Prometheus, Vol. 20, No. 1, 2002

Accelerating Technology: The Pace of Transmission Systems[1]

A. MICHAEL NOLL

ABSTRACT *The growths in capacity of various generations of transmission technology were studied. The results show that the growth rates for different transmission technologies are themselves increasing, which means that the pace of transmission technology is accelerating. What is somewhat surprising is that long-distance rates are not decreasing more steeply. What is not surprising is the bandwidth glut in backbone networks. However, the increasing availability of transmission capacity in the bandwidth-rich world of the future could herald a return to circuit switching for data telecommunication.*

Keywords: bandwidth, growth in capacity, telecommunications, technological change, transmission technology.

Introduction

Moore's Law—named after Gordon E. Moore (co-founder of Intel)—states that computer chips double in capacity every 18 months. This pace of chip technology has remained fairly steady since being first observed by Moore in 1965.

This paper reports on the growth in capacity of various generations of transmission technology used in telecommunication in the United States. The results show that the growth in the capacities of the various generations of transmission technology are themselves increasing. This means that unlike Moore's Law, the pace of the increase in the capacity of transmission technology is not steady but is actually accelerating. What might this mean for competition in telecommunication in the United States and telecommunication technology in general?

The Pace Accelerates

This acceleration of the rate of progress of transmission technology means that long-distance prices should be comparably decreasing at an accelerated rate. But this is not the case, and long-distance prices continue to fall at the same steady rate.

Prometheus ISSN 0810-9028 print/ISSN 1470-1030 online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/08109020110110286

This is particularly disturbing since access charges have greatly decreased during recent years, which should also cause an acceleration in the rate of decrease.

This paper first discusses competition in telecommunication and its expected impact on long-distance prices. The history of various generations of transmission technologies that have been used over the years in the Bell System in the United States to carry signals across the continent and under the ocean is then described. These technologies are coaxial cable, terrestrial microwave radio, undersea copper, geostationary satellite, terrestrial optical fiber, and undersea optical fiber. The capacities of each generation of transmission technology were examined and a compound annual growth rate (CAGR) was calculated for each. A graph of these CAGRs as a function of the year in which the first generation initially became available shows an impressive increase over time. Indeed, the pace of transmission technology has been accelerating.

The pace of growth in the capacity of transmission systems used in long-distance telecommunication has been increasing over the past five decades. Early systems installed in the mid-1940s were growing at a compound annual growth rate (CAGR) of about 15% a year; more recent systems are growing at least nearly 70% a year.

Competition in Telecommunication

Competition first came to the provision of long-distance service in the United States in the late 1960s and early 1970s. This early competition became a major factor in leading to the breakup of the Bell System that occurred on 1 January 1984. Although there appear to be many long-distance companies, most of them are simply reselling the facilities of a few major suppliers, such as AT&T, MCI/Worldcom, and Sprint. There are some smaller facility-based suppliers, such as Frontier and Qwest, but their market share is small. With the past MCI proposal to acquire Sprint, the major suppliers would have become only two—a real duopoly.

Competition is generally assumed to benefit consumers, since market forces should drive prices down to marginal costs. Thus, it is thought, competition in the provision of long-distance service has benefited consumers. But, a previous study showed that the cheapest 10-minute, coast-to-coast, long-distance call has been decreasing at the same rate since the first trans-continental call in 1919, long before there was even the smallest dream of competition.[2] There is no acceleration of this decrease from competition. In fact, this study showed that the costs of advertising and marketing had greatly accelerated because of competition. The study concluded that advances in technology were the major cause of decreases in long-distance prices—not competition.

However, one wonders whether the pace of progress in long-distance transmission technology has been constant over the decades. Each individual technology has experienced advances in capacity over the years of its life, but are the rates of progress constant or are they accelerating? The data reported in this paper shows that the rate of progress of transmission technology has been accelerating.

Summary of Telecommunication Technologies

The first trans-continental telephone calls made coast-to-coast across the United States in 1919 were transmitted over copper wires, with a single conversation being carried over a wire pair. The 'audion' triode vacuum tube—invented in 1906 by Lee DeForest—was used to amplify the weak signals along the way. But only one conversation could be carried on each pair of copper wires, and thus the tremendous cost of installing wires across the country could not be shared across many simultaneous users. The solution was broadband transmission media coupled with the multiplexing of many signals to share the same medium.

Multiplexing was initially accomplished in the frequency domain through frequency division multiplexing in which each speech signal was assigned its own unique band of 4,000 Hz. Today's multiplexing is accomplished through time division multiplexing in which each speech signal is sent in digital form at 64,000 bps. Broadband transmission media evolved through coaxial cable, microwave terrestrial radio, geostationary communication satellites, and optical fiber. Each of these individual media is described below in terms of how the capacity of each increased over time.[3]

Transcontinental Coaxial Cable

The earliest coaxial cable system across the United States was the L1 system which was placed in service in 1946. Utilizing vacuum tube repeaters placed every 8 miles and three working pairs of coaxs, the system had an overall route capacity of 1,800 two-way voice circuits. The technology progressed over the years through transistors to integrated circuits. The last transcontinental coaxial cable system, L5E, was placed in service in 1978 and had a route capacity of 132,000 two-way voice circuits.

Microwave Terrestrial Radio

Microwave radio in the 4-GHz and 6-GHz bands has been used for transcontinental telephone services by placing a series of towers about every 26 miles across the continent. The TD-2 system operating in the 4-GHz band became available in 1950 and had an overall route capacity of 2,400 two-way voice circuits. Polarization of radio waves, improvements in amplifiers, and the use of single-sideband amplitude modulation resulted in a steady increase in capacity. The last terrestrial microwave radio system, AR6A, was placed in service in 1981 and had an overall route capacity of 61,800 two-way voice circuits when combined with an existing TD system.

Communication Satellites

The Comstar I geostationary communications satellite was launched in 1976 and had an overall capacity of 14,400 two-way voice circuits. Comstar IV was then launched in 1980. The capacity of these satellite systems was increased in 1982 to 93,600 two-way voice circuits through the use of single-sideband amplitude modulation for each transponder. Geostationary communication satellites experience considerable round-trip delay because of their high altitude above the earth. Communication satellites hence are really not that suitable for two-way telecommunication, and they thus have been replaced in most areas by optical fiber.

Optical Fiber

An early optical fiber system utilized by AT&T was the FT3 system introduced in 1979. Each single fiber in the system was graded index and carried 45 Mbps.

Single mode fiber was developed, and each fiber in the FTX-400 system introduced in 1986 carried 400 Mbps. Today's terrestrial fiber systems have considerably more capacity in each strand. The sky's the limit with fiber, and the theoretical maximum capacity if the entire light spectrum were used is in the order of 50,000 Gbps.

Undersea Transatlantic Cables

The progress of undersea cable has been very dramatic. The early systems under the Atlantic Ocean used coaxial cable. The first transatlantic submarine coaxial system was TAT-1, which was placed in service in 1958. A total of 51 repeaters were placed every 44 miles to amplify the weak signals. Taking into account the silent intervals in conversations (a technique known as Time Assignment Speech Interpolation, or TASI), the capacity of this first system was 72 two-way voice circuits. The last transatlantic submarine coaxial-cable system, TAT-7, was placed in service in 1983 and had a capacity with TASI of 10,500 two-way voice circuits. This steady progress occurred as vacuum tubes were replaced by transistors and more sophisticated processing. The TAT-8 transatlantic submarine system was the first to utilize optical fiber. It was placed in service in 1988 and had a digital capacity of 280 Mbps. Undersea fiber technology has progressed at a very fast pace, and the AC-1 fiber system had a capacity of 80 Gbps in 1999. The TAT-14 system planned for 2001 will have a capacity of 160 Gbps. The most recent improvements in fiber capacity have occurred because of the use of wave division multiplexing.

Growth in Capacity

Each transmission technology has improved steadily over time from its first use in terms of overall route capacity. Table 1 below shows the route capacity of the various transmission systems for the year in which they first became available and a year at or toward the end of their use. The life in years is also shown. The factor of increase in capacity is calculated for each system, along with the compound annual growth rate (CAGR).

Table 1. Route capacity of transmission systems

Type	Name	Year	Capacity	Years	Factor	CAGR
Coaxial cable	L1	1946	1,800 circuits			
(transcontinental)	L5E	1978	132,000 circuits	32	73.3	14%
Microwave radio	TD-2	1950	2,400 circuits			
(transcontinental)	TD + AR6A	1981	61,800 circuits	31	25.7	11%
Undersea copper	TAT-1	1958	72 circuits			
(trans-Atlantic)	TAT-7	1976	10,500 circuits	18	145.8	32%
Geostationary satellites	Comstar I	1976	14,400 circuits			
	Comstar IV	1982	93,600 circuits	6	6.5	37%
Terrestrial fiber	FT3	1979	45 Mbps			
	FTX-400	1986	400 Mbps	7	8.9	37%
Undersea fiber	TAT-8	1988	280 Mbps			
(trans-Atlantic)	AC-1	1999	80,000 Mbps	11	285.7	67%

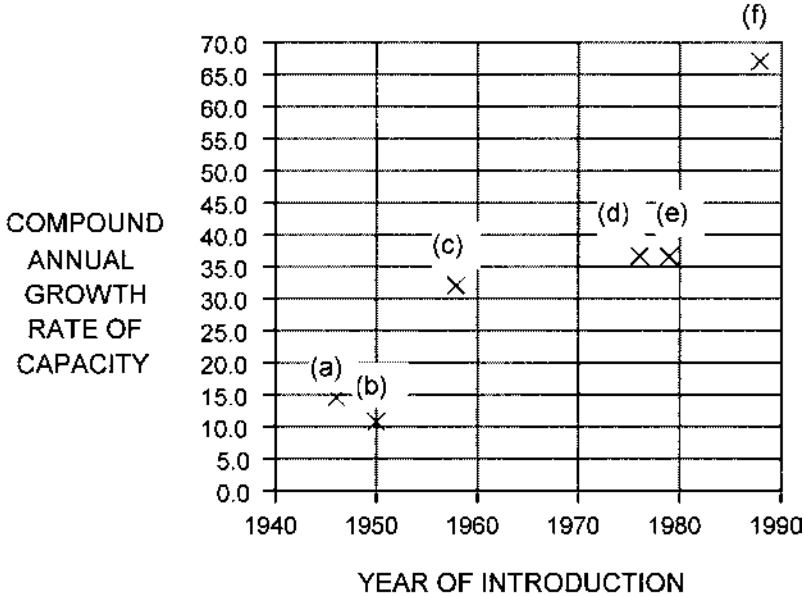

Figure 1. Compound annual growth rates for various transmission systems as a function of the year of their first introduction. In order by year, the systems are: (a) coaxial cable; (b) terrestrial microwave radio; (c) undersea copper; (d) geostationary satellite; (e) terrestrial optical fiber; and (f) undersea optical fiber.

The graph of Figure 1 shows the compound annual growth rate of the capacity of each transmission system. The earliest systems became available in 1946 and 1950 and experienced annual growths in capacity of 14.4 and 11.0%. Systems initially installed in the late 1950s and 1980s had growth rates from 32 to 36%—a substantial increase over the earliest systems. The latest system, installed initially in 1988, is experiencing annual growth rates of 67.2%.

Clearly, not only does each transmission system experience improvement over time, but these growth rates are themselves increasing with each newer generation of transmission system. The compound annual growth rates of the various transmission systems seem to be increasing linearly over time at a rate of about 1.3% per year.

Implications for Long-Distance Prices

The cost of providing long-distance service is dependent on the costs of transmitting signals across great distances and also the costs of switching these signals. If transmission costs were decreasing at a constant rate, one would expect long-distance prices to likewise be decreasing at a constant rate. Indeed, an analysis of the long-term trend in the cheapest distance price for a 10-minute, coast-to-coast, long-distance telephone call using AT&T showed that the price has been steadily decreasing at a compound rate of about 5% per year over a period of nearly 80 years.[4] Although the pace of technology has been accelerating, the decrease in prices has continued to fall at the same steady rate.

The charges paid by long-distance companies for access to the local networks have greatly decreased during recent years and along with advances in technology probably should have accelerated the decrease in long distance. However, the costs of marketing (advertising and promotion) have been increasing and perhaps have consumed the benefits of advances in technology. Also, transmission and switching are today such a small proportion of the total cost of providing long-distance service that any accelerated decrease in their cost probably has little impact on the final price to consumers.

Implications for Network Infrastructure

Packet switching was invented as a way for many data signals to share the same transmission circuit—a technique known broadly as multiplexing. The complexity and cost for doing this was the need for computer processing to examine packets of data and route them to their destinations—a technique known broadly as store-and-forward switching. The tradeoff was between processing and transmission, and processing clearly won. But transmission capacity and bandwidth are available on a tremendous scale—possibly even a bandwidth glut—that seems to be accelerating in its increase. This means that the tradeoff needs to be re-examined and might be tilting away from processing (which probably increases at a constant rate according to Moore's law) toward transmission. Circuit switching of data might be dead today but might make more sense in tomorrow's growing bandwidth-rich world.

Discussion

Transmission technology today uses integrated circuits and would be expected to advance in capacity as chip technology has advanced. The acceleration in transmission capacity for different generations of transmission systems is a surprise for which the explanation is not apparent or clear. Also not clear is whether new generations of transmission systems will be invented and whether they will experience a similar acceleration in the growth of capacity.

Transmission and multiplexing are only a portion of the overall system needed for telecommunication. Signals also need to be switched. Switching technology today relies much on computer processing. Future research contemplates study of measures of switching technologies and their growth over time.

Notes and References

1. This paper was presented at the 2000 Telecommunications Policy Research Conference in Alexandria, Virginia.

2. A. Michael Noll, 'A study of long-distance rates: divestiture revisited', *Telecommunications Policy*, 18, 5, 1994, pp. 355–62.
3. A. Michael Noll, *Introduction to Telephones and Telephone Systems*, third edition, Artech House, Boston, MA, 1998; E. F. O'Neill (Ed.), *A History of Engineering and Science in the Bell System: Transmission Technology (1925–1975)*, Bell Laboratories, Indianapolis, IN, 1985.
4. Noll, *op. cit.*, 1994.