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Taking It All Apart:
Principles of Network Modularity

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I. Introduction

When the Federal Communications Commission (FCC) acted to remove the regulatory barriers to entry for the long distance and customer premises equipment (CPE) markets, it sought to increase the number of suppliers in these markets so that consumers could realize the benefits of competition. In moving to deregulate these markets, the FCC reasoned that there were no inherent features to the structure of these markets, or adverse impacts on other policy objectives, which should preclude competition. Subsequently, consumers have arguably enjoyed lower prices and more innovative service offerings in these markets due to the ensuing competition. The long distance and CPE markets serve as notable examples of the general policy direction taken by the FCC to reduce the old telephone monopoly into a set of competitive markets for the purpose of bringing the benefits of competition to telecommunications consumers. But while the long distance and CPE portions of the monopoly have been stripped away in this process, the barriers to entry to compete with the local access network--the portion of the public telecommunications which extends between the interexchange carrier's network and the end user--still remain largely in pre-divestiture form.

It now appears to be an opportune moment in time to further consider the extent to which competition can be brought to the local access switching and transport market. The proliferation of network alternatives improves the prospects for facilities-based competition in the transport of communications services. Private

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networks using a number of different technologies have emerged such as cable television networks, wireless telephone networks, local area networks (LANs) and metropolitan area networks (MANs). The local exchange carriers (LECs) themselves have indicated that they foresee their network evolving to become a multimedia platform capable of delivering a rich variety of text, imaging, and messaging services. Many take this multiple service scenario a step further and imagine an "open" network platform--a network with well defined interfaces accessible to all--which would allow an unlimited number of entrepreneurs to offer services in competition with one another limited only by their imagination and the capabilities of the underlying network facilities.

In this context, the policy question of current interest is the extent to which the local access network might be decomposed to stimulate competition in markets for local switching and transport. If there are weak or nonexistent economies of scale and scope in the transport services offered by the local exchange network, then the rationale for barriers to entry is weakened. However, if there are elements of a natural monopoly in the local exchange network, then policies which promote open access to these centralized network resources can be instrumental in promoting competition in spite of the monopolistic network elements. Indeed, the FCC has already begun to consider what open access requirements are necessary in the local exchange network to insure open and equal access to the network in its Open Network Architecture (ONA) policy. Likewise, the Europeans also have their own initiative, called Open Network Provision (ONP), for opening up access to their public networks.

The cornerstone of the ONA policy is the notion of unbundling network components to open access to network resources for the purposes of promoting competition and efficient use of the scarce network resources.[3] Formally, network unbundling refers to the process of reducing the network into separate functional elements, or building blocks. Independent service providers would be given the flexibility to select only those unbundled components which best suit their applications since the network operator cannot bundle the availability of one element to subscription with another. If the price of the unbundled component

[3] An equally important role of ONA is to establish the tariff guidelines for the unbundled offerings to insure that access to the network is on an equal basis.

exceeds what it would cost the service provider to provide this functionality on its own, the service provider has the flexibility to use its own private resources as a substitute for the unbundled component.

Clearly, one could continue almost ad infinitum in this unbundling process, and one of issues raised by an open access policy using network unbundling is the appropriate limit to this process. Network components can be classified into either logical or physical element categories. A logical element is a software defined network feature or capability, such as the number translation performed in a switch to establish a call; a physical element is the physical resource employed in the transmission or switching of the service.[4] Thus, a complete network service, whether it is offered by the network operator or a third party provider, would consist of a unique sequence of logical elements that are implemented by physical hardware elements. But should open access requirements apply to both physical and logical network elements? The FCC has just initiated a *Notice of Inquiry* into future network capabilities and architectures to investigate this question.[5] In particular, the Commission is examining how a modular network architecture could open access to the logical functionalities of the network.

There are several important issues which need to be carefully considered if network unbundling is to be applied as a policy tool to open network access for the purposes of promoting competition.

1) To begin with, what are the fundamental network functionalities from a technical perspective, both physical and logical, that could serve as candidates for unbundling?
2) What is the appropriate framework for measuring the total benefit of an unbundled component? The benefits of open access to enhance the network platform are offset by the costs of the interface itself as well as the potential

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[4]The notion of unbundling physical and logical elements is not original to this paper. For example, Bellcore has described a future network architecture consisting of service and delivery segments, which correspond to the logical and physical elements described above. The goal of the Bellcore architecture is to offer the functionalities of the service segments independent of the capabilities or functions of the delivery segment. This technology independence could offer service providers more flexibility in using the network platform. See *Information Networking Architecture (INA) Framework Overview*. Bellcore Framework Technical Advisory FA-INS-001134, Issue 1, (August, 1990).

[5]See CC Docket 91-346.

loss of economics of scale and scope across the interface. Is a quantitative measure possible to justify whether a network component is to be unbundled?

3) To what extent should public policy mandate further network unbundling than might otherwise arise naturally through network evolution? What should be the criteria for such a requirement?
4) Is there a satisfactory pricing structure in place to support a cost-based schedule of tariffs for the network components?

The focus of this paper is confined to the first issue listed above. Addressing this issue offers useful insight into the other issues noted above by describing the technical context through which the process of network evolution might have to proceed. To accomplish this, the paper examines in a qualitative manner how a local exchange network could be unbundled in light of new technological developments. Obviously, any network element could be unbundled if cost was not an issue. The approach taken in this paper is to investigate the prospects for unbundling network architectures which have been proposed by the LECs. This includes exploring how network elements might be separated using new technologies such as fiber optic transmission systems, digital switches, or intelligent network platforms. By selecting outcomes for analysis which might be "naturally" occurring through the process of network evolution, the paper is implicitly identifying network components that could be unbundled at relatively low cost.[6]

The resulting set of unbundled network components is important because it defines the set of options available to independent service providers. They have the option to offer any one of the unbundled components using their own resources. Thus, the extent to which a future network architecture provides a set of low-cost unbundled service element also defines the flexibility afforded to independent service provider in building their service offering.

[6]The consequence of this assumption is that the analysis will not uncover any unbundled network components which do not arise naturally from the proposed architecture. Of course, the LEC has incentive to modify its network architecture to unbundle a particular component if sufficient demand existed to warrant its inclusion.

To begin, the first section examines how physical unbundling might be achieved as digital optical transmission systems are introduced throughout the public network. Section II examines how logical unbundling might be possible using the advanced intelligent network (AIN) platform model as a guide. The final section synthesizes the results of these discussions and presents some general principles and consequences of unbundling physical and logical network components in this technological environment of the future.[7]

II. Physical Unbundling

This section of the paper examines the prospects for physically unbundling the network transmission and switching technologies which appear likely to be adopted into the network architecture over the next two decades. With regard to transmission technology, the paper focuses upon the increasing use of fiber optic cable in the subscriber loop. With regard to switching and multiplexing, the paper investigates the trend to a digital cell-based technique known as asynchronous transfer mode.

Before proceeding further, however, it would be useful to better clarify how network unbundling might occur with physical components. Basically, unbundling allows for a service provider to offer a service using a combination of LEC provided and private network components. Thus, the first choice of an independent service provider is to provide any network component using its own private resources. If the service provider selects the LEC's unbundled component, it might be presented with two options. First, it could use the LEC elements to form it own dedicated network to deliver a service independent of any other services on the public network service platform. In this case a service might be delivered partially, or entirely, to the customer over unbundled physical elements purchased from the public network operator for the exclusive use of the service provider. Second, unbundled physical components could be applied to deliver a service which is integrated with other network services (although perhaps on a "virtual" basis). For example, the service provider might interconnect to the public network to receive dial tone by

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[7]The scope of this paper is limited to examining the unbundling of the public telephone networks in the subscriber loop. The discussion does not focus directly upon the impact of unbundling on urban networks where fiber-based metropolitan area networks (MANs) are current proliferating.

purchasing unbundled physical elements. Either application for unbundled physical elements may be appropriate depending upon the particular situation.

Unbundling Network Transport Using Fiber Optic Networks

The purpose of a transmission link is to transport information from one location to another with an acceptable quality of service. Three key functional attributes of this link are its capacity, location and quality of service. If network unbundling is a beneficial process, then an unbundled network should somehow enhance one or all of these attributes of the transmission networks. That is, an unbundled transport network would presumably improve at least one of the following criteria: a) access to network capacity; or b) access to intermediate interconnection points along the transmission path.[8] If an unbundled network does improve one or both of these criteria, than one outcome could be to lower the cost of transmission by either allowing more efficient access to bandwidth or the independent provision of the some transport elements. The methodology taken in this paper to use these two criteria to qualitatively evaluate the prospects for unbundling physical transmission elements of the existing copper and proposed fiber-based network architectures. A quantitative assessment of unbundled transmission links is beyond the scope of this study.

The current copper-based network presents limited opportunities for unbundling the transmission components with regard to these two criteria. First, for the transmission distances associated with the subscriber loop, the amount of bandwidth available over twisted wire pair is limited roughly to the ISDN rate of 144 Kbps. Thus, the copper network cannot provide enough bandwidth to carry any broadband services above this rate. Second, the current switched-star architecture runs at least one dedicated twisted pair from a central switching node all the way to each customer without any intermediate locations available to unbundle the transport segment. Beyond the central office, there are generally no nodes present which provide an opportunity for interconnection which would unbundle transmission segments in the subscriber loop. For these reasons, the current network does not appear

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[8] Another criterion not listed is the improvement an unbundled network could achieve in allowing service provider more flexibility in specifying the reliability or grade of service of the transmission path. This capability depends more upon the network operating system and transport protocols then the physical transmission links, and therefore is not a major factor in the discussion of this section.

particularly well suited for physical unbundling due both to the limited capacity of the copper pairs and the switched-star architecture.

While the current network may not be an attractive prospect for unbundling physical transmission components, fiber networks would appear to offer more opportunities. Figure 1 shows the local access network architecture that could be used by telephone companies to deploy fiber in the future. The figure indicates the customary central switching node in addition to nodes at a remote site and the curb-side pedestal. These network nodes serve as network *flexibility points* where, depending upon the architecture, signals can be switched or multiplexed to the appropriate destination. The switched-star network architecture, which serves the great majority of telephone lines in the U.S., only includes one network flexibility point at the central office switching node. A small percentage of lines (less than 7% in 1989 according to (Vanston, Lenz, et al., 1989)) are served by digital loop carrier (DLC) systems which incorporate a second flexibility point into the architecture at the remote node. The third flexibility point at the pedestal has been proposed for fiber-to-the-curb systems in the future. The architecture of Figure 1 also includes a central node for network intelligence, where the functionalities of the proposed advanced intelligent network are to be located.

How do fiber networks rate according to the unbundling criteria? With regard to the first criterion, the fiber cable itself will offer no constraints in the amount of bandwidth available for unbundling. Indeed, the reason LECs choose to install fiber is due to the enormous increase in bandwidth and lower transmission losses it offers in comparison to metallic transmission lines. One fiber has the capability to transmit information at a data rate several order of magnitude higher what a copper wire pair is capable of carrying.[9] The bandwidth limitations of a fiber system are not due to the intrinsic properties of the fiber, but the capacity limitations of the switching, multiplexing, and transmission equipment connected to each end of the fiber.

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[9]While comparing fiber and copper cable according to the total data rate it can carry demonstrates the large differential in bandwidth capability between the two, a more accurate description of the capacity of fiber in the future is likely to be the number of wavelengths that can be transmitted over a single fiber. Instead of increasing the data rate of the transmission link as demand warrants, the capacity of a fiber link could be expanded by additional new wavelengths.

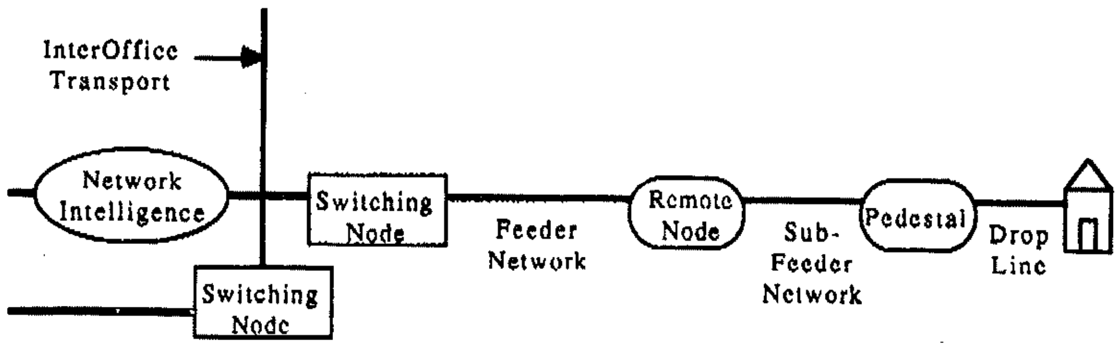

Figure 1: Local Access Network Architecture

In sum, because of the tremendous bandwidth potential of fiber optic cable, there is virtually unlimited bandwidth available for unbundling purposes. This simple observation must be accompanied with two important caveats. First, the abundant bandwidth that is theoretically available for unbundling on a fiber cable is not likely to accessible for some time until the capabilities of the network equipment improve enough to utilize it. Second, this bandwidth is only available over the fiber links of a network. Because the adoption of a new technology is likely to be a gradual process, fiber will first be deployed in hybrid network architectures which continue to utilize existing portions of the copper network. As a result, until fiber is deployed all the way to the customer premises, portions of the network will continue to present the same limitations on physical unbundling as the current network.

While fiber systems may not present any intrinsic bandwidth limitations to unbundling system bandwidth, the second important criterion is the degree to which different transmission segments of the fiber network can be unbundled. To answer this question requires an understanding of the transmission elements of the local access network architecture, and the strategy of network evolution for incorporating fiber into the network.

The trend in the transmission technology of the telephone network has been the deployment of fiber progressively closer to the customer premises (Reed, 1991). Fiber was first used in long distance and interoffice portions of the telephone network where the large volume of traffic justified the additional cost and bandwidth of fiber links.[10] As the costs of optical systems have fallen, fiber may now be deployed in the feeder portion for DLC systems when the length of the feeder network is long enough to justify its higher costs, or the additional flexibility of a digital, optical system is desired to accommodate the needs of more sophisticated business users. As the cost of fiber equipment declines further and more services are added to the network platform, the economics of deploying fiber will favor further extension of fiber closer to the end user.

The point at which the fiber portion of the network ends and the optical signal is converted to an electrical signal is called the optical network interface (ONI). As noted above, because the costs of fiber systems are declining, the location of the ONI has been gradually sliding closer to the end user as optical transmission technologies mature. Where the ONI is located at any particular time in the transition to a fiber network will depend upon the network architecture of the telephone network. For the vast majority of lines, the ONI is currently located at the switching node; for those lines served by optical DLC systems, it is located at the remote node. Future systems deploying a fiber-to-the-curb architecture would place the ONI at the pedestal, while a fiber-to-the-home architecture moves the ONI all the way to the end user's premises.

The significance of the ONI with regard to the unbundling of network components is that it represents a natural flexibility point--or low-cost interface point--for the system where the local access transport segment can be broken into unbundled elements. As will be illustrated below, as the ONI moves progressively closer to the end user, the network platform will evolve to different network architectures, and new, or lost, opportunities for network unbundling. Recall from the previous discussion that the current network, with the ONI essentially located at the switching node, was not an attractive architecture for unbundling network transport. But this situation will change as fiber is incorporated into the network through the gradual progress of network evolution.

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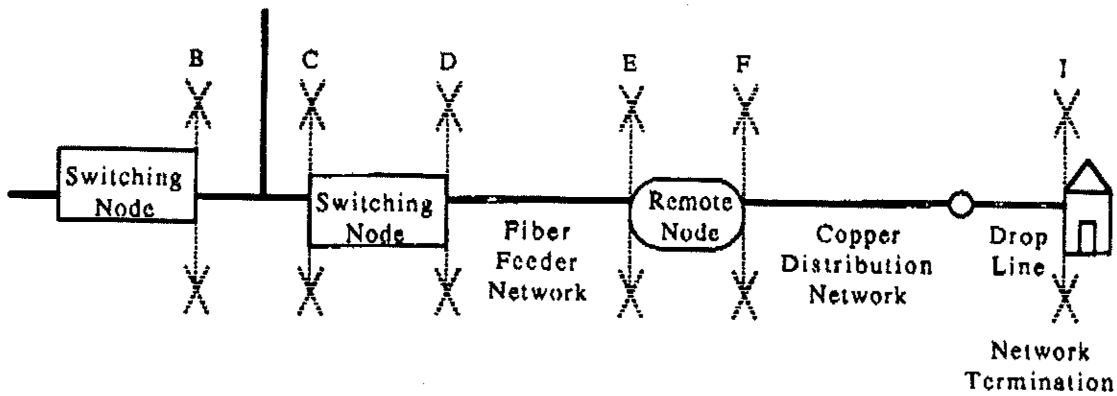
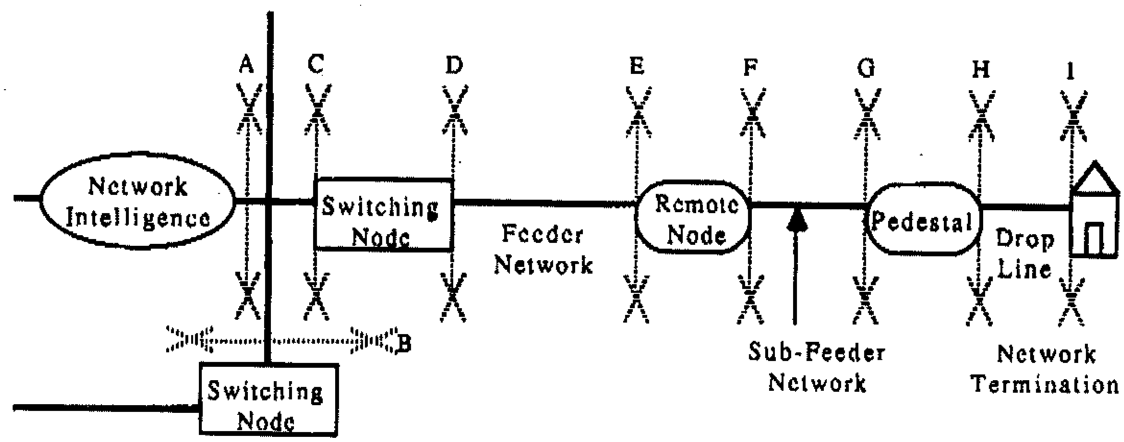
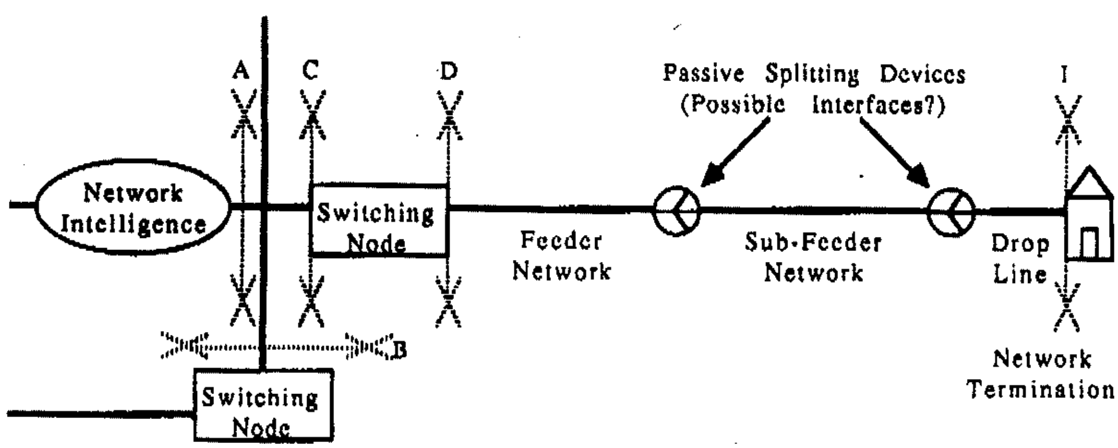
[10]One study estimated that in 1989, 84 percent of interoffice voice circuits in use were digital, with 41 percent of the circuits being carried by fiber links. The same study forecasted that the interoffice network will be essentially all digital by 1995, and all fiber by 1999. See (Vanston, 1989).



(a) Near-Term Network Architecture



(b) Fiber-to-the-Curb Network Architecture



(c) Long-Term Passive Optical Network Architecture

Figure 2: Evolution of Network Architectures Using Fiber

Figure 2 illustrates three examples of how the location of the ONI can influence the extent to which portions of the local access transport can be unbundled at minimal cost. The first case considered in Figure 2(a) could be regarded as a near-term network architecture using an optical DLC system without an intelligent network service platform. The figure illustrates the possible network interfaces that could be available to unbundle local access transport. For example, using this architecture transport could be unbundled between interfaces B and C for interoffice transport, interfaces D and E for feeder transport, and F and I for transport in the distribution network. Thus, unbundling the local access portion of this architecture could result in two transport elements: a fiber-based feeder portion and a copper-based distribution portion of the network.

Figure 2(b) illustrates a more futuristic network architecture with a fiber-to-the-curb system and an intelligent network platform.[11] The fiber-to-the-curb system places another flexibility point into the network architecture which provides another level of unbundling local access transport. Under this architecture, transport could be unbundled between interfaces A and B for transport of network signalling, between B and C for interoffice transport, between D and E for feeder transport, between F and G for sub-feeder transport, and between H and I for the drop. As will be apparent with the next step in network evolution, this architecture could be viewed as a high water mark for unbundling transport because of all the flexibility points in the architecture.

With the gradual deployment of fiber toward the end user, there is an accompanying trend to passive optical networks (PONs) which. utilize some of the unique transport properties of optical signals. A PON places only passive components at the network flexibility points. Instead of electronic multiplexing and switching electronics at a flexibility point, a PON deploys optical couplers and splitters which take advantage of optical properties of the transmission signal to rout signals without the need for electronic equipment. PON architectures have fibers that fan out from the switching node via passive optical splitters similar to a tree and branch topology. In this way, PON networks can reduce costs by achieving a high degree of shared

[11] This architecture is similar to what has been proposed by Bellcore as a the next step for using fiber in the local access network. See Bellcore Technical Advisory. *Generic Requirements and Objectives for Fiber in the Loop Systems.* Bellcore, TA-NWT-000909, (December, 1990).

plant throughout the network. The lowest branch in the distribution tree connects to the individual homes.

Figure 2(c) is an example of a PON architecture where the remote node and pedestal flexibility points consist of passive optical components. As can be seen in the figure, if the passive nodes cannot offer access or interconnection services, then there are no low-cost interfaces in the local access portion of a PON. Passive nodes could provide interfaces like those described in Figure 2(b) if it is possible to inject or receive an optical signal using the passive components. In a PON system, the optical power budget determines the number of successive splitting nodes in the network. Larger bandwidth signals have smaller power budgets, so broadband services cannot be split as often as narrowband services. Thus, where a signal can be injected or removed from the network will depend upon the power budget as dictated by the PON architecture.[12]

The important point is that a different set of requirements arise when accessing a fully optical network as opposed to the current metallic or proposed hybrid networks. The bandwidth limitations of the metallic transmission media no longer exist, but they are replaced by concerns for the power budget and costs imposed by the network design. In addition to the network topology, the margin of the power budget is set by the characteristics of the optoelectronics. Thus, expected advances in optoelectronics will have the effect of increasing the power budget while lowering costs, and hence the flexibility of the network to accommodate unbundling of network capacity. Note, however, that one of the principal benefits of the PON approach is to eliminate 'active' nodes in the network to avoid the high costs of providing power to these locations. Receiving or injecting an optical signal would require electronic equipment with power needs that might not be otherwise supported by the underlying network.

Finally, with the continuing rapid advance in optical transmission technologies, an unresolved issue of great interest remains to be the fiber-based network architecture most suited for the subscriber loop. While the strategy of network evolution

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[12]Of course the power budget could be adjusted (increased) at a cost. However, such a cost could be very high in the PON architecture if it required a new photodetector in every household ONI device.

presented above is representative of many forecasts, there have been a number of alternative approaches proposed for installing fiber in the subscriber loop which will vary depending upon the services carried by the network. This discussion has clearly demonstrate how the opportunities, and costs, for network unbundling can vary with network architectures. Thus, one would clearly expect both new and lost opportunities for network unbundling with each proposal.

Unbundling Digital Transfer Modes

The transfer modes of the network define the switching and multiplexing techniques that characterize the transmission structure of the system. The current network uses synchronous transfer mode (STM) techniques for switching and multiplexing digital signals.[13] Future networks will continue to assume a synchronous transmission hierarchy at the physical layer using the synchronous optical network (SONET) standards defined by the International Consultative Committee for Telephone and Telegraph (CCITT) standards group. The SONET standard describes a family of broadband digital transport signals operating roughly at multiples of 50 Mbps. As a result, wherever SONET equipment is used, the standard interfaces at the central office, remote nodes, or subscriber premises will be multiples of these rates in the telephone network.

Above the lower layers of the network architecture, however, the network will probably not continue to be entirely synchronous, but will instead employ some asynchronous transfer mode (ATM) techniques. ATM uses packet switching and routing techniques to carry information signals, independent of their bandwidth, over one high speed switching fabric. For example, a data signal would be separated into fixed length *cells*, each consisting of a header for routing and an information field for data. These cells then combine with the cells of other signals for transmission to a common destination. In time division multiplexing (TDM) the *position* of the data channel in time is important, in ATM the *label* of the channel distinguishes the channels from each other. Current thinking calls for the cells to fit into the payload of the SONET frame structure for transmission. In fact, ATM promises to blur the distinction between switching and multiplexing on the cell level

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[13]Transmitting information in digital form requires a timing reference to control the transmission. Without a clock synchronizing the entire digital network, the system would not be unable to determine when to sample a signal to receive the transmitted information.

since an ATM switch is likely to integrate these two functionalities together. However, there will continue to be SONET multiplexers which combine and separate SONET signals carrying ATM cells.

What distinguishes ATM from a synchronous approach is that subscribers have the ability to customize their use of the bandwidth without being constrained to the channel data rates of the network transmission scheme. This characteristic, often touted as "bandwidth on-demand," allows variable data rate services to be easily combined by simply inserting the ATM cells into the SONET payload. In contrast, combining variable data rates using TDM can be difficult due to the different timing requirements of each signal.

With regard to the question of unbundling, the most important component of the transfer mode is the switching element (the multiplexing elements are unbundled by their very nature). An important trend in the current switching system is to move much of the network intelligence out of the switching software onto an intelligent network platform (see Section III for more on the logical functions of the intelligent network). Consequently, once the intelligent network platform has been implemented, much of the logical network elements will be separated from the physical switching element. The physical component of a current digital switch would therefore constitute access of 64 Kbps data signal (DS1) access to the network switch.

ATM techniques could improved the prospects for unbundling the physical switching elements of the network. The attribute of the ATM switch which could facilitate more is the bandwidth flexibility it affords. Because each information signal is formatted into cells, the switching element becomes more efficient. Today, a switched element provides the capacity to switch a DS1 signal whether or not the user has the need for this much bandwidth. With ATM, the switching element resources can be much more efficiently matched to the bandwidth requirements of the user. By reducing the increment of access to switching resources, ATM can make more convenient increments of switching elements available on an unbundled basis. Access to the ATM switch will be specified according to the maximum data rate forecasted for the particular access arrangement, instead of specifying the number of DS1 circuits required as is the case today.

III. Logical Unbundling

In addition to the physical components discussed above, logical network features might also be included in the network unbundling process. For example, one of the questions raised by the Notice of Inquiry initiated by the FCC into future network architectures is the extent to which a network switch could be programmed by an independent service provider as part of its service application software. In the same way that the personal computer has served as a platform to spawn a new industry of application software developers offering computer services, could the public network play a similar role as the public platform that stimulates an new applications software industry for innovative network-based services? An essential characteristic of the public network platform, if it is indeed capable of assuming such a role, will be the extent to which the logical elements of functionalities of the network can be offered on an unbundled basis.

This section investigates what opportunities may be available for unbundling the logical elements of the network in light of the new technologies being developed for the operating system of the telephone network. Like the applications software market for personal computers, the future success of service provider on an open network platform is certain to hinge upon the distinctive features implemented by the service software. In this competitive environment, all service providers will place a high premium on being able to customize their services using unbundled logical elements combined with their own proprietary software functionalities.

There will be the most need for those logical features which can most efficiently offered by a centralized network resource. Otherwise, the logical function could be implemented through private software on a decentralized basis. Finding which logical features can indeed be offered best through a public network platform requires an analysis of the costs of unbundling versus the benefits of the unbundled network. Such an analysis is beyond the scope of the current discussion. As was the case when examining the physical unbundling of network components, the approach taken in this paper is to look at the proposed direction of network evolution, and examine how this network architecture might offer inherently low-cost unbundling of logical components. Accordingly, the discussion begins with the capabilities of the advanced intelligent network (AIN), which telephone companies are proposing to implement within the next decade.

The Advanced Intelligent Network

Telephone companies have been developing the AIN to provide themselves with the capability to rapidly create new services or customize current services. Today's switching system software contains most of the network intelligence. The design of this software is such that the applications software for particular functionality is fully enmeshed into the systems software. Consequently, whenever a new feature or any other software modification is necessary, the entire switching system software must be tested by the switch manufacturer. Eventually, the repeated addition of features and modifications degrade the original switch architecture to the point where it becomes increasingly difficult to respond in a timely manner to the dynamic needs of the customers.

The limitations of this architecture became particularly apparent with the deployment of intelligent services with functional elements which require a centralized network architecture. For example, the first network-wide intelligent service available over the public network was the 800 number service (Sable and Kettler, 1991). The network intelligence for this service resided in the switching software of the toll exchanges. Yet as the need increased for more intelligence in the service, maintaining the intelligence in a distributed architecture (i.e. in every toll exchange) became increasingly difficult and impractical. Telephone companies now want to develop a network architecture which enables more efficient and rapid network management of service creation, provision, and deployment.

The AIN attempts to satisfy these criteria by defining a network architecture where the logical features are distributed from the switching nodes to intelligent network nodes (see Figure 1). By moving this intelligence away from the switching node, the telephone company is able to concentrate logical functions at more centralized intelligence nodes instead of the more numerous local exchanges--assuming such a concentration is desirable from a cost standpoint (Wyatt, Barshefsky, et al., 1991). For example, a new sequence of logical instructions, called the *service logic*, could be installed at the intelligent node without requiring software upgrades in all the switching systems. Yet the degree of centralization that might be desirable for any particular service will vary, depending on service characteristics and the type of network.

The important characteristic of AIN is that is offers the flexibility to configure the network according the characteristics of the service. The modular architecture is capable of adding adjunct processors, such as voice processing equipment, data communication gateways, and alternative switching systems, to the platform, without modifying the application interfaces (Lemay, Chorley, et al., 1990; Wyatt, Barshefsky, et al., 1991). These adjuncts, which consist of service logic and local customer data, have capabilities similar to centralized intelligence nodes but are situated at the local level (i.e. on the local exchanges). They are an attractive option if the particular application requires local, transaction-intensive services (e.g. Centrex services) as opposed to network routing services, which can be supported at the central intelligence nodes. The functionalities of the adjuncts, however, are limited by the capabilities of the application interface to the switch.

At a more fundamental level, the difference in a architecture with the network intelligence unbundled from the switch is how the switching node processes each network connection request. When a call is placed on the current network, the switch executes the service logic according to the call model embedded in the switching software. The call model defines what steps, or check points, are executed during the call. AIN specifies a new call processing model with a new set of steps, or check points which depend upon external processors to operate. When a call is placed, the switch executes the call model and launches queries to the external processors of the intelligent network depending upon the instructions. By designing the call model in this way, the switching functions are separated--or unbundled--from the application functions residing in the intelligent nodes.

The basic architecture of AIN is to take these application functions and break them down into a collection of function specific components which interact using a standard communication protocol (Arnold and Brown, 1990). The sequence of these unbundled logical elements, and the specific parameters within each logical element, distinguish one application from another.[14] Interestingly, the crucial technology

[14] Bellcore offers one example which demonstrates how different services can be built by linking basic features in different orders. A 800 service with interactive

necessary to implement this architecture is the software which can support network services in this environment of unbundled logical components.[15] Ultimately, the objective of the AIN is to allow modifications to application software without having to access or alter the operating system of the switch. This is the crucial characteristic of an open architecture. For if any service provider is going to be able to develop to operate over the network, it is imperative that the application software will operate on top of the operating system of the switch without any modification. The ability for the network platform to accommodate new applications in this fashion is therefore an essential requirement of an open architecture featuring unbundled logical elements. The tool in AIN to allow new services to be created is called the service creation environment, the details of which are the subject of the next section.

The Service Creation Environment

The objective of the AIN service creation environment is to provide the necessary platform to create, debug, and test new services. As with any computer, any new software (or service logic) must undergo extensive debugging and verification before it can be used to reduce the probability that it will have an adverse effect on the overall operation of the network. The service creation environment would test whether any of the new features of the service would interact with existing services to cause the system to crash. When a new feature is introduced, there are three feature interaction categories which must be managed to insure operability (Russo, Abdel-Moneim, et al., 1991): 1) interactions between the new locally based feature with other locally based features; 2) interactions of a local based feature with remotely based features (either in a adjunct or intelligence node); and 3) interactions of the remotely based new feature with other remotely based features.

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dialing requires 4 features, which in sequential order are: number translation, play announcement, collect digits, route call. A 976 number with screening (using a personal identification number) also requires 4 features: play announcement, collect digits, then either route call or play announcement. Example taken from a presentation to the FCC by Elizabeth Ireland, "Advanced Intelligent Network: An Overview," September 19, 1991.

[15]The programming language used to connect each building block is likely to be a object-oriented language which treats the system as a network of interconnected functional components or objects. In contrast, the traditional software approach has been to represent the system as a set of interacting functional activities.

The most interesting question, of course, is the extent to which independent service providers could use this tool to create new software applications of their own on the network service platform. The expense of service verification, along with associated security issues, could preclude extending this capability directly to service subscribers (Morgan, Cosky, et al., 1991). On the other hand, it may be possible to design the system software to protect itself from network reliability and security threats while still offering open access to some logical elements. At this point in time, it remains unclear concerning the magnitude of the tradeoff between the benefits of open logical access and the costs of an open, modular architecture. In a special issue on the intelligent network it manufactures, AT&T states that services residing in the adjuncts and intelligent network nodes could be created "either by vendors, service providers, or enhanced service providers" (Sable and Kettler, 1991, p.8).

The usual method to control network reliability and security is to design the operating system into logical layers. A layered architecture can isolate the service logic executing in a higher layer from lower layers and thus reduce the chances that it will impact the operations of the lower levels. In the context of local exchange network, a layered software structure would attempt to isolate the switching system core, which includes basic call control functions, from the application features. The basic system functions necessary to most of the application features are consolidated in the lowest level. The AIN architecture can be described in three layers (Lemay, Chorley, et al., 1990; Morgan, Cosky, et al., 1991). If a design can be achieved which allows each layer to operate independently, and access to lower levels can be restricted according to access privileges, then the concerns for network reliability and security might possibly be met. In this scenario, the switch manufacturer could supply the platform software for the bottom layer, while the service providers design and operate service scripts on the top two layers upper layers.

This description of the AIN architecture is useful in portraying the possibilities that the future may hold for unbundling logical elements to foster competition and a more efficient use of scarce network resources.

- As customers of the switch vendors, telephone companies are seeking the means to unbundle all the functionalities of the service platform from the switch manufacturers to obtain the flexibility they desire to create new services.

- Thus, for policy makers, the important observation is that the LECs are designing this network using many of the same principles that they have been applied in ONA to open network access and give independent service providers more latitude to compete through the flexibility of unbundled network components.
- Trade-off between the benefits of modular logical architecture versus the costs of unbundling and more costly mechanisms for network reliability and security.

IV. Logical and Physical Concepts for Network Modularity

Fundamental issue is the extent to which government policy should mandate network unbundling. Framework for unbundling needs to consider the following criteria:

- Technical feasibility
- Economics of unbundling (economics of scale and scope of network components)
- Benefits of unbundling (demand and utility of component)

This paper has shown how the costs of unbundling will vary with the network architecture. Need to weigh constraints on network design imposed by regulating different degrees of unbundling.

Results of this paper:

Physical unbundling:

- **Fiber cable offers** virtually unlimited bandwidth for unbundling, although **access to** bandwidth is constrained by the limitations of the switching, **multiplexing,** and transmission equipment on each end of the fiber.
- As the ONI moves closer to the customer premises through the normal process of network evolution, it represents an opportunity for low-cost interfaces to the local access network.
- The number of unbundled transport elements (or interconnection points) in the local access network will vary with network architecture. A fiber-to-the-curb network architecture appear to offer the most low-cost unbundling opportunities, while a PON might decrease the opportunities for

interconnection. Also, mandating interconnection points could hinder the most efficient strategy of network evolution (interface basically eliminates any economies of scope across the unbundled network elements).

- Implementation of an ATM network will further unbundle switching by offering more efficient access to the switching function.

Logical Unbundling:

- Telephone companies' desire for flexibility through the AIN is similar to the flexibility that regulators want to provide independent service providers through the process of network unbundling.
- Trend to modular architectures is actually unbundling logical functionalities away from the physical switching element.
- Tradeoff in network reliability to open access to logical layers. Need for layered operating system

Consequences of increased competitive environment for local switching and transport on the process of unbundling:

- Telephone companies are well positioned in this market with their existing monopoly on telephone transport.
- If a number of competing transport suppliers, such as cable television operators, PCS suppliers, or alternative local access suppliers, emerge to compete for share of this market, the bottleneck power of the telephone companies will be limited.
- If a competitive transport market can develop, the outcome might be analogous to the computer market where customers actively seek out the lowest cost suppliers because there is no significant differentiation in the underlying functionality of the hardware.[16]
- A significant degree of competition could obviate the need for any formal public policies requiring network unbundling. Telephone companies, like any other transport provider, would have to respond to consumer demand to

[16]For example, some believe the reason that the PC has become a commodity because Intel Corp. and Microsoft Inc. effectively have monopolies for microprocessors and operating system software and sell their technologies to practically all comers. As a result, there is little differentiation in the functionality of the computer hardware beyond the intrinsic speed of the devices. See *The Wall Street Journal*, Thursday, September 5, 1991. p A1.

remain in the market. Even if they had their own services, they would be forced to offer the most flexible network platform to service providers, or face the consequences of losing customers to more responsive transport service providers. For example, even though Apple Computer Inc. markets its own application software for the Macintosh computer through its Claris software division, other application software companies have successively developed Macintosh software. Because the Macintosh computer does not dominate the personal computer market, the need to compete offers strong incentives to Apple to develop an open platform for application software. The same incentives will work on the telephone companies if they do not have a monopoly in transport.

Regarding the increased concerns for network security and reliability due to logical unbundling:

- There can be no denying that an open network increases the risks to intrusions, system failures, and potential privacy breaches to those predisposed to electronic vandalism.
- In addition, the potential for thousands of applications operating on the platform increases the chances of a system failure due to incompatible software instructions. Because the network is a shared resource, the troubles of one application can send shock waves through the entire network.
- Nevertheless, whether out of public policy or competition, a new level of openness will have to be incorporated into the network that is capable of balancing the benefits of an open architecture with network security and reliability requirements.
- Simply stated, the concern for network security should not preclude the possibility of an open architecture. One could imagine designing a network platform with a layered operating system where successively more verification is necessary to enter a lower level of the system. By designing the platform such that applications are not integrated with operating system, network reliability can be maintained. Designing reliable open networks represents a engineering challenge.
- Possibility that access by independent service providers to logical functionalities could be mediated by the LEC software and/or hardware.

Other relevant issues to unbundling which need to be considered (but not covered in this paper):

- Pricing unbundled elements.
- Time periods for installation, maintenance, and repair must be equivalent.
- Strategy of network evolution must be available early enough for competitors to plan accordingly.
- Colocation issue (equipment compatibility--equipment can be certified by Bellcore and national safety laboratories)

Policies for ONI are terribly important because of the implications for network design, and the long term strategies of network evolution for both LECs and independent service providers. Any policy decisions made now regarding open network architectures will materially affect the network design. If a strategy of unbundling network elements is pursued, policy makers will necessarily be operating along a fine line for how this policy can be implemented and how much responsibility will be retained by the LECs to design and implement their own strategies of network evolution.

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