of 1996 deregulates data networks.
- 1996: In the United States, more email is sent than postal mail.
- 1997: Internet2 consortium is established.
- 1997: IEEE releases 802.11 (WiFi) standard.
- 1997: Barry Leiner *et al*., publish a paper on A Brief History of the Internet [32].
- 1998: Blogs begin to appear.
- 1998: Voice over IP (VoIP) equipment begins rolling out.
- 1999: Thirtieth anniversary of the Internet celebration hosted by UCLA.
- 1999: Napster rolls out.
- 2000: Dot-com bubble begins to burst.
- 2001: Napster forced to suspend service.
- 2001: English is no longer the language of the majority of Internet users. It falls to a 45 percent share.
- 2001: One-half billion users on the Internet.
- 2002: Broadband users exceed the number of dial-up users in the United States.
- 2003: Flash mobs gain popularity.
- 2004: Thirty-fifth anniversary of the Internet celebration hosted by UCLA.
- 2004: U.S. mobile phone revenue of $50 billion equals that of U.S. fixed-line phone revenue.
- 2004: The United States leads the world in average number of minutes for a cell phone call.
- 2004: Camera-enabled phone sales exceed combined sales of digital plus film cameras.
- 2005: 812 million cell phones sold; 219 million laptop computers sold.
- 2005: Google is the darling of the Internet.
- 2005: Peer-to-peer networks grow; Supreme Court decision supports Recording Industry Association of America (RIAA) position.
- 2005: Grokster closes down.
- 2005: AT&T disappears after being the world’s largest corporation.
- 2005: AT&T reappears when SBC buys AT&T and renames itself AT&T
- 2005: Google Maps and Google Earth appear.
- 2005: Web 2.0 technologies heat up.
- 2005: MySpace has more page views than Google.
- 2006: YouTube purchased by Google.
- 2007: AT&T largest U.S. carrier again.
- 2007: Mobile TV ads, applications, and content emerging.
- 2007: Apple introduces the iPhone.
- 2007: Microsoft buys into Facebook at a $15 billion valuation.
- 2007: Google lays out Android, its open cell phone platform.

It is clear that the Internet is a vital force and has grown considerably over its lifetime. Based on the numbers that one can find in the literature [33], we have constructed the graph in Fig. 1, which shows the year in which the number of Internet hosts first exceeded a size of 10^k where k ranges from 0 to 9.

The list of Internet events we have presented highlights a long sequence of its contributions and developments. The contributors themselves have been composed of first, the early pioneers, followed by the implementers, then the value adders, then the launchers, and finally, let us not forget, the billionaires!

A Vision of the Flexible Future

As we move into the twenty-first century, it is worthwhile to revisit the visions that were articulated by Licklider and by the 1969 UCLA press release. Neither vision has as yet been fully realized, but we are well on our way to that goal.

Licklider predicted a future in which we would all be connected to a world of information that would enhance the symbiosis between man and computer; it is fair to say that the former is happening and that the latter is just beginning.

The vision I articulated in the UCLA press release can be parsed into five elements; namely, that the Internet technology will be everywhere, always accessible, always on, anyone will be able to plug in from any location with any device at any time, and it will be invisible. The Internet almost got it right. Indeed, the first three elements have already come about. However, the Internet as we know it today has not yet achieved the last two elements of the vision, which are fundamental not only to enable completely new categories of networked services and applications, but also to match the ease of use and availability issues associated with truly consumer multimedia applications.

The major thrust for the future of the Internet is that the edge, rather than the core, is evolving. It is at the edge where user participation, flexible applications and services, and innovation are appearing.

One of the strongest drivers of growth at the edge is the rapid development and deployment of wireless capability. As I see it, there are five phases through which the Internet will evolve over the next few years, some of which are already well along in their realization, and all of which are driven by the deployment of wireless technology. These five phases are described below.

Nomadic Computing

Nomadic users travel from location to location and often find themselves with significant variations in the computing platform to which they have access, in the quality of the printers and displays that are available, in the communication device they use, as well as in the communication bandwidth that is available to them (including the now-common case of complete disconnection). Nomadic computing refers to the system support to provide the nomadic user with trouble-free Internet service from any device, any place, at any time. When a user arrives at a "foreign" destination, that user appears to be an alien in that environment. Our nomadic technology must provide the ability for the user to easily gain access as a "friendly" in this new environment.

The goal of nomadic computing is precisely to permit users and programs to be as efficient as possible and as unaffected as possible in this environment of uncertain connectivity and unfamiliar locations. Nomadicity is to provide the illusion of connectivity even when the nomad is disconnected, and to provide access to Internet services seamlessly wherever the nomad travels. To achieve this, not only must the infrastructure be enhanced to provide these capabilities, but also it is necessary for applications to become nomadically enabled. One of the components that enhances nomadicity is the availability of wireless access both for tetherless operation, as well as for access in a mobile environment, albeit many of the issues surrounding nomadicity are present without any wireless elements.

Smart Spaces and Smart Networks

A smart space refers to small intelligent devices embedded in the physical world and connected to the Internet. Currently, users see cyberspace as trapped behind the screen of their workstations. But most users have no idea what is going on behind that screen, hence they see cyberspace as trapped in the netherworld. We are fast approaching a time when the netherworld of cyberspace will move out into the physical world. Most things in our physical, real-world environment will be Internet-enabled via embedded technology.

These embedded devices will interact with one another to provide a smart space that adds intelligence to the environment. Indeed, our environment will be alive with this embedded technology. It will appear in the walls, in the floors, in our desks, in our lamps, in our clothes, in our eyeglasses, in our refrigerators, in our automobiles, in our hotel rooms, in our wristwatches, in our belts, in our fingernails, and in other places throughout our bodies. Likely, we will have a "body net" connecting all the devices we are carrying, and this will act as our surrogate in communicating with the body nets of others, as well as the rest of the smart space in which we will be immersed. This embedded technology will be made up of sensors, actuators, logic, memory, processors, communicators, cameras, microphones, speakers, displays, radio-frequency identification (RFID) tags, and so on. When I walk into a room enabled with this embedded technology (an intelligent room), the room will know I just entered. I will be able to converse with the room in natural language asking for information on a given subject, and perhaps four books will reply with their table of contents (and possibly one will inform me that it is located in my colleague's office down the hall). The Web will present me with links and information via natural language speech, video, images, eyeglass displays, holograms, or other human-centered intuitive interface technologies.

It is clear that the availability of wireless communications is key to many of the operations described for the realization of smart spaces. As we improve the bandwidth and reach of our wireless infrastructure, we will see ever more capable smart spaces. One of the exciting areas of research involves the use of low-power, short-range, very high bandwidth wireless links that enable very effective and efficient spatial reuse of spectrum.

As I see it, there are five phases through which the Internet will evolve over the next few years, some of which are already well along in their realization, and all of which are driven by the deployment of wireless technology.

A person who carries a digital watch, a two-way email pager, cell phone, MP3 player, PDA, camera, GPS, and notebook computer is carrying: eight displays, six keyboards, five speakers, three microphones, eight clocks, eight batteries, seven chargers, and four communication devices! This is ridiculous.

UBIQUITOUS COMPUTING

Ubiquitous computing refers to having Internet service availability wherever the nomad travels on a global basis. Indeed, the first technology that provided ubiquitous access to data networks was the dial-up modem, notwithstanding the fact that it was a low-speed solution. Following dial-up, we saw the rise of higher speed solutions for access in the forms of copper DSL, cable modems, satellite access, various forms of cellular (3G and its variants), WiFi, WiMax, and fiber.

As a result of these technologies, we have seen computing go tetherless. We have seen the spread of WiFi across the world, truly pervasive cellular access, ultra-wideband showing up on various product maps, cognitive radio emerging in our standards, RFID gaining use in inventory management and elsewhere, IEEE Zigbee moving forward in pervasive low-cost sensor networks, and more.

CONVERGENCE

We are currently witnessing a dramatic move toward converged hand-held platforms that bring together content, function, and services.

A person who carries a digital watch, a two-way email pager, cell phone, MP3 player, PDA, camera, GPS, and notebook computer is carrying: eight displays, six keyboards, five speakers, three microphones, eight clocks, eight batteries, seven chargers, and four communication devices! This is ridiculous. It would be far better to converge these devices into one device, and we have seen significant progress in that direction. In fact, the converged smart phone of today already contains the following features: a cell phone, messaging, calendar, email, Internet access, camera, music player, game player, Bluetooth, WiFi, and a wireless headset. Emerging and future enhancements will undoubtedly contain a touch-screen, a large high-resolution screen, powerful processor, vast storage space, considerable battery life, an intuitive input system, video phone, movie player, mobile TV, GPS mapping, compass, accelerometer, a software defined radio, and it will be pocket-sized. The device earlier known as a cell phone will become a communicating multifunction rendering device.

But all this comes at a price. Those keyboards are getting smaller but my fingers are not. The screens are getting smaller and my eyes are getting weaker. More attention definitely must be paid to the user interface.

The hand-held device that is emerging can be viewed in a number of ways, depending on who is involved. From the traditional view, it's a phone; from the Hollywood view, it's a tiny TV; from the Silicon Valley view, it's a PDA; and from the game industry view, it's a Gameboy. The correct view is that it's a whole new medium. It does provide the user with the fourth screen, the first three being the movie screen, the TV screen, and the PC screen.

With these converged hand-held platforms, a variety of new services have arisen, each of which is a multi-billion dollar industry. They include: ring-back tones (fan tones), music streaming, full song downloads, music video downloads, full video downloads, gaming, gambling, and sports.

An entire segment of applications and services has arisen in the domain of location-based services. There are obvious existing location-based services: basic mapping, direction finding, and yellow pages-style listings. There are new location-based services that include mashup services that let users create, tag, and annotate their own maps. There is the notion of a passive location-based service that prompts the user as he or she navigates a physical space with suggestions, such as "this is a quality restaurant," or "this is city hall." There are the more active location-based services, where time-based information is delivered; for example, a note left for a spouse to "buy milk here" or that "family or friends are nearby" or that an "interesting performance is going on in this auditorium"; it could also be an ad from a store offering a time-sensitive discount. It is likely that camera phones will be available that can read bar codes or that can read coupons directly from your cellphone on which they have been downloaded.

But not everything can be or should be converged onto one device. We already see signs of divergence in a number of devices and domains. For example, one does not want their Bluetooth earpiece on their converged device — one wants it remotely located next to one's ear. Certainly a pacemaker must be implanted in one's body, not in one's cell phone. Moreover, there are those advanced nerds who prefer to have their many gadgets located on their belts. We are seeing the appearance of intelligent shopping carts in supermarkets where there is an intelligent screen mounted on the shopping cart. Intelligent rooms are being designed and deployed that offer a variety of advanced functions distributed around the room and one's office or home. Moreover, intelligent devices are being implanted in our automobiles and other vehicles that offer a variety of advanced and integrated services; certainly one does not expect all of that to be in one's hand-held converged device.

INTELLIGENT AGENTS

As intelligent agent technology matures, we will likely see the deployment of these agents across the network. These are autonomous software modules whose functions will be to mine data, act on that data, observe trends, carry out tasks dynamically, and adapt to the environment. A number of technologies are developing that will provide this capability, and some are already deployed. In fact, we have seen examples in the financial industry, in search engines, in botnets, in peer-to-peer networks, and more. As they gain more capability, it is likely that these agents will generate considerable traffic and offer broad-based functionality to support a variety of applications.

CONCLUSION

The rise of ad hoc networks, sensor networks, nomadic computing, embedded technologies, smart spaces, ubiquitous access, convergence of content, function, and services, and the deployment of intelligent agents will enable cyberspace to move out into our physical world, provide everywhere access and open up new vistas and opportunities. The concept of these technologies disappearing into the infrastructure (as has electricity) suggests some far-reaching capabilities in terms of how these disappeared technologies are organized into global systems that serve us and our information and decision-making needs in adaptive and dynamic ways.

Except for our discussion of converged applications and services, much of what has been described here is infrastructure, and infrastructure is far easier to predict than are applications and services. In fact, looking back over the history of the Internet, it has been the applications and services that have surprised us, have come out of the blue, and have been totally unanticipated. Examples are email, the World Wide Web, peer-to-peer file sharing networks, social networking, blogs, photo and video generation and sharing, and so on. It is safe to predict that we will continue to be surprised with the sudden appearance and explosion of as yet unanticipated applications and services.

If fact, in my mind, we have reached a tipping point in the following sense. Until recently, our network infrastructure was driving the creation of new applications and services. As our technology produced ever more capability, so followed the applications. We delivered more bandwidth, smaller and cheaper platforms and storage, better displays, more ubiquitous wireless access, and so on, and the applications exploited what we offered. But the applications were constrained by the limits of our technology, and improved only as our technology did; in other words, the technology was pacing the applications that were trying to catch up to the technology. Now we have reached a tipping point where the applications are taking the lead. It is the applications (and services) that are pushing and driving the technology, which is trying to catch up with the ever-increasing demands they present. A true reversal has occurred. This is likely to be the driving force for the foreseeable future and provides a considerable level of flexibility and unpredictability.

There is another trend that was recently observed by David Reed of MIT. He pointed out that in the past, the network was the center, and the user view was to think about how to connect from the periphery and fit into the global network technology, applications, and services; that is, the view was network-centric. Reed points out that the view has changed, and now the user thinks of an environment that is user-centric. The focus is on the users who sit at the center of their dynamic personal networks and who reach out to include only the network of applications, services, and affinity groups with which they interact.

In my vision of the flexible future of the Internet, I see users moving more into a mode of mobility where they access the net, not only from their corporate desktop environment, but also ubiquitously at any time from wherever they happen to be with whatever device they have, in a seamless, secure, broadband fashion. I see small pervasive devices ubiquitously embedded in the physical world, providing the capabilities of actuators, sensors, logic, memory, processing, communicators, cameras, microphones, speakers, displays, RFID tags, and so on. I see intelligent software agents deployed across the network, whose function it is to mine data, act on that data, observe trends, carry out tasks dynamically, and adapt to their environment. I see considerably more network traffic generated, not so much by humans, but by these embedded devices and these intelligent software agents. I see large collections of self-organizing systems controlling vast and fast networks. I see huge amounts of information flashing across networks instantaneously, with this information undergoing enormous processing and informing the sophisticated decision support and control systems of our society. I see all these things and more as we move headlong into the 21st century. Indeed, I foresee that the Internet will essentially be an invisible infrastructure serving as a global nervous system for the peoples and processes of this planet.

I see all these things and more as we move headlong into the 21st century. Indeed, I foresee that the Internet will essentially be an invisible infrastructure serving as a global nervous system for the peoples and processes of this planet.

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BIOGRAPHY

LEONARD KLEINROCK [F'73] (lk@cs.ucla.edu) received his B.E.E. from the City College of New York (CCNY) in 1957, his M.S. from MIT in 1959, and his Ph.D. from MIT in 1963. He created the mathematical theory of packet networks, the technology underpinning the Internet, while a graduate student at MIT. He has served as a professor of computer science at the University of California, Los Angeles, serving as chairman of the department from 1991 to 1995. He was listed by the *Los Angeles Times* in 1999 among the "50 People Who Most Influenced Business This Century." He was also listed among the 33 most influential living Americans in the December 2006 *Atlantic Monthly*. He received honorary doctorates from CCNY in 1997, from the University of Massachusetts, Amherst in 2000, from the University of Bologna in 2005, from Politecnico di Turino in 2005, and from the University of Judaism in 2007. He was the first president and co-founder of Linkabit Corporation, the company that spawned numerous wireless spinoffs in San Diego, California. He was the first CEO and co-founder of Nomadix, Inc., one of the first firms that introduced nomadic computing technologies. He is also founder and chairman of TTI/Vanguard, an advanced technology forum organization based in Santa Monica, California. He has published approximately 250 papers and authored six books on a wide array of subjects including packet-switching networks, packet radio networks, local area networks, broadband networks, gigabit networks, nomadic computing, performance evaluation, and peer-to-peer networks. During his tenure at UCLA, he has supervised the research of 46 Ph.D. students and numerous M.S. students. These former students now form a core group of the world's most advanced networking experts. A number are full professors at leading universities, and many are associated with major research firms in the area of computer-communications. He is a member of the National Academy of Engineering, a member of the American Academy of Arts and Sciences, an IEEE fellow, an ACM fellow, an INFORMS fellow, an IEC fellow, a Guggenheim fellow, and a founding member of the Computer Science and Telecommunications Board of the National Research Council. Among his many honors, he is the recipient of the L. M. Ericsson Prize, the NAE Charles Stark Draper Prize, the Marconi International Fellowship Award, the Okawa Prize, the IEEE Internet Millennium Award, the ORSA Lanchester Prize, the ACM SIGCOMM Award, the NEC Computer and Communications Award, the Sigma Xi Monie A. Ferst Award, the CCNY Townsend Harris Medal, the CCNY Electrical Engineering Award, the UCLA Outstanding Faculty Member Award, the UCLA Distinguished Teaching Award, the UCLA Faculty Research Lecturer, the INFORMS Presidents Award, the ICC Prize Paper Award, the IEEE Leonard G. Abraham Prize Paper Award, and the IEEE Harry M. Goode Award.