330

Past and Future Perspectives on Communications Infrastructure

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Contents

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> *This is the age of miracle and wonder; this is a long-distance call.* — "The Boy in the Bubble," *Graceland,* ©1986 Paul Simon BMI.

IN GENERAL, ERRONEOUS FORECASTING models have come in two varieties: failures of assessment, and failures of imagination[1]. Failures of assessment occur when one looks backwards and attempts to make simple linear extrapolations. Not only is this error based on insufficient history or misleading cases, but more important is the false belief that such processes are, indeed, linear. Non-linear equations are unsolvable; more important, feedback from externalities generated by the innovative process may 'seed' a random event with totally unpredictable consequences somewhere down the road — now understood as the 'chaos' factor[2].

Failures of imagination are more complex. Here relevant facts are known, but process innovation is ignored. Such 'forecasting' lacks the ability to look forward. Here we have to consider feedback in its positive and negative forms [3].

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[1] This discussion of forecasting is based on an article by Loretta Anania & Richard Solomon, "Divining the Demand for a General-Purpose Digital Network," *Telecommunications Magazine*, Dec. 1987.

[2] Even well-modeled physical systems exhibit this factor. See James Gleick, *Chaos: Making a New Science*, Viking, 1987. This is not the place for an extended discussion of chaos theory, which among other things explains how snowflakes work and has presented us with Fractal geometry and other insights. A simple explanation is that of the "butterfly effect" — a single butterfly flapping its wings in Tokyo will eventually affect the weather in Paris. No matter how well-defined a (weather) pattern can be stated, it takes very little change in its non-linear system dynamics to iterate to a level where an unpredictable effect is manifest. Chaos theory shows why the general weather pattern for a season can be predicted, but 48 hours out there is no sure way to know whether it will rain or be sunny. Similar dynamics take place in industrial policy planning and market forecasting.

[3] For feedback in general, see Norbert Weiner's classic 1949 text, *Cybernetics*, MIT Press.

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An example of a positive feedback model is desktop publishing: inexpensive laser printing technology has launched a whole new set of publications within a short period of time. This was an easy, short-term projection once the initial set of conditions were understood. Though a complex forecast, it was linear, solvable, intuitively correct, and not very interesting.

In some processes positive feedback may be part of its internalized algorithm permitting its stabilization (a thermostat). In other processes, feedback has no such built-in stabilizing factor so unpredictable events occur — the discovery of electromagnetic waves and the application of vacuum tubes leading to the growth of entirely unexpected industries such as television broadcasting, which we discuss below.

The other form of feedback is called 'negative,' though both terms have neutral value connotations. While positive feedback uses current information to control or influence processes, negative feedback uses information which correctly predicts the future. For example, most automobile steering systems merely respond to the driver's control and to immediate information from the suspension system; under rapidly changing conditions this may lead to catastrophic instabilities. But more advanced steering systems predict road conditions (based on various movements of the car) using negative feedback to prevent over- and understeering and to stabilize the ride — a particularly valuable technique on slippery roads.

Though subtle, negative feedback could be usefully employed in modelling and to prevent processes from reaching undesirable states, but only if process innovation is fully understood. That means that details count.

For example, functionality is not an additive process. Often when you change just one key element, you can change the process — an underpinning of chaos theory. Assessing the past in order to understand what the future may bring requires an uncanny ability to understand which technologies are key, and how today's technology expands — feeds back — to fit tomorrow's applications.

Feedback — positive or negative — plays an important role in determining governmental policies, and here there are two pitfalls: One is correctly quantifying the problem as it relates to employment and industrial output, and another are attempts to control a novel regime such as computers and electronics. Beyond that, it is quite impossible to predict specifics of how the systems may evolve, and therefore where feedback may take place in the policy process.

With this in mind we will examine several critical factors which are converging and which must be considered in any scenarios for the implementation of broadband systems in the U.S. These are:

- An increasing recognition of the role of infrastructure — particularly telecommunications and related opto-electronics industries — in modern society;

- Vastly shortened product cycles for telecommunications devices;

- Linkages between telecommunications and trade;

- Paradoxical confrontations between implementation of digital virtual networks and legal systems intended to protect sovereignty and tangible property.

Most important is the inevitability of digital, broadband networks, themselves. This is primarily a technology 'push,' but a push which is completely in the mainstream of communications working symbiotically with other revolutions in technology: computers, television and visual displays, and the thorough integration of telecom with virtually all commercial and administrative endeavors — from design and manufacturing to transportation and distribution, including advertising, entertainment, and the role of government in our daily lives. Communications infrastructure defined this way has become fundamental to all other processes over the past two centuries; this is so patently obvious that it is not worth demonstrating. The only interesting field to explore is how broadband networks will fit and manipulate this continual integration. This paper will give a few examples:

Broadband technology is sufficiently different from today's dominant telecom infrastructure that it will change communications dramatically, so much so that we may speak of a paradigm change[4] — a new model of how things will work. This new paradigm is directly dependent on the convergence of telecom with computing, and will affect the entire chain, from network architecture to applications and has already had a significant impact on who will be the suppliers of equipment and services.

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[4] For a discussion in general on paradigm shifts, see T. H. Kuhn, *The Structure of Scientific Revolutions,* MIT Press.

1 Infrastructure

THOUGH SOME STILL doubt that communications and the digital computer will ever merge, the simple fact is that this merger has been continual ever since the stored-program digital computer was introduced 45 years ago. We will contrast broadband's departure from past history by first examining some of that history. Following is a cursory look at why computerization has progressed so far in a relatively short period of time, and some parallels in transport with similarities to telecom; during the evolutionary period of transport mechanization, movement of goods and people were considered functional equivalents for communications. (Divergence between the two infrastructures has had to await relatively highspeed and low cost computer/communications technology.)

1.1 The Digital Computer

The first modern, electronic computers, built by Tommy Flowers of the British Post Office under Max Newman's and Alan Turing's direction, were a set of online decryption devices which "downloaded" signals directly from the spectrum, searched for German grammatical structures, then passed the data on for further machine and human code-breaking.[5]

Called the "Colossi," 14 machines were underway by June 1944 to track Nazi troops for the Normandy invasion. The effort had a higher priority for Allied resources than even the Manhattan Project, cost was no object (and apparently never tabulated), and the chief engineer was sufficiently in the dark that he was not sure what use would be made of the machines other than as a high-tech heating plant for Bletchley Park. (As a side matter, Turing handled the low-life expectancy of vacuum tubes by programming in probability algorithms to automatically switch out banks of tubes before they deteriorated[6]). Turing, often considered the father of Artificial

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[5] Basic sources for this discussion are from an oral history project (mostly videotapes), *The Computer Pioneers*, conducted by this author at MIT and Harvard University with John McCarthy, Brian Randell, Tommy Flowers, Gordon Brown, William H. T. Holden, and others. Towards the end of the war, the U.S. Army Security Agency (later NSA) received versions of these machines, and they were installed by Bell Labs for continued cryptographic work, probably at least for another decade. The German encryption devices they were designed to crack were used by many third world countries during the 1950s, and likely even later. For obvious reasons, the workings and details of these machines are still classified. For a not very coherent view of this early history, the basic printed sources still remain: N. Metropolis *et. al*, *A History of Computing in the Twentieth Century*, (esp. Randell's "The Colossus") Academic Press 1980; Brian Randell, *The Origins of Digital Computers—Selected Papers*, Springer-Verlag, Berlin, 1982; T. H. Flower, *Introduction to Exchange Systems,* Forward and Chapter 1, Wiley 1976.

[6] After all, *probability* was his dissertation topic.

Intelligence, also built the first pulse-code modulated (PCM) voice encoder for crypto voice the following year at Bletchley and then Bell Labs.[7]

So, computing started off telecommunicating, with fuzzy forecasts for applications, way over budget, and with robust (negative feedback) self-healing designs and "expert systems" contextual software right from the beginning!

There is sufficient evidence that all subsequent, stored-program digital computers, as well as the entire generation of current digital telephone switches and digital transmission systems to this day, derive directly from these early cryptographic devices.[8] Both Turing's mathematical theories of computing, Flowers' work on electronic digital switching, and that of other innovators in computing in the U.S., France, and Germany began in the 1930s; much of it — such as Nyquist and Shannon's work on information theory — was related to telecommunications. There is a long history of communications and computing coming together.

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[7] Bell Labs and the British Post Office turned this into a working device for encrypted voice before the war was out, for radio-telephone communications between Roosevelt, Churchill, Eisenhower, MacArthur, and Montgomery — the first digital telephone system, and it spanned the world from the Philippines, the Marshall Islands to North Africa, London, and Washington. PCM, AT&T's digital 'carrier' T-1 system, and digital electronic switching was the ultimate outgrowth. In the 1960's when the patents for PCM could be declassified and solid-state technology made it commercially feasible, T-1 had a rapid growth as a pair-gain carrier system, especially for congested urban wire-pair tandems (some of the key wartime patents were not issued until the mid-1970s!). See M. D. Fagen, ed., *History of Science and Technology in the Bell System—National Service in War and Peace (1925-1975),* Bell Telephone Labs, 1978; and Hodges, *The Enigma,* 1983.

PCM has even a longer history, since the basic concepts date back to 1861 with the first working telephone by Reis in Germany, and the 'multiplexed' telegraphs of Bell, Edison, Gray and others in the 1870s which led to the modern telephone instrument. PCM research resurfaced with intensive work on mechanical television in the 1925-1935 period and led to Nyquist's seminal Bell Labs theses on digital transmission systems. This was integrated with WW II Radar work, and with digital switch prototypes by Flowers in Britain and at ITT's Paris labs by H. Reeves in the late 1930s, which passed directly to Turing, and thence Bell Labs in the U.S. via the cryptographic establishment. PCM and the early electronic computer were thence intimately related.

[8] Flowers and his staff went on to design the first electronic digital telephone switch in the 1950s, which culminated in GEC/Plessey's System X many years later (Flowers, *op. cit.*) Other key individuals (including Turing) who worked at Bletchley such as Maurice Wilkes, the EDSAC designer (represented then as the first working stored-program machine), and Johnny von Neumann, who worked out the general mathematical theory of the machines and influenced later ENIAC design, Bell Labs researchers, Vannevar Bush at MIT, etc., could not reveal their World War II connections to cryptography, and so re-invented designs in the early years based on what they knew had worked during the War.

1.2 Role of Government Investment

However, while the military culture on both sides during the Second World War, with its emphasis on technology for strategic advantage, may have given a general impetus for our digital age, one burst of impetus is not enough to change the world — money, lot's of it, must follow continually. And that it did in spades, to mix metaphors. Computing took off because the U.S. defense community, after some early fits and starts, spent tens of billions of dollars on computing technology during the 1950s for three primary purposes: cryptography, air defense, and nuclear energy and weapons research.[9]

The National Security Agency, alone, funded at least $10 billion of unclassified R&D specifically for computing and computers between 1950 and 1960! NSA's accomplishments included: reducing the cost of magnetic tape so dramatically that it became cost-effective for cheap audio cassettes by the early 1960s, and made Ampex's (and Bing Crosby's) videotape machines practical endeavors for broadcasters[10]; state-of-the-art, highspeed (by the standards of the time) machines; introduction of solid-state logic devices to replace vacuum tubes; and significant advances in software tools. Control Data (neé Electronic Research Associates) and part of Univac (now Unisys) were early spin-offs from NSA's efforts to build a

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[9] It should be noted that exactly 100 years prior to the building of the Colossi, Charles Babbage and Ada Lovelace had invented precisely the same architecture as Turing's for a digital computer — the Analytical Engine — which included the fundamentals of programming. For various reasons partly germane to this sketch of infrastructure, the machine was not quite completed, though six different mechanisms were built at various times. Babbage lacked sufficient resources, and the British Government pulled out of the project thinking its utility not worth its projected costs. The dream did not go away, and Turing, von Neumann, Bush and others were quite aware of and influenced by Babbage's work and Lovelace's writings. The ENIAC group at the University of Pennsylvania, however, were unaware of virtually all of this pre-history, nor of contemporary work in Britain until after WW II was over; there is a strong probability that von Neumann was the critical link between ENIAC and Colossus, but he entered the scene at ENIAC in late 1944, well after the machine had been designed and was underway; ENIAC was extensively modified after the war following stored-program concepts pioneered by Colossi workers, including Wilkes. Some of these ideas were documented in the famous 1945 report by von Neumann (written as letters to H. Goldstine from Los Alamos in 1944) "First Draft of a Report on the EDVAC," reprinted in Randell, *op. cit.* based on von Neumann's research and travels in the U.S. and Britain in 1942-43. The EDVAC was later finished at Princeton and in Israel in 1953-5.

[10]. It also resulted in probably the first dual-use communications technology export-control *brouhaha*, in that Ampex's VTRs and 3M's tape were so good that DOD did not want their signal processing and data acquisition potential in Soviet hands. This export ban resulted in the USSR turning to France for its SECAM color TV system, instead of adopting the FRG's PAL or U.S. NTSC-Color. See Rhonda Crane, PhD. thesis, MIT, 1982.

strong and financially secure U.S. computer and components industry, though it could not be revealed at the time what was happening.[11]

Air defense — the Semi-Automatic Ground Environment (SAGE) system which begun as a crash project in the summer of 1950 after the Soviets exploded an Uranium Bomb — gave us realtime machines, CRT displays, the light pen, and even the first computer game[12] Not the least, SAGE's 'spinoffs' included the world's two largest computer firms: IBM — a novice in computing, but quite old by then, and which changed directions in the nick of time[13]; and another, very new company which found a niche which others had ignored in logic circuits and small computers, Digital Equipment Corp.

SAGE also resulted in several national laboratories being formed which contributed to significant advances in telecommunications and computing over the years: Lincoln Labs, MITRE Corp., and Draper Labs. Among many innovations: Draper devised software techniques so that programmers did not have to set binary registers any longer; and Lincoln invented the modem, and designed the first data networks. Prior to SAGE (and in the nick of time), the Air Force had financed Jay Forrester's Whirlwind realtime computer research at MIT, and thereby gave him the resources to develop magnetic core random-access memory. This alone may have been the single most significant advance which stimulated the computer revolution until VLSI and ULSI memory and logic.[14]

And SAGE also promoted a rapid development of continent-wide microwave links, all the way to the Arctic. It facilitated very close relationships with Canada on telecom technology and operations, with nary an agreement signed in advance, since AT&T could perform this function internally when Bell Canada was still part of the Bell System. Western Electric was the prime contractor for SAGE, as they had been for radar development a decade earlier. One little-understood side benefit was that Direct Distance

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[11] Based on Samuel S. Snyder, "Computer Advances Pioneered by Cryptologic Organizations," (reprint of sanitized NSA documents) *Annals of the History of Computing,* January 1980, pp. 60-70; Vannevar Bush papers, Library of Congress; Bush, *Pieces of the Action*, Morrow 1970.

[12] "Pac-man," in the form of a CRT version of Claude Shannon's robotic logic mouse maze, was written by John Ward for TX0, the first transistorized computer, in 1958. This author was a witness in the Pac Man copyright infringement case.

[13]. The IBM engineers learned much about civil engineering and sub-contracting in those days, too, since they were prime for the construction sites.

[14] See for further elaboration of the U.S. military's input into the computer revolution: Kenneth Flamm, *Targeting the Computer: Government Support and International Competition,* Brookings 1987; Flamm, *Creating the Computer: Government, Industry, and High Technology,* Brookings 1988.

Dialling was implemented (not only nationwide, but, transparently, between Canada and the U.S.) somewhat earlier than had been planned. Antitrust issues, particularly between the telecom and computer industries, were submerged for awhile in Consent Decrees that appeared to be innocuous and met the national emergency, only to emerge with vengeance two decades later.

The changes this brought upon computing — and telecom — was technology pushing and pulling. The results were unpredictable at the start of the process, and not planned by any central body which had been formed to create an "information revolution." The output entered the civilian arena — including that of the telecommunications industry — very slowly. In the next decade, we got NASA and the aerospace programs pushing computing technology even further. Outputs from the aerospace/defense sector included timesharing, packet networks, satellite communications, workstations, word processors, and finally the microprocessor. But the next major impetus, including such earthshaking advances as the digital watch and the pocket calculator[15] — not to mention Walkmen and Watchmen— came from the Japanese, who saw the profits on the consumer side, which brings us to the present: While defense is not any less an important player in technology push for computing and telecom today, in the past decade or so we have added another engine of change, consumer electronics. The mad scramble to make high-definition TV the *raison de être* for broadband services is a prime example of this new technology push, which is likely to yield a paradigm quite different from what its proponents are after (more about that below).

Lest the past 50 years appear as an aberration in either American or world industrialization and infrastructure-building, it is important to underline that infrastructural change coming from government intervention is neither new, nor unusual. At least in the area of communicative-like structures — transport included — this has been the normative mode. And oddly enough, no matter what the precise structural characteristics in different countries and cultures, we tend to end up with very similar metaphors and applications of the infrastructure.

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[15] It should be noted that both of these, as well as the VCR, were products of U.S. R&D, but which the Japanese capitalized and marketed.

2. Infrastructural Metaphors & Paradigms

2.1. Transport

An extremely condensed history:

DEVELOPMENT OF THE RAILROAD and the telegraph were symbiotic[16]; the railroad could not cover a continent, or a region beyond 30 miles[17], without the telegraph; and telegraphy needing transport for maintenance and for resource development. (We are not arguing that transport technology has anything to do with models for future telecom technology; we are only describing here structural relationships. As we shall see in the technology section, while telecom did originally follow transport architectures, the computer has permanently changed all that.)

The railroads in the U.S., and elsewhere — by virtue of their interaction with land tenure, and with land economics — were significantly guided, financed, cross-subsidized, and ultimately regulated (or nationalized) by their respective governments. For example, in the U.S., land grants and direct appropriations built the four principal railways which first crossed the Alleghenies by 1840; the model included New York's financing of the Erie Canal in the 1820s, the Federal Governments' unsucessful, but expensive, efforts to build a National Road system just before steam railway technology began to mature, and other such examples.

From the 1850s to 1880s, the Federal government directly subsidized the railways which colonized the Missouri-Mississippi basin and then the trans-Continental links; these were gargantuan projects for their day. Less known is that the Land-Grant Telegraph Act of 1861 financed the construction of Western Union's lines during the Civil War, 7 years before the Union Pacific Railroad was completed along the same route. With War Department help, WU had become a near-monopoly by the end of that war, and had begun construction of an ill-fated, trans-global link via Russian-America (soon to be Alaska), the Bering Strait, and Czarist Siberia to China and Europe[18]. Then with Postal contracts, and other governmental monies, Vanderbilts's New York Central and Hudson River Railroad became the major carrier in the postwar years, taking over WU in the process of merging numerous railway links. AT&T was an "anti-monopoly" spinoff, forced on by various corporate competitors, because of these leveraged buy-

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[16] Richard Solomon, "What Happened After Bell Spilled the Acid?," *Telecommunications Policy*, June 1978, pp. 146-157, extensive review of source materials on telecom history from the Civil War to pre-divestiture AT&T. Also, R. Thomson, *Wiring A Continent,* 1947.

[17] We will leave the sophisticated reader with a geographical background to see why 30 miles is the operative figure.

[18] The opening of the privately-financed trans-Atlantic cable stopped construction in 1869.

outs of a century ago; and so were also the beginnings of transport and telecom regulation the result of this activity. (At this point, the interwined corporate histories of transport and telecommunications in the U.S. gets too complicated to relate further.)

Transport infrastructure became more involved with government with the intensification of urbanization: public transport in our largest cities benefitted (if that is the correct term) from planning, rights of eminent domain, rate regulation, and direct financing of capital intensive technology — New York's rapid transit system being a prime case for the early 20th Century. The development of the automobile shifted resources[19], and became another technology push, though not in the way it is generally thought to be. Paved streets and paved highways preceded the penetration of auto ownership, partly due to the cycling movement of the 1890s, partly due the growth of suburban telephony and rapid suburbanization which followed the electric streetcar (at the turn of the century, a lower cost, railway "bypass" technology), and partly due to lobbying from the railways for government to provide better access to their railheads for farmers. So much for forecasting.

Superhighways followed an even more intensive governmental path. In the U.S., the Interstate Highway system was first proposed as a public works program in the late 1930s. By the time it was completed some 50 years later (after only about two decades of peak construction), the routes more or less followed the structure laid out in 1938, but the capacity and detailed design of pavement and access points had changed quite radically. R&D, mostly paid for by the Federal government, accounted for this alteration. Neither R&D, nor actual route planning and land acquisition began in earnest until Congress changed financing from a 50-50 Federal/State split to a 90-10 split with the 1956 Interstate and Defense Highway Act. Lobbying, of course, came from the highway construction and automotive interests; financing was by increasing the gasoline tax as a proxy a user fee. (The "Defense" attribution was dropped after passage of the Act.)

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[19] Automotive and electric railway technology began development at the same time in the last decades of the 19th Century, but a dispute centered around the patent for steering delayed mass production of autos by about a decade. Little details like that can make major shifts in investment, but in the long run, the auto dominated anyway. (See George Hilton and John Due, *The Electric Interurban Railways in America,* Stanford University Press, 1960.)

Toll freeways had been built since the 1930s[20] — some were even privately financed — but there was no way to justify to the bond market a need for equitable penetration of toll roads across the nation, from the viewpoint of the general populace. However, simple politics dictated the national highway layout (and railroad planning a century earlier) — in order to rationalize Bruckner Boulevard in The Bronx[21], the nation had to fund 6-lane freeways in Montana as well. This should be a lesson to broadband planners, for Theodore Vail, in exchange for de facto monopoly privileges, understood the same politics of the national social contract when he pushed for "universal" telephone service in the early decades of this Century.

2.2. Radio

One last, lengthy, but relevant example of how critical infrastructure develops will close the circle for our tale on the origins of the information age — that of radio technology[22]:

During the Versailles Peace Conference of 1919, it became apparent to Wilson and his advisors that three main areas of international infrastructure (they did not use that term) would be critical in postwar trade: energy; the merchant marine; and the very new technology of radio-communications. All three were linked in some way, most particularly the latter two. Most important, the wireless (and undersea telegraphy) was dominated by the British at that time.

Assistant Secretary of the Navy Franklin Roosevelt came up with a plan for the Navy's Bureau of Steam Engineering to guarantee Navy contracts to a new corporation to be organized by the General Electric Company which would take over British Marconi's assets in the U.S. (the Marconi Wireless Telegraph Corporation of America), and pool radio patents among the key U.S. players. A Navy/GE partnership was attractive because:

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[20] Private toll roads were built quite extensively in the early 19th Century as well after the Federal government dropped financing of the first national road system. All went bankrupt after the railways came in, and this was used to argue against the concept of public toll roads a century later (see *Toll Roads and Free Roads,* U.S. Congress, 1938). Those states which could justify toll freeways before the 1956 Act was passed received their infrastructure about a decade earlier than other regions, with consequent increases in land values; they were also eventually compensated for potentially missing 90-10 financing with additional "pork barrel" projects — such is the mechanism of politics.

[21] The most expensive highway ever built.

[22] See Richard Solomon, *Telecommunications Policy, op cit.* for a detailed chronology and list of sources for this extremely complex story; also, E. Barnouw, *A History of Broadcasting; and* Gleason Archer, *A History of Radio to 1926,* 1938 (reprinted Arno Press, 1971).

1) Radio used steam-driven, high-frequency electric generators (alternators). GE was the major U.S. manufacturer of alternators. Its main rivals overseas were the British, French, Hungarian, and German electrical industries. Formation of a U.S. patent cartel was seen as critical for international competition. Moreover, GE had been approached by Marconi to sell them the rights to the Alexanderson alternator for manufacture in Britain, and for worldwide exclusive sales *including* the U.S.

2) The only generally-accepted, practical application of electromagnetic waves then was as radio-telegraphy to enhance maritime safety. (There was little public knowledge at the time of the secret experiments performed by AT&T during the war with vacuum tubes for trans-Atlantic radiotelephony; indeed, the Germans thought such techniques were impractical.) The 1912 Titanic disaster had underlined radio's utility in the public mind. And an international convention to regulate maritime radio traffic (a forerunner of the CCIR), with the Navy as our representative, had been held in 1911. The Navy could not tolerate complete loss of the component technology to a foreign power, even an ally.

3) FDR had a close relationship with GE's CEO and legal department. Their main plants were in his Congressional district.

Soon after the formation of the RCA holding company, it became clear that three other firms held key patents: Westinghouse (which GE was in the process of purchasing through an LBO at the time); AT&T; and United Fruit. The latter had developed radio technology to improve command and control of its vast merchant marine and plantation operations in Central America. Each participant, therefore, brought something essential to the table and shares of RCA were more or less distributed among these five according to the value of their technology; the U.S. Navy held in the beginning about 20% of RCA's stock.

But things changed: within two years of the formation of RCA, commercial radio broadcasting became practical (and profitable), something undreamed of by RCA's founders. The first two broadcasting stations were AT&T's WEAF in New York City, and Westinghouse's KDKA in Pittsburgh. Quite rapidly, AT&T built three separate networks of stations based on their Long Lines transmission system — the "Red" and "Blue" networks east of the Rockies, and the "Brown" network in the Pacific states. GE's attempts to do the same were thwarted by lack of access to quality intercity telecommunications lines. RCA, however, began a radio-telegraph service which competed with Western Union and Postal Telegraph, and threatened to compete with AT&T's private telegraph lines. (AT&T had to go out of its way to assure stockholders that wireless communications was really not a threat to "wireline" circuits.) AT&T's Western Electric began to manufacture radio receivers in competition with GE. And television research had begun in earnest (and in secrecy) at GE, Westinghouse, and Western Electric.

By 1926, RCA had been transformed by its internal contradictions into a manufacturing subsidiary of GE/Westinghouse. The Navy had sold its stock after the Harding Administration took office. United Fruit bowed out. But AT&T's relationship was more complicated:

During 1925-6, AT&T and GE held a secret arbitration to settle a complex patent dispute. This resulted in AT&T selling its RCA stock, and an agreement that RCA would manufacture only home receivers, while Western Electric would make only station transmission equipment. (RCA purchased the Victor Phonograph Corporation to gain access to a consumer distribution system.) AT&T sold its radio networks to the new National Broadcasting Company — a wholly-owned subsidiary of RCA. NBC agreed to use WE transmission equipment and only AT&T Long Lines for its network connections. GE agreed not to enter the wireline business. The Justice Department encouraged GE to spin off RCA the next year, while Congress blessed the GE/AT&T agreement by writing its principal terms into the 1927 Radio Act (and hence the 1934 FCC Act).

Television research was transferred from Westinghouse to a new RCA laboratory. In turn, AT&T formed Bell Labs combining WE's labs and Long Lines' radio research department. AT&T and RCA then competed for the sound movie business, but that is another story.

While the original RCA did not work quite as its sponsors had hoped, its principal goal, strengthening the incipient U.S. electronics industry, had been met. As we have seen, for the next two decades, the U.S. dominated the world's industrial and consumer electronic technology. During the Second World War, AT&T and RCA were the largest two military contractors among all the belligerents, by an order of magnitude.

With this infrastructure in electronics (and telecom technology), it is no wonder that the U.S. was able to dominate dual-use (civilian/military) electronics technology during World War II and the Cold War era. This was despite significant British (and French and German) advances in the 1930s due to military needs that Americans were only dimly aware of at the time.

2.3. Infrastructure Metaphors

Of course, the details of these infrastructures in Europe and elsewhere followed other paths, yet despite surface differences as to how transport and communications developed, technologies tend to be more or less similar[23], operations follow the same pattern, nationalization became prevalent, if not dominant (CONRAIL and Amtrak are no exceptions), and finances became precarious. The major differences have to do with the intensity and rate of

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[23] For example, the worldwide dominance of 4'-8 1/2" for the track gauge, outside of Russia.

penetration, passenger railway service — a purely societal decision — being a prime example.

We see the same pattern in the development of other 'communications' metaphors — telephones, highways, airlines, broadcasting: organizational structures may be different, but the infrastructure still looks the same everywhere.[24] Intensity varies, while implementation is generally the same: Telephones have dials or buttons, calls are made the same way, and handsets are handsets — perhaps because all phones tend to be made in the Far East according to Danish or Italian designs. Television sitcoms (formalized 'sight gags') and game shows are so much the same anywhere that one can sit in a foreign hotel room and follow the action without understanding a single word: TV trash has become a world culture. Infrastructure has a power of its own: kids walk around with boom boxes everywhere, and everywhere the tunes have a common metaphor — politics, governments, ancestry notwithstanding.

It is likely that future infrastructures will follow the same patterns.

Radio, television (sound movies), microwaves (co-axial cable, too), radar, carrier telephony, and hence the work of AT&T's Bell Labs and their rival radio pioneers were linked. Telephone switching, however, came from another source: railway signalling. And computation from yet another. Still all three eventually came together at Bletchley, over a fortuitous lunch among some very strange individuals.

Technology push is hard to plan. Today we have a new set of technology pushes: a trade crisis, brought on partly by the merging of consumer electronics with computation.

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[24] Ithiel Pool makes this point in discussing how it is common to find that the regulation of new technologies is patterned after some older one which it appears to resemble, at least at first — see *Technologies of Freedom,* Harvard University Press, 1983; also Pool, ed., *The Social Impact of the Telephone,* MIT Press, 1977; and Pool, *A Retrospective Technology Assessment of the Telephone,* National Science Foundation, 1977.

3 Technology

DESPITE HEAVY COMPUTERIZATION for switching, the true power of the digital computer has rarely been applied to networking, for reasons ranging from politics to ignorance.[25] While computers that switch circuits may permit interesting new services — calling party identification, or user-to-user signaling — computers will do much more to radicalize networking in the near future.

Fiber optics-based, digital broadband networks may have the most impact on how networks are perceived and used in the near future. This is because:

1) high-speed, stored-program, digital computers *inherently communicate* in a broadband fashion internally (for they could not work any other way);

2) communications between machines up to now has tended to be *orders of magnitude slower* than their internal communications, so computer architecture has had to compensate for telecom choke points instead of using distributed resources in some optimum processing manner; and,

3) by definition, *stored-program machines are recursive* — they are capable of modifying their own programs — and so modified they become different machines. By linking up machines at speeds equal to or exceeding their internal bus speeds, we will end up with radically different network architectures.[26]

Therefore, the most significant aspect of broadband networks is that, for the first time, telecommunication links can now work at speeds equal to or greater than that of most computer processors. This creates new opportunities for hypermedia (described below), and applications quite different from those found today on conventional telecom networks. The technology would affect every form of business and educational application, from database access to online expert systems. Residential use, is, admittedly more problematical, though entertainment applications are quite readily envisioned.

Though the technology to do most of this is here today (and in selected circumstances: for example, fiber optic local area networks already exist, as discussed below), diffusion of broadband will depend more on how governments and regulators treat these concepts, than on the availability of technology. Yet, this is a true example of technology push, since implementation of broadband is happening anyway as carriers add new

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[25] P. Huber, *The Geodesic Network — 1987 Report on Competition in the Telephone Industry*, U.S. Dept. of Justice, January 1987.

[26] P. McCorduck, *Machines Who Think*, Freeman, 1981; J. Weizenbaum, *Computer Power and Human Reason*, Freeman, 1976.

optical fiber plant, and retrofit old distribution plant for strictly outside plant economies.[27]

3.1 Bandwidth & Fiber Optics

The term "bandwidth" is interchangeable with "line speed," of course, but demand for long holding time, high bandwidth traffic has little to do with basic implementations of the new broadband technologies. After speeds get above a certain threshold — approximately that of the faster process or processor for to a select application — one can *literally exchange bandwidth for speed.*

These seemingly paradoxical, albeit radically different telecom metaphors may be explained with an example using the transmission of motion pictures. The driving force of such applications in the consumer field may have a significant impact on the economics of future telecom networks, and cannot be discounted for the near term:

A motion picture or video is normally transmitted in the same time ("real" time) as it is viewed — a one hour movie takes one hour to be sent on a transmission line. But another way would be to encode it and transmit it in "delayed" time: with compression algorithms digital encoding yields about 10^9 bytes of information needed to reconstruct a typical video at approximately VHS (NTSC) quality. Since realtime is not necessary (there is no interaction for a movie — the transmission is strictly one way), the encoding itself can take much longer than one hour. (Just how long it does take, in this case, is irrelevant since the encoding is only done once and offline.)

Now the 10^9 bytes could be sent on a standard, 64 kilobit, ISDN B channel in about 35 hours — 35 times as long as the movie's display time. If a suitable storage device becomes available, a processor which can work about 35 times as fast as the input channel would permit the movie to be viewed in the correct, one-hour time span. That is the way most compression works today (though films are yet to be transmitted on today's phone lines, due to obvious impractical economic circumstances).

There is another way: send the 10^9 bytes on a very fast channel. A North American primary-rate ISDN circuit (T-1 or CCITT H_{11}) operates at 1.544 million bits per second[28], 24 times as fast as a 64 Kbps channel. Primary rate could be transmitted uni-directionally over normal 2-wire copper 26-gage pairs up to 15 kilofeet, with proper interface equipment.

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[27] L. Anania & R. J. Solomon, "Arbitrage on ISDN Networks," *Intermedia*, Jan. 1988.

[28] The PCM technology described above.

With some more compression — about eightfold according to some clever algorithms being tested — it would be possible to transmit a one-hour movie in about 8 minutes on a conventional telephone wire pair. That means the application is transmitted in compressed time, to be viewed in realtime, at a ratio of 1:6 (compressed time to realtime[29]). With a fiber line working at 10^9 bits per second (or a co-ax using all 450 MHz of bandwidth in bursts), even without sophisticated algorithms, a one-hour movie could then be downloaded in less than 10 seconds!

Extending these ideas, one can see that bandwidth and channel speed will be used in ways never contemplated on older, slower-speed networks. Thus the real utility behind the broadband telecommunications *paradigms* is that it will permit application of new communications *metaphors* which today are not prevalent among telecom professionals. Use of delayed time and compressed time are temporal modes which are not normally in the telecom professionals' lexicon. Swapping spatial modes for temporal modes are even more difficult to internalize, but such is the nature of most compression and cryptographic systems. These systems are being prototyped in labs today, and may become prevalent within the next decade as extremely fast terminals and workstations enter the marketplace, connected with very highspeed, wide-area networks.

3.2 Open Architecture

Application of these new metaphors are forcing a merger between the telecommunications and data processing fields. A major impetus for hardware and software is coming from an unexpected direction: a response in the U.S. and Europe to industrial threats by Far East manufacturers of advanced consumer products, especially proposed high-definition television (HDTV). The EC has Eureka and RACE, and in the U.S. the Defense Department's Defense Advanced Research Projects Agency (DARPA) is soliciting "proposals for the development of product and/or manufacturing technology for high-definition, low-cost, dynamic, multi-media displays."[30] This DOD initiative has inspired a groundswell in the U.S. of ideas and concepts for merging evolving television, telecom and computer displays.

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[29] The MIT Media Lab has simulated such a display device using an Apple Macintosh II for decompression and display and a DEC Microvax II for the original compression (see *MacWeek,* August 6, 1988. These ratios are practical today, except for the highspeed, user end storage devices which have yet to be invented.

[30] Defense Advanced Research Project Agency, Contracts Management Organization (CMO), Broad Area Announcement (BAA#89-06): "High Definition Display Technology/Display Processor," *Commerce Business Daily Express* (online service), item 89-06, December, 1988. See also for background, Glenn McLoughlin, "SEMATECH: New Model for Government-Industry Cooperation?," *CRS Review,* June 1988.

Most of the devices being proposed to DARPA come under the rubric of the "open architecture receiver" (OAR)[31], which would act as a generalized interface between users and very highspeed fiber optic networks (see figure 1 [32]), over-the-air transmission, and satellite networks. The OAR would be equally suitable as a computer display or a video display, and would incorporate significant computational power, memory and storage to permit the application of many advanced services. Telephony and messaging would be a given, and indeed a "plug-compatible," RJ-14 jack, with an internal PCM decoder, would be trivial to add to the OAR for narrowband ISDN service.

Should the OAR become a commodity — a relatively inexpensive, high-definition general-purpose display — in the next decade, the business community will benefit by the immense economies of scale consumer electronics brings to bear on manufacturing and distribution.[33] Or the converse may be true: business, industry, and the military may adopt these display designs first, making an OAR attractive for advanced video technology if the consumer field continues to bicker about standards. The OAR as an interface device alone makes the debate over HDTV production, distribution and transmission, and display standards irrelevant, since the OAR could display any scan rate, aspect ratio, or temporal frequency — only the actual interface need be set. The OAR's bus may be designed to be upward compatible so that its backplane would mesh with standards for SONET or other B-ISDN or optical LAN systems.

However, the paradigm of the OAR is even stronger: it will permit the generalized application of many advanced dp tasks, expert systems and "hypermedia" being examples.

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[31] See W. F. Schreiber, A. Lippman, *et. al.*, "A Compatible High-Definition Television System Using the Noise-Margin Methods," *SMPTE J.* January 1989; Schreiber, *et. al,* "Reliable EDTV/HDTV Transmission in Low-Quality Analog Channels," *SMPTE J.*, January, 1989; and Schreiber, "A Friendly Family of Transmission Standards for All Media and All Frame Rates,..." MIT Advanced Television Research Program report ATRP-T-97, Feb., 12, 1989, MIT Media Lab, Cambridge.

[32] This figure is an early version. The correct drawing cannot be released until Feb 28, 1989 due to patent restrictions. It will appear in the final version of this paper.

[33] Indeed, this is the precise reasoning behind the U.S. DOD's initiative. DARPA's goal — like the European Commission's EUREKA project — is to regenerate the U.S. consumer electronics industry because of the 'dual use' concept. They recognize that without such an effort, by the 1990s military and computer electronics may follow consumer electronics to the Far East. This then is a distinct threat to national security.

3.3 Hypermedia

Hypermedia, (or hypertext) is one of the most exciting concepts for information transfer. (Apple's Hypercard is the first such commercial application, but is only a tiny subset of what is possible). With such applications, the utility of the OAR and broadband virtual memory space driven by optical networks becomes clearer. Essentially Hypercard is a sophisticated database management system optimized for networking and information display. Hypertext permits a reader to point at a portion of text and instantly get more information: footnotes, text from other sources, clarifications, and interactive processes to guide the user through a complex task, such as creating a mortgage or loan, getting instant First Aid advice, or shopping for obscure items. An early work described hypertext in general as:

> [A hypermedia] Handbook would include: principles, working hypothesis, practices, special-term glossaries, standards, goals, goal status, supportive arguments, techniques, observations, how-to-do items, etc. An active community would be constantly involved in dialogue bearing upon the contents of the last formal version of its Handbook — comments, errata, suggestions, challenges, counter examples, altered designs, improved arguments, new experimental techniques and data, etc. ... flexible aids for 'on- line' navigation and view generation would be very important, as would the facility for automatic publication...[34]

For such applications to be practical and have the most utility requires enormous bandwidths to access online virtual memory, and to keep up-to-date. Its utility for business, in terms of document retrieval, preparation, and information transfer, is of course obvious. Expert systems programs to guide users through an ever more complex world would become practical.

The new technologies for broadband transmission and switching will be a true shift in thinking for telecom engineers and communications planners — a different *zeitgeist*.[35] The new networks are virtual networks, as in "virtual computer memory," or "virtual computer networking" — two sides of the same coin. In a virtual digital network, the physical network becomes transparent to the user, only the logical network can be perceived (unless

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[34] Douglas Englebart, 1973, based upon Vannevar Bush' *Memex*, detailed in his 1945 *Atlantic Monthly* article. Attempts were made immediately after WW II by the U.S. intelligence agencies to build Memex based upon rudimentary computer technology, but the first efforts were not successful then.

35. Another word for 'paradigm.' See for further elaboration on paradigms and long-wave (Kondratieff) theory: R. J. Solomon, "Changing the Nature of Telecommunications Networks," *Intermedia*, May 1986; and L. Anania & R. Solomon, "Capital Formation and Broadband Planning: Can We Get There From Here?," *Telecommunications Magazine*, Nov. 1987.

access is given both to system control and to the machine room or wiring closet).

With B-ISDN transmission and routing an order of magnitude or more faster than that of the fastest, non-optical local area networks being sold today, coordinated standards for optical LANs are being worked on. Identical standards — down to memory word addressing — would enhance the connection of computers at the direct memory access (DMA) level. If network speeds are the same order of magnitude as computer central processing units, true cross-network 'peer-to-peer' communications becomes feasible.[36] This would make hypermedia more likely.

Narrowband ISDN primary rates, and packet switching as we know it today, are simply too slow to be effective for DMA, expert systems, and AI. Networked microcomputer applications could finally implement sophisticated artificial intelligence with its requirements for enormous memory.

3.4 Integrated Networks

In integrated digital networks, switching (which is computer data processing) and transmission work in conjunction. There is no way to separate the switch DP process from its transmission process. It is all a matter of electronic timing circuits internalized by the network. The link is merely an extension — a virtual extension — of the switch or node's electrical (or optical) bus, just like on a computer motherboard. This is a difficult concept to explain to many individuals who — for whatever psychological reason — are uncomfortable with logical, Boolean "states" and prefer things which can be seen and felt.

In an integrated network, control of the physical components is all-important, and control is very complicated. An end-to-end digital system, is a totally different kind of network than today's analog, or hybrid networks. In an analog network, digital signals (in the form of binary digits) are merely carried in analog forms for later reconversion back to bits; not much can be done with such signals on or by the network. But in an all-digital system, the bits are buffered by computers using timing pulses, until they reach their 'destination,' which can be another computer, another digital network, or a digital device which translates these signals into a form a human (or another machine) can understand.[37]

System timing is crucial to the understanding of control, for at any one slice of time control of the signal may extend halfway across the world, or just down to the end of your coiled phone cord. Digital machines are designed to

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[36] Such as IBM's Logical Unit 6.2 interface.

[37] Rec. I.112, and "ISDN Network Functional Principles," Rec. I.310, CCITT "Red Book," 1984.

give over control to other machines ('interrupts'), depending on complex 'states' of their programs (we discuss this further below). Control becomes vitally important in integrated network designs where speeds of transmission and connections are many orders of magnitude faster than so-called narrowband ISDN:

3.5 Narrowband ISDN

The telecommunications standards-setting community has essentially adopted a narrow-band format for integrated services digital networks, consisting of two 64 Kilobit/second channels running simultaneously with a signalling "D" channel into subscriber premises. ISDN is best characterized as a carrier computer-driven, intelligent network basically emulating today's voice and slow-speed data systems.

Such a standard, while possibly sufficient for residential users who do not require either full-motion or high-resolution graphics, simply will not fit the needs of business, education, or industrial processes in the near future. The popularity of ever faster LANs should attest to that. But even for residential voice, 2B+D makes little sense: the B channel is more than is needed for a voice circuit, modems are available that operate within the range of the D channel for such things as standard videotext, and getting a second, analog loop for another voice circuit is not a major problem for the overbuilt outside distribution plant in the U.S.

N-ISDN has two major conceptual problems (and several technical implementation problems): its defined channels are of fixed bandwidth and its distribution circuitry is narrowband — less than 1.5 or 2 megabits per second.[38] While that sounds fast to users of 1200 bps modems, it is not fast enough to carry and switch certain services such as high-def video, nor it is fast enough for certain types of user-shared network control, for direct interfacing to local area networks, or for direct memory access to computer central processors.

Probably the most detrimental technical defect in N-ISDN design is the poor switching times inherent in the system. Even on ISDN PBXs, such as the new system installed at MIT, the minimum time to switch states of anything — including "hold" and "transfer" is 400 milliseconds. Humans find that a bit annoying, but computers will find that intolerable. The SONET standard (see discussion below) is set for 125 μsec frame times, which will be just about the maximum threshold for swapping memory space as desktop machines begin to approach supercomputer speeds.

Furthermore, tests in real plant in Europe have shown that typically N-ISDN switching speeds will be in the range of 6 to 15 seconds within metropolitan regions, and much worse between urban areas. Multiple

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[38] See J. Turner in *IEEE Selected Areas in Telecommunications*, November 1986 for specific technical critiques of current narrowband ISDN standards.

transits degrade even further, and interconnects between analog and digital plant worse yet.[39]

In addition, N-ISDN apparently has severe electromagnetic emission problems which affect cross-talk design parameters and more important security issues. The technical details are beyond the scope of this paper, however the costs for eliminating these defects — by shielding or burying copper pairs (or both) — may well exceed the cost of installing fiber in the first place, including its associated electronics.[40]

If N-ISDN standards become accepted for commercial subscriber loops, the capital investment may hinder deployment of fiber-based, broadband infrastructure by the common carriers. Retrofit to broadband may become impractical because of depreciation expenses associated with the first iteration of change and the lack of any use for the multiplexors and switchers with 2B+D systems.

3.6 Broadband ISDN

B-ISDN is not just a bandwidth extension of N-ISDN. With proposed B-ISDN standards, we find the original N-ISDN concept turned upside down: instead of an intelligent network, carriage becomes somewhat passive — but with all-important options for variable bandwidth and minimum delay times. Routing and other operations may be under *shared* carrier/user control — driven by the user's computers. This is a big difference from today's networks. It permits true virtual networking. B-ISDN may mean that it will be impossible to tell which is the carrier and which is the customer.

Applications will require much intuitive insights by telecom managers of the future. The promise of B-ISDN technology is so powerful and overwhelming that narrowband ISDN increasingly may be seen as obsolete before its time. This is due to the curious fact that the physical elements which make B-ISDN practical — fiber optics and certain types of passive switching called 'cross-connects'[41] — are rapidly being installed by telephone carriers for narrowband ISDN engineering reasons, in any case.

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[39]. "Field Experience with CCITT Number 7 Signaling in Alcatel E10 Exchanges," *Electrical Communications*, Vol. 62, No. 2, 1988, pp. 190-194.

[40]. H. R. Daneffel, "EMC and COMSEC Problems on ISDN Subscriber Lines," Zellweger Telecommunications; "EMV-Prufung von Tielnermerausrustugen," Swiss PTT, VL-43, June 17, 1988, CCITT SG XVIII D-1740.

41. J. Nagel, "Photonic Switching and Automatic Crossconnect Systems," *Telecommunications* (International Edition), May 1987, pp. 43-46; Bellcore, "Wideband Digital Cross-Connect System (W-DCS)," Technical Advisory TA-TSY-000233, Issue 3, December 1987.

New forms of broadband switching may be closely coupled with the use of optical transmission.[42] Superconductors and optical processors may revolutionize switching nodes yet again.[43], though there is sufficient capability in silicon and other semiconductor materials to handle these order-of-magnitude speeds above N-ISDN.

The new technologies come right out of the international committees which had been establishing the narrowband ISDN standards since the mid-1970s.[44] Most interesting for a large proportion of advanced business applications is that the technique which evolved for B-ISDN is based on computer database methodology. While this was done so that B-ISDN could overcome numerous problems with narrowband ISDN —from user control of network administration and maintenance, to the ability to handle video, distributed data processing and requirements for flexible, and instantaneously variable bandwidth and connectivity[45] — it also means that cleverly designed CPE can take advantage of *direct memory access* between the network and remote machines to bring machine cycles down to a minimum.

This was made possible by advances in fiber optics, beginning less than four years ago, when fiber economics changed drastically. Based on current trends, single-mode line costs may drop below that of wire pairs by the early 1990s.[46] But more important, for all practical purposes, single-mode offers the unique feature of "almost unlimited capacity on a single fiber," to quote an AT&T paper.[47]

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[42] K. Phillips, "Applications of ISDN: An International Perspective on User Research," in ISDN in the year 2000, conference held at the European Patent Office, Munich, 24 June 1987.

[43] A. M. Rutkowski, "The View from Copper Mountain: T1D1's Summit on Advanced Digital Networks," *Telecommunications*, July 1987, pp. 75-82.

[44] S. Minzer, "Broadband User-Network Interfaces to ISDN," *International Conference On Communications*, Seattle, June 1987, pp. 364-368.[**Editor:** add references to other papers on SONET and ATM in this book.]

[45] "Framework for B-ISDN Standardization," (chairman's report) CCITT SG XVIII/7, TD23, Hamburg, July 1987.

[46] D. Snelling, "Fiber to the Living Unit," Southern Bell Telephone Co presentation to the Eastern Communications Forum, May 1987.

[47] "Economics of Fiber as Feeder Cable," *AT&T Technical Journal*, Jan.-Feb. 1987, p. 109. The concept of unlimited bandwidth is a bit of an exaggeration, since all media have physcial limits; it is just that the limit of single-mode fiber is so large, and is constrained more by the optoelectronic interfaces than the *fiber itself*, that for certain forecasting purposes it can be considered as limitless, and virtually costless. The interfaces, including nodal points and switches, are another matter.

Here we have a revolutionizing concept — for first time, there is bandwidth to play with! This huge excess bandwidth permits a large fraction of the digital transmission rate to be used for 'overhead' bits to route, and keep track of the 'payload' bits. Switching may be under the dynamic control of the user or shared with the carrier.

The primary constraints for single-mode capacity in the near future are dependent on the type of laser drivers used. Single-mode's enormous capacity offers extraordinary opportunities for network design which were not obvious with the first digital time-division multiplexed trunks. The ratios are critical: while H_{12} uses about five percent of throughput for overhead data, at the 150 Mbps (H_4) rate,[48] about 10 percent of the fiber throughput can be allocated for overhead and still yield a 'payload' of about 135 Mbps. H_4's 15 Mbps overhead is 10 times larger that the entire capacity of H_{11} or H_{12}, and yet H_4's payload is about *90 times larger!*

With 15 Mbps excess capacity on an integrated system for control and administrative data, this huge overhead can be used to build different, and potentially superior, flexible network architectures.[49] Such order-of-magnitude changes in the ratios of overhead to payload permit complex routing and switching to be manifest on the circuit, instead of only at a node. Junctions can be simpler, networks can be extremely robust, and the user can take control of routing and level of service.[50]

The current applications of fiber optics in the intercity and local distribution plant already permit the carriage of extremely wide bandwidths (as compared to the narrowband ISDN basic rate of 160 kbps), upwards of 150 to 600 megabits/sec.

3.7 Asynchronous Modes

"Asynchronous Transfer Mode" (ATM)[51] is a generic name given some set of these new fundamentally software-based technologies. But, ATM/B-ISDN is neither a new form of packet switch nor a mere extension of switching as we have learned to understand it.

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[48] . M. Beckner (Bellcore), "A Broadband Channel (H_4) Bit Rate and Format Proposal," T1D1.1/86-046(R1).

[49] . Minzer, *op cit*; and R. J. Solomon, *Intermedia*, op. cit.

[50]. P.E.Green, Jr., and D. N. Godard, "Prospects and Design Choices for Integrated Private Networks," *IBM System Journal*, advance copy, July 6, 1986.

[51]. "Report of the Broadband Task Group," XVIII/TD 55, 56, 57, Hamburg, July 15-17, 1987; updated for the 1988 Blue Book in "Final Report for the IXth CCITT Plenary Assembly, Part IV - Recommendations of teh I.200 series," Doc. AP IX-144 (COM XVIII-R59) Melbourne, June 1988.

ATM was not planned to be a revolution, just a new interface. The original intention of the various broadband planning groups had been to harmonize the different primary rates — CCITT's H_{11} (1.5 Mbps) or H_{12} (2 Mbps) — used in various countries so as to permit a gradual upgrading from narrowband ISDN. But, the interface for wideband fiber required a different method of handling the packetized bits than that used on conventional copper digital transmission lines.[52] Unlike earlier packets with framing bits just for synchronization and addressing, ATM packets are called 'envelopes,' or frames, with the data framed in the form of a matrix. The matrix is constructed as if it were a relational database, with pointers or labels. This pointer technique is very powerful, permitting routing and data massaging as part of the transmission procedure itself. Pointers and envelopes can be contained within other envelopes with more pointers, expediting the ready, dynamic construction of virtual networks invisible to the carrier. ATM's overhead contains its own signalling as part and parcel of its interface framing.

Only the synchronous interface standard for broadband fiber at the H_4, 155 Mbps rate has been adopted by the CCITT. Though it now appears that the overall standards issue have been settled in favor of an eventual asynchronous network,[53] the exact format of ATM architecture will be the subject of much R&D in the next few years. (H_4 can handle either asynch or synchronous frames, though the physical interface on the fiber has to be synchronized with some external clock.) There have been some minor differences between the U.S. and European approach, but they appear to have been rationalized in the past 2 years.

Exactly how frames will be handled by customer equipment have yet to be settled; asynchronous modes, however, are gaining currency because of their flexibility and close match for broadband services especially remote database massaging and HDTV transmission. In the U.S., a nationwide ATM system running at 500 Mbps to 3 Gigabits per second is being planned by Darpa and the National Science Foundation to connect universities and research centers. This will push the state-of-the-art for B-ISDN even further in the near term.

3.8 Virtual networks.

The virtual, connectionless network becomes the guiding premise of B-ISDN under ATM. Circuit delay times become much more important than on today's networks, because switching could become more dependent on the processing capabilities of customer premise equipment (CPE) instead of on network storage capacity. Shifting intelligence to the CPE could make a network less expensive to use and easier to maintain. The subscriber will be

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[52] . CCITT 1984 Red Book, Rec. I.412.

[53]. CCITT TD 55-57, Hamburg, *op cit.*

able to order the network to control delay, with the network dynamically predicting and feeding back state information in realtime — like on well-designed computer operating systems.

It may be useful to begin to think of B-ISDN as a gigantic timesharing network with computer software efficiently interfaced with ATM protocols, calling for close coordination of DP with telecom standards-making. Since bandwidth can dynamically vary in ATM, statistical algorithms can be applied by customer equipment to efficiently compress full-motion video, voice, and bursty database transfer. This will enhance distributed processing demand, placing more network intelligence in the CPE where it can be used for critical memory-dependent artificial intelligence or expert systems applications.

3.9 LANs , WANs & MANS

Implementation of Metropolitan Area Networks (MANs) and Wide Area Networks (WANs) are moving at a fast pace, at least in the United States. Deregulation has yielded fiber-based networks originally as support for satellite teleports, but now as standalone networks in Washington, Boston and New York. Within two years, there are plans for some 60 major U.S. cities to have at least one alternate, fiber-based broadband carrier to the conventional telephone operator for highspeed data (and likely private-line voice)

Until recent years, there were few signs of the needed coordination of standards for MANs and LANs, however the endorsement of 802.6 presents some glimmer of hope. In the past few months, the IEEE and U.S. B-ISDN (ANSI T1.D1) committees have agreed on common interfaces so as to permit linking fiber LANs and MANs with SONET-based systems at speeds of 100 Mbps and higher. The standard proposed by IEEE for optical MANs is the "Distributed Queue Dual Bus" (DQDB) proposal from the Australians. The IEEE committees have representatives of all the main U.S. telephone carriers and manufacturers, as well as British Telecom, Telecom Australia, Canadian telcos and manufacturers, and key Japanese telecom interests. A joint proposal from ANSI and IEEE to the International Standards Organization (ISO) is being prepared on these standards. It should be noted that there are other active groups in studying broadband standardization, including the EC's RACE project working with the newly-formed European Telecommunications Standards Institute (ETSI).

DQDB, and other optical broadband systems, may prove to be competitive (or fungible) with SONET B-ISDN proposals. Indeed, the precise architectures for B-ISDN are yet to be worked out; there are many candidates and many variations for switching, distribution, and access. And there may be multiple network types and carriers in broadband as the field develops in coming years.

4 Policy Implications

TECHNOLOGY PUSH HAS BEEN BEHIND all of the FCC Computer Orders (I, II, III, and surely IV, V, and VI)[54], but in none of the decisions has it been explicitly recognized that the 'computer' in the title is not merely a new application, but a permanent, restructuring of how people (and machines) communicate.

Computer I and II — with their emphasis on such trivialities as attempts to distinguish between 'basic' or 'enhanced' services or the role of the carrier in data processing[55] — illustrate the general misunderstanding policymakers have in dealing with computers, what they do, and how they network.[56] With the introduction of computers into a network, the conceptual models of how analog systems really work are no longer valid. We have discussed earlier how a virtual network changes the telecom paradigm.

It is difficult to get meaningful legal definitions when dealing with logical things — the mathematical definition of logic — especially things that are self-definable according to the whims of programmers, and are physically based on elusive electrons or photons.

For example, how do you enforce non-discriminatory clauses for computer network interrupts?[57] How would you explain this to a programmer setting up an interrupt table? Will we have FCC designated, non-tamperable chips on each and every network interface with fair-minded tables in ROM establishing interrupt priorities?

System timing is crucial to the understanding of control, for at any one slice of time (which can be a very small slice, indeed) control of the signal may extend halfway across the world, or just down to the edge of your coiled phone cord. Digital machines are designed to give over control to other

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[54] *Computer I:* 17 FCC 2d 587 (1969) and Docket No. 16979 (FCC 66-1004) *passim.*; Computer II: 77 FCC 2d 384 (1980) and Docket No. 20828 (FCC-76-745, July 29, 1976); and *Computer III* (Open Network Architecture): Docket No. 85-229 (104 FCC2d 958, May 1986).

[55] More extensive treatments of this subject by the author are in: I. Pool and R. Solomon, "Intellectual Property and Transborder Data Flows," *Stanford Journal of International Law,* Summer 1980, pp. 113-139; R. J. Solomon, "Vanishing Intellectual Boundaries: Virtual Networking and the Loss of Sovereignty and Control," *Annals of the American Academy of Political and Social Science,* January 1988; and "WATTC Continues Never-ending Story: Telecom Regulation and DP Bad Mix," *International Networks* , May 15, 1987.

[56] Weizenbaum, *op. cit.*

[57] H. Hellerman, "Interrupt," in Ralston, ed, *Encyclopedia of Computer Science,* 1st Ed, 1976, pp. 733-736.

machines (hence 'interrupts'), depending on complex 'states' of their programs. That is what happens all the time on a PC when it sends data to the printer, the screen, checks the keyboard, or the modem, or beeps. The same concept applies to end-to-end digital telecom networks, but it is much more difficult to pinpoint at any single point in time.

It doesn't help that words for technical concepts often do not mean what they say (hence we use a lot of quotes around technical terms in this paper). ISDN is a prime example: because telecom carriers initially approached the digitization process with a view of finding new things to sell to their customers, services was put in front of digital; the other way 'round would be a better indication of what ISDN has become — an end-to-end (customer premise equipment to CPE) network of digital (computer) processors. The key ISDN word is integrated.

Control of the physical components in an integrated network is what is important, and that gets very complicated. Since an end-to-end digital system, will be a totally different kind of animal than today's analog, or hybrid networks. In an analog network, digital signals (in the form of binary digits) are merely carried in analog forms for later reconversion back to bits; not much can be done with such signals on or by the network. But in an all-digital system, the bits are buffered by computers using timing signals no different than those found inside of a desktop PC, until they reach their 'destination,' which can be another computer, another digital network, or a digital device which translates these signals into a form a human (or another machine) can understand.[58]

Averages do not mean much here, such as statements which attempt to indicate 'dominant' modes for 'most' of the time, since whatever they do, they do millions or billions of times each second. Furthermore, computer science teaches us that there is no way to know what has just taken place, nor what will come next, just by looking at any one time slice; even in the context of a large program, a human programmer (if there is one) has difficulty in determining what is happening at any single point in time.[59]

Again, those looking for analogies to current networks for regulatory purposes will quickly find themselves going around in circles.

4.1 Models

The metaphor of analog telephony has been patterned on an 19th Century rail transport model. This telephone wire/rail model followed a trunk and branch/loop architecture, and was generally monopolistic for local access and for tariffing purposes. It is no surprise that the Federal

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[58] Such connections are explicitly recognized by the CCITT Red Book Recommendations for ISDN. See Rec. I.112, and "ISDN Network Functional Principles," Rec. I.310.

[59] D. R. Hofstadter, *Godel, Escher, Bach*, Basic Books, 1979, p. 18 *ff.*

Communications Act of 1934 was carried over almost word for word from the Interstate Commerce Act of 1888, replacing transport language with the relevant communications language, and merely adding the 1927 Federal Radio Act wordage for spectrum management!

The policy implications of this transport/communications paradigm are illustrated in table 1.

Table One

U.S. Common-Carrier Model of Telephony[60]

- **State-mandated universal service**, but with business and residences splitting the cost of the fixed plant according to a Ramsey pricing scheme—differential pricing for essentially the same service. Business paid value of service, while residential prices reflected ability to pay (even if below cost).
- **Capital** was raised by the 'dominant' carrier for the entire, end-to-end system.
- **Cost-engineering function averaged for the network** as a whole, but the network was artificially separated into state and federal domains, which reflected the fact that calls were predominantly local.
- **Rates were based on plant investment.** With most calls being local, unlimited flat rates for local service stabilized revenue projections.
- **No creamskimming.** To prevent erosion of the rate base, no resale, and no private attachments were permitted.

Though, over the decades, telecommunications traffic patterns and applications have changed in the U.S., especially with post World War II suburbanization and the further growth of de-centralized management and production,[61] this fundamentally railroad transport model was, until

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[60] From Loretta Anania & Richard Solomon, "Flat—the minimalist rate," paper presented at the Airlie Telecommunications Research Policy Conference, Nov. 1988.

[61] The U.S. has been more decentralized than most industrialized nations ever since the later decades of the 19th Century—a socio-economic national preference aided (or abetted) by the rapid spread of first steam and then electric interurban railways into the countryside (the latter the functional forerunners of the U.S. highway system built in the 1920s); this transport revolution took place simultaneously with the growth and penetration of the telephone. This decentralized infrastructure may help explain the tolerance for its de-centralized and fragmented common carrier regulatory system. Only prewar

recently, rarely challenged in telecommunications. However, beginning in the 1960s, the telephone network underwent a fundamental transformation by incorporating digital connections and signal processing. Adoption of digital computer technology was essential for modernization and economic efficiency.

The current network is computer-controlled (SPC), provides different levels of network access, and connects sophisticated customer-owned equipment including other networks. As new services other than 'plain old telephones' abound—at least in name and in advertising vaporware—the available rate structures vary tremendously. They range all the way from lifeline flat rates to complex Centrex packages. As a system, today's 'telephone' network is very different from the original wireline-cum-transport model.

The assumptions of the old integrated national network included: fixed overhead, fixed bandwidth, physical analog connections, and a hierarchical network architecture. The new public and private networks that are being built are increasingly fiber-based and digitally switched. The state-of-the-art technology of broadband fiber under ATM will bring with it a new set of assumptions — variable bandwidth allocations with logical, instead of physical connections and a non-hierarchical network architecture with distributed processing nodes and terminals, under shared carrier/customer control.

On the old network it was possible, originally, to separate embedded local plant from interoffice and interregional plant. That physical distinction became more artificial as more integrated equipment evolved. Still, the economics of regulation and the corporate structures of the telephone companies encouraged this artificial separation for local/long-distance, and across state boundaries, even where it was not in the public interest and probably not even in the companies' economic interest. In the future, as single-mode fiber makes possible even greater efficiency from resource sharing and intense use of all-digital networks,such separations just for accounting purposes will be almost impossible to justify rationally justify

4.2 Broadband Security.

ISDN and B-ISDN standards committees have had great difficulty in adopting satisfactory operations, administration and maintenance (OA&M) procedures for users that carriers feel would not interfere with network security. But with ATM, security may be much more robust, for all the network sees are unintelligible bitstreams, routing, and administrative flags. The customer, however, has access to sufficient overhead bits to run any type of virtual network OA&M needed.

Germany approached the U.S.' level of industrial decentralization; but communications in Germany, like its railways, has always remained centralized under the national government.

Certain types of security is likely to be much higher for ATM than on other digital networks: AT&T Bell Labs has shown mathematically that routing algorithms could be designed to prevent fraud. Tampering or accidental misrouting of a frame would cause them to self-destruct.[62] And self-routing frames offers potentially greater robustness for the user, and would be difficult to track, even by internal network procedures.

4.3 Satellites in a Fiber World

Satellite technology will also be a casualty of the combination of fiber optics and the new B-ISDN asynchronous transfer modes. This will be dictated by the growth of applications using low-delay time connectionless systems, having dynamic, variable and very high bandwidths, and demanding very low bit-error rates (BER). Fundamental B-ISDN principles[63] require a BER between 10^{-7} and 10^{-10}, and a packet length of 125 microseconds, both of which effectively eliminate satellite links for burst traffic due to inherent equatorial orbit delay.[64]

Most international traffic may be on fiber links within a decade, particularly the trans-North Atlantic circuits which comprise the bulk of today satellite traffic. Unless some provision is made for cross-subsidies — or radically new technology is invented — this may create a financial crisis for telecom in the lower traffic density parts of the world which may have needs for low-cost advanced communications, just to keep up trade with the developed world.

4.4 Intellectual Property

The law of *geometric increase* is the critical electronic publishing problem.[65] If you send the article not to one, but just two correspondents,

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[62] N. Batis (AT&T), "Fraud,Vulnerability and Misrouting of Frames in a Frame-Relaying Network," T1D1/87-127 (T1D1.1/87-206R), May 18-22, 1987, Copper Mountain, CO.

[63] CCITT XVIII-COM-16, June 1986.

[64] R. J. Solomon and L. Anania, "Open Networks: Is There a Role for Satellites in a Fiber World?," *Telecommunications*, June 1987.

[65] These intellectual property issues related to the new communications systems have been covered extensively in:

Ithiel de Sola Pool and Richard Jay Solomon, "Transborder Data Flows: Requirements for International Co-operation," in *Policy Implications of Data Network Developments in the OECD Area*, OECD, 1980, pp. 79-139.

I. Pool & R. J. Solomon, "Intellectual Property and Transborder Data Flows," *Stanford Journal of International Law*, Summer 1980.

and then they *each* send a copy to two others, ... and if each recipient retransmits the article, say, every 15 minutes (only a stroke of a key on the computer terminal) to two others, how long before the whole world sees it? 2^{32} is 4.29 billion (coincidentally, the same as the address space for a 32-bit central processor).

The ability to protect or set a value on intellectual creations which transcend boundaries via digital networks will be very difficult due to the ease of replication of digitized materials. The very concept of intellectual property on ISDN and especially B-ISDN networks runs into definitional problems, because of the way text and graphics can be manipulated, merged, enhanced, and stored. Computer graphics can be used to counterfeit and pirate graphic products with unprecedented speed and accuracy. Complications abound: pages no longer have to be static, but may include animated graphics, or raw data so a user may manipulate or combine items from numerous sources.

General agreement on the basic principles of copyright today appears in two international conventions — the Universal Copyright Convention and the Berne Convention on Copyright. These copyright fundamentals give authors and writers:

> "the right to ownership in their works. They are entitled to protection against unauthorized use of their work as well as a share in any

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Richard Jay Solomon, "Evolving Computer Infrastructure and its Effects on Corporate and Political Boundaries," OECD, ICCP(86)10, 19 Feb. 1986.

____, "Computers and the Concept of Intellectual Property," in Martin Greenberger, *Electronic Publishing Plus*, White Plains: Knowledge Industries, 1985.

____, "Electronic Printing Innovations Affect Counterfeiting, Copyright, and Int'l Trade," *International Networks* newsletter, March 15, 1986.

____, "Computers & Highspeed Telecommunications: The Old Copyright Rules May No Longer Apply to Intellectual Property," *International Networks* newsletter, February 1984.

____, "New Technologies Hoist 'Jolly Roger' Over Intellectual Property Worldwide," *International Networks* newsletter, February 1985.

____, "Intellectual Property and the New Computer-Based Media," August, 1984. Consultant's report for the Office of Technology Assessment, U.S. Congress, Washington, D.C.

____, "International Database Issues: A Case Study of NLM's Medlars," in Anne Branscomb, ed., *Toward a Law of Global Networks*, Longmans, 1986.

____, and Jane Yurow, "The New Electronic Technologies and International Intellectual Property Issues," Jan. 18, 1985. Consultant's report for the Office of Technology Assessment, U.S. Congress, Washington, D.C.

> earnings from its use by the public.... But more than that, the rewards that copyright assures the individual creator ... provides a stimulus to creativity from which all society benefits. In promulgating copyright laws, legislators have recognized the needs of society for access to knowledge. They have therefore attempted to find a balance between the essentially conflicting needs of society for knowledge and learning and the rights of the individual creator." [66]

Similar words are in the preamble to almost every national copyright law, proposed revision, and survey of problems created by the computer. The fundamentals are not an issue, but questions brought on by the stored-program computer are virtually unresolvable in the context of these principles. Along with the new paradigm of virtual digital networks, we will need a new model of how to compensate producers and disseminate information without making all users criminals.

The basic questions for computer-based creations are no different than for print, but the answers are quite elusive. These are:

1) What types of subject matter are to be protected? How will this be recognized in the digital form of a relational database, particularly if the database uses relational concepts?

2) How can publication be resolved where data bases overlap, are created independently, are based on standardized formats or indexing rules, and in virtual mode prove to be identical, though in real mode cannot be identified at all?

3) Is the right to be conferred upon some form of registration? How can or should this be done with networked distribution which eliminates the common standards of what constitutes publication? How would laws that require deposits be harmonized with reality?

4) How long should protection last? How will this be determined in an electronic environment when there is no specified publication date? How does one pinpoint publication in a dynamically varying relational database fed by swapping data a hundreds of megabits per second over a B-ISDN? Are database and ATM pointers to be copyrighted?

5) Is whatever right that is conferred to be good only against imitators, or should it be a full monopoly that affects independent creators of the same idea? How would this be enforced against machine creations? What arguments could be used to prove plagiarism or infringements? What is the meaning of an idea as expressed in terms of relational database constructs? What is expression? How much can be derivative? What is derivative?

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[66]. UNESCO, *The ABC of Copyright*, 1981.

6) Can an interface to an integrated digital network be copyrighted or patented such that information cannot be obtained from the network without permission of the interface owner? How does this correspond with concepts for Open Network Architectures?

How will these definitions work where the intellectual property is in the form of a chip (firmware), neither a "writing," nor a program, but a data management system which access a set of specialized statistical and materials database for automated mask manufacture.

Sui generis legislation which pretends that a mask is something other than a special form of database does not help, for microchips are functional outputs of software engineering; "silicon foundries" are the names of place that produce chips, for they are the modern equivalent of iron-mongers factories. Circuit database output is engraved on semiconductor materials, much as the manipulation of a chemical database may be stored on magnetic media or fanfold paper. That these tiny outputs may themselves control other programs or processes, or *be* a process, is consistent with computer fundamentals; the output from stock quotation services or news wires may be made to control other processes: an automated stock trading procedure, for example.

Across national boundaries, these questions are likely to be interpreted differently by different national courts, no matter what the treaties state. Such variances in interpretation does little to protect property rights. That these are not trivial questions can be understood in terms of trade in intellectual property, as expressed by W. R. Cornish in his treatise, which addresses problems of print media

> "the growth of trade competition ... has brought ever-increasing advantages to those in the van of innovation. Intellectual property rights, which help to sustain the lead of those with technical know-how, with successful marketing schemes, with new fetishes for pop culture, have come to foster immense commercial returns.... But in some of these fields particularly, success has been accompanied by advances in copying techniques which make piracy possible on a scale that is just as new. The resources of exiting legal techniques are under considerable strain....
>
> "The obvious purpose of intellectual property is to give protection against rival enterprises which would otherwise sell goods or provide services in direct competition. In international trade these rights have acquired a separate significance. In many cases, by adopting the appropriate legal technique, goods ... can be prevented from moving from one territory to another, a barrier of private rights can be set up against imports or exports which is as effective as an embargo or tariff imposed by a state...."[67]

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[67] .Cornish, *Intellectual Property,* Sweet & Maxwell, 1981.

The nature of the computer process is such that at any one time there may be multiple "copies" of a text residing in various parts of the machine, or spread far and wide over a multi-machine network. More complicated, the text may not exist at all in any continuous, human comprehensible fashion, but be instantaneously reassembled by a series of database pointers; on B-ISDN each frame matrix may contain such a set of pointers.

Some of the copies may be intended to be transitory, and some copies may stay around for a long time until some other program or data needs its memory space and overwrites it. But there is no guarantee of its erasure at any particular slice of time.

With optoelectronic transmission systems and extremely highspeed switching, a workstation's temporary memory can be configured to hold bits equal to several billion characters; this memory could be filled within a few seconds. This is very different from today's paradigm of paper publishing.

4.5 Rates and Tariffs

As variable costs approach zero with a B-ISDN network, a flat rate for access may be the only practical pricing method. Pricing per bit, usage, or by differential services can only encourage the sophisticated user to manipulate future systems software, re-configurable via dynamic online and CPE software, for various types of arbitrage.[68]

Figure 2 suggests that the true variable costs of very highspeed fiber systems will approximate a step function based on incremental costs for bandwidth, dependent on the laser access to the fiber (ie., the remote electronics) [69]

Access to the network via the 'local loop' would be based on the maximum instantaneous bandwidth a subscriber requires. This might be the simplest, effective way to tariff broadband transactions. (In addition to access, a charge may be levied for degrees of non-blocking or priority service.) While the average user of POTS may not need to access all of the Library of Congress online via B-ISDN, video-on-demand could well justify a flat rate for fiber access to the home. And it is likely that even narrowband ISDN will find that access is a more productive policy for capital expansion than policing bit-per-second usage.

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[68]. The details of this argument is discussed in Loretta Anania & R. Solomon, "Flat — the minimalist rate," *op. cit.* This section summarizes that paper.

[69]. Based on work by Northern Telecom and AT&T Bell Labs.

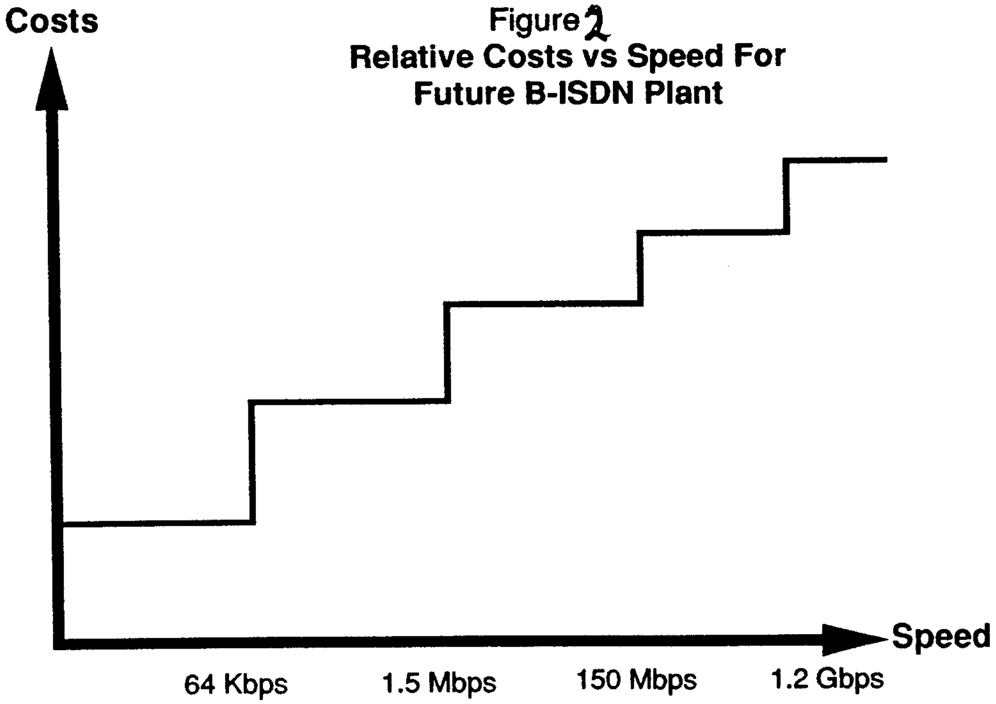

Figure 2
Relative Costs vs Speed For
Future B-ISDN Plant

Until 1980, 80-90% of the costs of the Bell System plant were joint for local, short-haul and long-haul services.[70] On a distributed computer network like the ARPANET, or even BITNET (where ownership of each link is somewhat mysterious!), the users mainly pay for access; usage costs vary depending on their CPE architecture. Like these relatively slow-speed, customer/carrier shared packet nets, future transparent networks, based on asynchronous frame transfers (working their way at Gigabit speeds through a mesh instead of an hierarchical network) will find variable switching costs too small to measure or detect. ATM architectures make pricing the whole of the network relevant to any local tariff scheme. Local will be inseparable from medium-, if not long-distance in B-ISDN. Artificial costing separations, as in today's state/Federal network, will only encourage bypass.

As the separation of basic service elements increase in complexity with end-to-end digitization, the only feasible solution from the aggregate user perspective becomes a universal flat rate for access. A flat rate is even more attractive under B-ISDN. With the vast inherent capacity of optical fiber,

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[70] Oettinger, A. et. al., "Players Stakes and Politics ...", Harvard Program on Information Resources Policy, Harvard University, 1981.

fixed costs of the distribution plant overwhelm any variable costs. With a flat-rate solution, the sum of customer access costs then would be equal to the total revenue requirement for each carrier.

However, the most telling argument is that with mixed services ranging from 64 Kbps (or even 16 Kbps) voice to, say, 100 Mbps HDTV, there is no practical way to charge a customer five cents for a local call and $836.97 for a 1-hour TV program.[71] If a TV program were to charge what the market would bear, the phone call would approach zero to anywhere on the continent in our new telecommunications paradigm. Which is not such a bad new metaphor either.

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[71] Robert Pepper [cite paper submitted to this conference].