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Satellites in the National Information Infrastructure

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SATELLITES IN THE NATIONAL INFORMATION INFRASTRUCTURE

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Abstract

The public discussion on the National Information Infrastructure (NII) has been wide ranging and lacking in consensus as to the nature of the proposed NII itself. This paper in acknowledgment of the national policy origins of the NII debate begins with relevant remarks by President Clinton in his State of the Union Address. It defines an initial working definition of the NII based on the President's challenge. It then provides some clarification to the discussion in terms of planning horizon, subscriber transport services and transport media. The working definition is further developed to incorporate the type of traffic the NII will be expected to support following a discussion of an emerging desktop computing imperative. From this implications are drawn as to the feasibility of the so called fiber solution and an argument made that in the evolution of the current infrastructure to the future NII satellites offer the best solution for a timely manifestation of the vision.

INTRODUCTION

The public discussion of a future National Information Infrastructure is based on an extraordinary and broad vision. In his State of the Union Address to Congress on January 25, 1994, President Clinton defined the challenge: build the national information superhighway by the year 2000. A major component of the vision, the Information Superhighway, is typically described as a broadband digital network capable of bringing the information age to the people of America. Fiber optic cable has been the metaphor for this network and the interstate highway system the analogy. But while fiber has captured the imagination of the public and is no doubt an inspiration for the vision, fiber is not the vision. The network is only one component of the NII; and fiber is only one component of the network. The biggest challenge for the network architect of the NII can be distilled into one succinct phrase, *the first-mile problem,* how to provide transport services to the end-user possibly three orders of magnitude greater than that offered by today's network at a price the American household is able to afford and willing to pay. This paper will argue that a very promising, yet largely ignored, approach to the first-mile problem is communications satellites. Underlying this argument is the assertion that the challenge of the first-mile problem is fundamentally one of capital deployment, the cost of a fiber-to-the-home strategy. An advanced satellite network could instantly make the equivalent of fiber available to anyone anywhere in the country in a much shorter time period and at a fraction of the cost of fiber.

Background Discussion

The NII properly speaking is a broad federal program first expressed in the context of national policy in the President's and Vice President's Technology Initiative released February 22, 1993. The NII is motivated and influenced in part by a more mature government activity, the High Performance Computing and Communications Program (HPCC). The purpose of the HPCC Program is to accelerate the development of future generations of high performance computers and networks with a goal of achieving sustained teraflop (trillions of floating point operations per second) performance. President Clinton and Vice President Gore can be credited with bringing the NII to the people in that they have promoted the idea of an NII for the classroom, the household and the general business application as opposed to the grand challenge applications addressed by HPCC.

This paper will emphasize the latter concept of the NII in particular the President's comments in his State of the

Union Address. Consistent with those comments the goal of an information superhighway is to be achieved by the year 2000. Beyond this some assumptions must be made which may be debated, but are still useful for the elucidation of some important issues related to any notion of a new information superhighway.

One concept of the NII is provided in the report of the Office of Science and Technology Planning.

> "The NII will consist of computers and information appliances (including telephones and video displays), all containing computerized information, linked by high speed telecommunications lines capable of transmitting billions of bits of information in a second (an encyclopedia in a few seconds)....The NII will be as ubiquitous as the telephone system, but will be able to carry information at least 1,000 times faster." (OSTP, p.8)

It is not realistic to expect the deployment of an NII as ubiquitous as the telephone system and 1,000 times faster by the year 2000. This paper therefore does not subscribe to the HPCC concept of the National Information Infrastructure. This paper defines the network component of the NII as a national digital communications infrastructure to network America's desktop computers, not its supercomputers, reaching into all echelons of the American public. In contrast to the HPCC view, this paper believes the desktop computer, not the supercomputer or supercomputer center, will be the driver behind a broad market demand for a ubiquitous NII serving the general population of America.

Fundamental Considerations

Planning Horizon

The telecommunications infrastructure enjoyed by Americans today is the result of over 100 years of research, planning, financing and deployment under the leadership of AT&T, more than a company, an American icon, which clearly ranks among the greatest commercial organizations to have ever existed in the history of mankind. A proper respect for the magnitude of the accomplishment of AT&T and the telecommunications industry must, in short order, humble any planner of a new national infrastructure. Planning horizons on the order of decades are the norm in such an environment. On the other hand, the NII debate is couched in comparatively short term objectives, and consequently, the emphasis of this paper is on the near term. Given the President's comments, a planning horizon of the year 2000 is assumed.

Subscriber Transport Services Rates

This paper takes the position that the trickle down theory of information wealth is inconsistent with a year 2000 horizon only six years away. We can not expect to build gigabit networks for supercomputers today and expect megabit per second networks for personal computers to appear in six years as a consequence of some trickle down phenomenon. Furthermore, much speculation can be made about 155-Mbit/s data rates to the desktop in the year 2025 or beyond, but the economics and applications of the projected desktop computing environment in the year 2000 indicate a much more conservative range. For reasons discussed below this paper assumes that range to be 384-kbit/s to 155-Mbit/s with a nominal average rate of 6-Mbit/s .

Transport Media

There tends to be a misconception that broadband (greater than 45-Mbit/s) and even wideband (1.5 to 45-Mbit/s) communications are the exclusive domain of fiber. In fact, data rates in all the classifications: narrowband, wideband, and broadband can be and are carried by any of the common transport mediums: twisted copper pair, coaxial cable, microwave, satellite and fiber. In practice, networks often use a mix of media types. The notion of an all-fiber network is not a proper planning objective. And this is where 'fiber' the metaphor is misleading and detrimental to the NII debate. Proper planning objectives are such things as transport service rates commensurate with market needs, bit error rate guarantees, blocking probability and so on. The choice of media is a dependent variable based on proper planning objectives, economics, and physical environment factors. If the requirements of the residential market in the year 2000 as one example are determined to be 1.5-Mbit/s inbound and 64-Kbit/s outbound, then fiber, coax, twisted pair and satellite are all candidates. To speak of the future infrastructure only in terms of fiber is unrealistic.

The Desktop Computing Environment Imperative

A brief discussion of applications which might generate data traffic at wideband and broadband rates will serve to make the point that the future desktop computing environment is *the imperative* for the information superhighway. The largest class of traffic by far in the national infrastructure today is voice. Voice is not digital by nature, but through very well established techniques is digitized for transport through the network. It is digitized at a rate of 64-kbit/s. This is far below the rates considered as wideband or broadband. And, in fact, 64-kbit/s is much faster than is necessary. The 64k standard was established in the telephone industry some four decades ago. If the telephone plant were being designed today, no network engineer would select 64k as the rate for digitized voice. More likely, it would be 16-kbit/s or 4.8-kbit/s or even lower. The current network based on 64k channels is obviously over-engineered for voice, its dominant application.

This has an important implication for the NII. On the one hand we hear the call for "fiber to the home" and megabit transport services to the desktop; on the other hand the largest use of the infrastructure today is voice which could be provided at 4.8 instead of 64-kbit/s. It begs the question, why all the talk of increasing bandwidth? Why not a heated debate over rebuilding the network around a 4.8-kbit/s voice channel? Without getting into such a discussion, we can make an important assertion about the future NII: clearly voice, the largest source of traffic today, will *not* generate the demand for a national information superhighway offering greater than the 64k rates already offered by the current embedded plant. We must look elsewhere for a market-demand imperative for the NII.

If an imperative is emerging in the marketplace, it is grounded in the burgeoning use of graphics in the desktop computing environment, both generated by the computer and real video or still images captured by cameras and scanners. PC-to-PC and PC-to-host communications require a two-way switched transport capability. Such communications are supported by the PSTN today through modems and by the Internet. Though the market is still much smaller than the market for voice, it is experiencing rapid growth.

But even graphical traffic will not demand subscriber rates in the gigabits. There is no application nor any piece of equipment in the classroom, the home, or even the average workplace today, or likely in the year 2000, that in the wildest visions of the most optimistic NII proponent will generate non-aggregated traffic at rates of 1.2 or 2.4-Gbit/s. To be certain, computer rendered radiology scans, particle beam accelerators, and nuclear test explosions generate large amounts of data. But, these are applications for special-purpose networks, not for a general purpose public infrastructure. As a benchmark, consider the rates at which a supercomputer communicates. Supercomputers today use an interface specification called High Performance Parallel Interface (HPPI) which defines a one-way data transport rate at 400 or 800-Mbit/s. HPPI is used for communications between supercomputers or supercomputer to mainframe. The communications link to the desktop workstation interacting with the supercomputer operates at much lower rates. What then is a realistic expectation for offered traffic from the desktop computer? ATM switch manufactures are already producing 155-Mbit/s interface boards for workstations although there are few machines on the desktop today which can support more than 30-Mbit/s. It seems incredible that individuals might be communicating at those kinds of rates in the future, but then again the incredible has become commonplace in the past decade of computers and communications. Lets consider 155-Mbit/s a high end of a range.

As a low end, a new infrastructure is bounded by narrowband ISDN. If the future NII does not offer significantly higher bandwidth than a 64-kbit/s ISDN channel, it can hardly be justified. The ISDN switch infrastructure is essentially deployed and capable of working over embedded copper facilities. This is somewhat arbitrary, but for sake of discussion lets consider 384-kbit/s, a rate significantly higher than ISDN, as a low bound giving us a range of 384-kbit/s to 155-Mbit/s for the future NII. One more back of the envelope analysis yields another data point especially for the home computer. An emerging new paradigm for desktop computing is multimedia applications. Multimedia applications are evolving as CD products in home entertainment and education. CD drives have a basic read speed of about 1.5-Mbit/s and the latest mass market products are 4X drives delivering 6-Mbit/s. Multimedia technologies for the desktop computer are being developed around the information rate that can be delivered by the CD drive. It is reasonable to assume a comparable rate for multimedia applications across the network.

Our working definition of the information superhighway can now be further modified: a national digital communications infrastructure reaching into all echelons of the American population by networking America's personal computers, supporting subscriber traffic rates in the range of 384-kbit/s to 155-Mbit/s with a nominal average rate of 6-Mbit/s by the year 2000. The offered traffic will be multimedia in nature originating from a geographically broad distribution of desktop computers in homes, businesses and schools across the country.

Economies of Scale and the Aggregation Ratio

Traffic aggregation is essential to network economies; it is the fundamental mechanism for achievement of economies of scale benefits in the terrestrial plant today. The three basic aggregation functions in the network are: switching, trunking and subscriber loop carrier systems. Switching defines the relationship of subscribers or call sessions to network channels; network trunks and subscriber loop carrier systems define the relationship of channels to facilities.

Aggregation is achieved in trunking and carrier systems by a variety of techniques which fall into the general category of 'multiplexing'. *Multi*ple discrete voice signals (or other traffic types) are aggregated together into a com*plex* signal forming a *multiple*x traffic stream. Without multiplexing every telephone would have to have its own pair of wires running through the streets all the way to the local switching office. This could typically be 40,000 pairs for every switch. In 1962, AT&T began digitizing voice and multiplexing discrete signals into aggregate traffic streams with its introduction of T-1 multiplexing into the network. A T-1 system operates at a bit rate designated the DS-1 rate, 1.544-Mbit/s, as defined by the digital service rate hierarchy and multiplexes 24 voice channels over two pairs of twisted copper wire. A *pair gain* of 12 to 1 is realized. While T1 is still a very important transport service, today pair gain ratios can greatly exceed 12. DS4 systems use coaxial cable to achieve pair gain ratios of 4,032; fiber optic systems go well beyond this. An AT&T Quad 417 System supports an aggregation ratio of 24,000-to-1 in major trunk routes.

One can readily appreciate the economy of scale benefits afforded by aggregation. This is also the great significance of digital technologies and fiber optics in the network today. It is aggregated facilities which are the major application of digital transmission technologies and fiber optics in the network today, not megabit or gigabit services to customers. Add switching to the equation and hundreds of thousands of customers might use the same fiber facility in the course of a day. Even at pennies per minute for each conversation these economics no doubt translate into a very respectable return on an investment in a piece of fiber.

This raises an important challenge for NII visionaries. The Regional Bell Operating Companies (RBOCs) are regulated by each state's public utilities commission. Different approaches are used with most states using some form of return-on-rate-base (ROR) formula ensuring (and restricting) their return to a predetermined value. The nation's long distance carriers though not restricted by a government regulated ROR formula are constrained by the competitive forces each imposes on the other. The point is this: whether the mechanism is regulation or competition the industry has achieved a level of price equilibrium acceptable to both its stockholders and its customers yielding a financially solvent industry and a generally very well serviced market. In fact, as demand for telecommunications has increased continually over the past decade, prices have actually come down. This has been achieved by, among other things, a relentless attention to the fundamental factor of economy of scale, aggregation, and to a significant extent that has been achieved by the deployment of fiber. In the absence of massive public sector financing any future NII will have to achieve an ROR consistent with the demands of the capital markets at a price affordable to the consumer markets.

The point to be made here is this: fiber is the wrong inspiration for futuristic visions of an NII. Such a vision is fiber-capacity motivated, its a "fill the fiber" campaign neither application nor market driven. Furthermore, waxing poetic about the integration of voice, data and video over a single fiber completely disregards the real motivation for the millions of dollars of investment in fiber for the network today. It is *aggregation* not integration which is driving the investment in fiber. Aggregation achieves economies of scale; integration creates captive markets. As subscriber rates prepare to take the leap to megabit rates the aggregated components of the network will offer major capital deployment if not technical hurdles.

We have already observed the kinds of aggregation ratios used in today's network to achieve the rather remarkable price-performance record of the American telephone industry. The challenge for NII visionaries is to envision an economically feasible infrastructure where aggregated transport rates which today support massive numbers of users become the standard rate for each home in America keeping in mind the need to maintain aggregation ratios in the network of 4000 and 24000 to one. Network economics demand it. If individual subscriber rates are to jump to what are today used for aggregate traffic, meaning, in the range of megabits per second, the network must achieve bit rates in the aggregated portions of the network three orders of magnitude greater than today's. By way of example, assume a new subscriber rate of 6-Mbit/s and an aggregation ratio of 24,000. The implied aggregate rate of trunking systems becomes 144-Gbit/s. There is no such commercial system in existence today. The highest optical carrier standard specified today, OC48, supporting 2.4-Gbit/s, is deficient by a factor of sixty. There is a similar impact on switching systems implied by the leap to subscriber rates of 6-Mbit/s rates. Current Class 5 central office switches with an approximate throughput of 1-Gbit/s would have to grow to 90-Gbit/s throughput capacity based on a simple multiplication by the ratio of future subscriber rates to the current 64k basis. Other factors might argue for much greater capacity. This simple analysis sheds important light on the implications of a prediction that subscriber transport rates will be "at least 1,000 times faster" than that offered by today's network. It also provides insight into fundamental forces which will drive the NII to the use of satellite technology.

SATELLITES IN THE NII

In contrast to the terrestrial network, economies of scale in a satellite network are not a function of aggregated facilities deployed at immense capital expense. The fundamental network mechanism for the achievement of economy of scale in a satellite network is the multiple access strategy. This is a key advantage of the satellite in terms of the capital cost required to build the NII. The future NII, if it is in fact to be purely a fiber terrestrial network, must resolve the economic paradox of the fundamental transport rate and the aggregation ratio. As the multimedia desktop computer in the future requires a significantly higher data rate to the individual subscriber, the network must achieve the requisite aggregation ratios to meet the hard economic constraint: return on investment. Satellites on the other hand eliminate aggregation from the economic equation because of its ability to assign channels on demand. There is no embedded capital asset in the link committed to a given subscriber; the medium is free space and it is already ubiquitously deployed.

The capital deployment advantage of satellites in the NII context is an important part of this proposition. There are some 20,000 telephone company central offices in this country supporting untold thousands of miles of subscriber facilities and transmission systems. The capital deployment task is simply too large to even consider the possibility of universal coverage before the year 2015 not to mention the turn of the century. To establish some frame of reference in regards to capital costs consider that NTT of Japan in October 1993 estimated it would cost $430 billion to deploy fiber to every home in Japan by the year 2015. Japan has 50% of the population of the US and 40% of the land area. It is very easy to extrapolate a $1 trillion price tag to deploy fiber to every home in the United States. PacTel has said it would spend $30 billion on fiber in the state of California alone over a similar time frame. By comparison to satellite deployment costs, $30 billion is enough to capitalize the entire INTELSAT network of eighteen geostationary satellites around the world plus every satellite filing currently under consideration at the FCC and still have money left over.

In the ubiquitous telephone network, the largest component of the capital investment is in the subscriber loop plant. The subscriber loop in the terrestrial network is a pair of copper wires and possibly in the future an optical fiber. In either case, it is an asset permanently deployed and dedicated at some point to a single terminal. Supporting that loop is an array of additional assets: multiplexers, T1 carrier facilities, digital repeaters, telephone poles, underground conduit, cross connect switches and so on. These assets represent a sunk investment; they are not easily redeployed and certainly not on a call-by-call basis. Yet, the satellite can do just this. The satellite "local loop" if you will is an assigned channel of an RF (radio frequency) beam. The channel represents a portion of the beam allocated to a given communication session. The satellite link, the equivalent of the terrestrial subscriber loop, is effectively "deployed" with each call setup and "recovered" with each call termination. This is referred to as demand assignment and is a feature which is unique to satellite networking. Demand assignment can be made as a function of one or more schemes for sharing the RF link resource: time division, frequency division, space division and code division. Similar to the terrestrial network, the channel might provide a full-duplex 64-kbit/s digital transport service, but in contrast to the terrestrial service there is no link resource committed beyond the duration of the call. The transport medium is free space, not hardware, not telephone poles, not conduit in trenches. Upon termination of the session the link can be reconfigured to serve another subscriber across the street or across town. The sophisticated multiple access schemes available to the satellite engineer today are an amazing example of the multiplier effect of high technology compared to the brute force of capital deployment.

An example of a demand assigned multiple access strategy (DAMA) is the hopping spot beam combined with onboard switching employed by the Advanced Communications Technology Satellite (ACTS). DAMA, onboard switching and high power spot beams (the satellite equivalent of fiber) combine to deliver a highly efficient scheme for on demand deployment of link resources by offering the resources where they are needed when they are needed. Multiple users can seize capacity from the system, use it, and return it when finished. The terrestrial analogy would be the ability to throw down a fiber to a user in Chicago for a seven minute session, pick it up and instantaneously deploy it to another user in San Diego for say an hour, pick it up again and give it to some other user in some other part of the country. This is not a very accurate analogy of the way multiple access works on the ACTS, but it serves to make the point: satellites have the ability to instantly deliver the power of fiber to any user anywhere in the country and in a moments notice give that fiber equivalent transmission power to any other user anywhere else in the country. This is not without its own cost. Terminals must be installed. In terms of the link though, there is no penalty of underutilized capital assets as thousands of miles of fiber or coax or copper pairs lay dormant in the ground ever ready, but often waiting for someone to make a call.

CONCLUSION

When vision is used in the context of a national agenda it must also serve the best interest of the public good and not the partisan interests of one industry or segment of an industry especially over the interests of the public whom the vision is meant to inspire and serve. The concept of a new National Information Infrastructure to fortify this nation to succeed in an information economy of the 21st century is worthy of the term 'vision' in the context of the national public good. "Fiber to the home" is a leap from national vision to industry strategy; and "fill the fiber" is nothing more than a marketing objective. The vision is a challenge of immense proportions which ultimately we as nation will meet or fail to meet with profound consequences in either case for the quality of life in 21st century America. Satellite technology offers advantages that can not be overlooked by the successful strategy. Technical and economic drivers imply the use of satellites in the NII. Whether by plan or the free-for-all of the competitive marketplace if this vision is realized, satellites will be there. The proposition being made here is that the NII will evolve as a migration strategy of several iterations as has historically been the case in the telecommunications industry; and that satellites can be an important component of the first phase of that migration, that is, a manifestation of the NII achievable by the year 2000.

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