Inventing the Internet again

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In the early 1960s, working on America's second-strike capability, Paul Baran conceived the Internet. Now he wants to save the Net itself.

FOR THE FIRST TIME IN HIS LIFE as an engineer, Paul Baran was "scared stiff." That can happen to people who stumble too close to the abyss of 20th-century history and look over the edge. Born in 1926 in a house in a corner of Poland that had been claimed by three different nations during his parents' tenure, brought to America by his family at the age of 2, Baran was a child of European tempests.

But now, in the heady Southern California of the 1950s, the young Hughes Aircraft engineer found himself working in an American crucible. He was a design engineer for the Minuteman missile control system. Unlike the liquid-fueled Titans of the previous era, which required hours of preparation before they could fly, Minuteman could be instantly rocketed into the sky. To the Pentagon this seemed safer. The solid-fueled rockets would not be vulnerable for hours on the ground awaiting fueling. But Baran and his colleagues knew that this would be the most deadly and was on its way.

Appreciating the risks in the proposed design, Hughes summoned Warren McCullough from MIT as a consultant on human behavior. An expert on command and controland a psychiatrist and brain surgeon to bootMcCullough explained the emerging facts of life. Throughout history, he told the Hughes engineers, the real command of the battle migrated to the men closest to the enemy. The man in the crow's nest, not the officers on the ship's bridge, was in de facto control. What he saw and reported determined the captain's orders. Regardless of nominal chains of command, the real governance of history moved to individual people on the front lines, often frightened or panicked at the time. But in the nuclear age, no such single person, necessarily fallible, could ever be trusted.

Analyzing the technical problems of creating a command- and-control system for Minuteman, Paul Baran found himself abruptly in the crow's nest, stricken by historic terror"scared stiff," as he recalls. It was clear to him that the problem was systemic; it could not be solved by tweaking the command-and-control schemes then being proposed at Hughes.

To explore the problem more broadly, Baran in 1959 left Hughes for RAND, the not-for-profit (the name stands for "R&D") set up after World War II to harbor the systems analysis skills developed during the war. At RAND the formidable strategist Albert Wohlstetter was demonstrating that in a matter of minutes Soviet short-range missiles could take out all U.S. foreign strategic air command bases encircling the Soviet Union. Then the Soviets could say stick 'em updemanding surrender on the basis of the vulnerability of remaining U.S. missiles to superior Soviet forces. In many vivid papers and speeches, Wohlstetter relentlessly presented his argument that U.S. forces faced a "missile gap." The famed Alsop brothers, leading columnists of the day (Stewart was the father of the computer writer), echoed the Wohlstetter claims. John Kennedy listened and made the gap a theme of his 1960 presidential campaign.

Wohlstetter and his colleagues urged that the Pentagon redeploy its strategic forces to the United States and endow them with a second-strike capabilitythat is, to withstand a first strike and retaliate in kind. Greatly reducing the temptation to go first, this posture would escape the dangerous hair-trigger tenterhooks of the early cold war.

A viable second-strike capability, however, assumed that the command, control, and communications systems would remain intact. It was here that Baran fretted. He saw that one nuclear explosion at high altitude would affect the ionosphere for many hours and thus wipe out all long-range, high-frequency radio communications. In addition, one strike at the centralized switching nodes of AT&T would destroy the rest of the control network. The missile system would endure, but it would be deaf and blind.

Plunging deeper into history than Kennedy had, Baran resolved to design a communications system that could survive a nuclear attack and save the second-strike deterrent. He took inspiration from another idea of MIT's McCullougha parallel computer system with adaptive redundancy. Like the human brain, such a system could reconfigure itself to work even after portions were destroyed. But using the noise-prone analog circuits of the time, it was impossible to build the necessary switches. Baran concluded that all the traffic would have to be digital. Moreover, the digital traffic would have to be broken into short message blocks now called "packets," each containing its own routing information, like a DNA molecule, and able to replicate itself correctly whenever a transmission error occurred. With many additions and permutations, his original design is today termed the Internet, and it is shaping the emerging history of the 21st century.

THE INEXORABLE LOGIC OF DIGITAL COMMUNICATION

Baran, though, is not satisfied with his creation. Contemplating its vulnerability to terrorism and other attack, he feels pangs of fear that echo his alarm of 40 years before. As more and more of the critical systems of advanced industrial society migrate to the Net, they become susceptible to new forms of sabotage, espionage, hacking, and other mischief. Air traffic controls, train switches, banking transfers, commercial transactions, police investigations, personal information, defense plans, power line controllers, and myriad other crucial functions all can fall victim to cybernecine attack. If the Internet is to fulfill its promise as a new central nervous system for the global economy, its security and reliability problems will have to be addressed.

Seventy-one years old, still with his Ph.D. economist wife Evelyn (their son David is director of information technology at Twentieth Century Fox Home Entertainment), Baran remains in the crow's nest, buffeted by inklings and projects merely fulfill the far-reaching logic of his original concept, elaborated at RAND between 1960 and 1962 and published under the title On Distributed Communications in 11 compendious volumes in 1964: a survivable "network of unmanned digital switches implementing a self-learning policy at each node, without need for a central and possibly vulnerable control point, so that overall traffic is effectively routed in a changing environment."

To fulfill this scheme, Baran specified all the critical functions of the Internet: packets with headers for addresses and fields for error detection and packet ordering. He described in detail the autonomous adaptive nodes found in Arpanet IMPs (interface message processors) designed by Bolt, Beranek & Newman (BBN).

Baran also included features only recently and selectively introduced, such as encryption, prioritization, quality of service, and roaming ("provisions to allow each user to 'carry his telephone number' with him"). He described a web of peer nodes each connected to three or more other nodes, and he offered the first of the distributed routing algorithms that have multiplied over time.

Unique to his vision was its grasp of the economics of a network that could handle "the expected exponential growth in the transmission of digital data." Declaring that "it would be possible to build extremely reliable communications networks out of low-cost unreliable links, even links so unreliable as to be unusable in present-type networks," he estimated that the price of the system would be some $60 million per year. That was some 20 to 30 times less than what was being paid by the Department of Defense for their leased communications systems without any of these features. It was two orders of magnitude cheaper than new analog national systems being proposed at the time by each of the three military services.

Thus Baran not only conceived the essential technical features of the Internet, he also prophesied the cliff of costs over which digital technology would take the networking industry. By imagining the compounding effects of Moore's law three years before Moore's own famous prophecy, Baran stressed the key economic drivers that impelled the prevalence of the Web as the universal Net.

RAND was the imperial establishment of AT&T. As Baran explains, "While AT&T did have digital transmission under examination, it was in the context of fitting directly into the plant by replacing existing units on a one-for-one basis. A digital repeater unit would replace an analog loading coil. A digital multiplexer would replace an analog channel bankalways a one-for-one conceptual replacement, never a drastic change of basic architecture. I think that AT&T's views on digital networks were most honestly summarized by AT&T's Joern Ostermann after an exasperating session with me: 'First, it can't possibly work, and if it did, damned if we are going to allow the creation of a competitor to ourselves.'"

In 1972 the company sealed its fate by turning down an opportunity to buy the entire Arpanet. As Larry Roberts explained in Where Wizards Stay Up Late, "They finally concluded that the packet technology was incompatible with the AT&T network." So it was and so it still is. The existing phone system remains the chief obstacle to the final triumph of the Net. But the logic of digital communications is inexorable. It will displace all the existing establishments of television and telephony.

WASTED FOREVER...LIKE WATER OVER A DAM

These days Baran's vision, however, goes far beyond wireline communications. Baran takes the Internet model and extends it boldly to wireless communications. On June 23,1995, on the occasion of the Marconi Centennial, marking the 100th anniversary of the invention of the radio, Baran gave a momentous keynote speech in Bologna, Italy. In it he demanded a radical reconception of wireless networks.

"The first 100 years of radio," he declared, were marked by a perpetual "scarcity of spectrum....One of the very first questions asked of young Marconi about his nascent technology was whether it would ever be possible to operate more than one transmitter at a time. Marconi's key British patent #7,777 taught the use of resonant tuning to permit multiple transmitter....[Yet] even today, with over 30,000 times more spectrum at our disposal than in Marconi's day, entrepreneurs wishing to implement new services encounter the same perpetual shortage of frequencies."

Focusing on the most desired bands between 300 and 3,000 megahertz (UHF), Baran asserted that when you "tune a spectrum analyzer across a

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