Communications Networks

A Morphological and Taxonomical Analysis

by Terrence P. McGarty Ph.D.

Columbia Institute for Tele-Information
Graduate School of Business
809 Uris Hall
New York, New York 10027
(212) 854 4222

Communications Networks

A Morphological and Taxonomical Analysis

Terrence P. McGarty Ph.D.

NYNEX Corporation

White Plains, NY

October 25, 1991

Private Networks and Public Objectives

Columbia University

New York, NY

NOTE: The author is an employee of NYNEX Corporation, however, the ideas in this paper are those of the author alone and do not represent the opinions of NYNEX or any of its subsidiaries. The concepts in this paper are based upon the work done by the author while on the faculty of MIT, visiting as a Lecturer in the academic year 1989-1990.

Abstract

Network structures are composed of a set of common elements that can be used to classify existing network architectures. This structure provides a basis for a taxonomy of networks. The taxonomy is based upon a description of networks in terms of four fundamental elements; transport, interconnect, interface and control. The paper allows for the classification and characterization of any network in terms of these elements. In addition, this taxonomical approach allows for the investigation of new network topologies as well as the evolutionary lineage of networks.

Contents

1.0 Introduction

Networks have been evolving for over the past one hundred years. In that evolutionary period there has been a change from a highly centralized architecture dedicated to voice transmission by a single company to networks that are local and are the providers of low cost data interconnection.

This paper develops the concepts of network taxonomies. Specifically we develop the concepts of the underlying structure of networks, the delineation and description of the elements and a characterization of those elements. In so doing we then provide a basis for the development of a characterization of networks along a consistent set of lines. The approach taken in this paper follows the binary type classification originated by Linneaus in the eighteenth century as applied to plants and animals. The botanical approach has led to the use of various schema for the identification of many plant species. The same objective is considered herein.

In this paper we address several key issues and build a framework for the development of a telecommunications morphology and taxonomy. Specifically our approach is as follows:

(i) We first develop the concept of an architecture. An architecture, as we show is the concatenation of a set of system elements, a set of available technology and finally a world view. The latter often reflects strongly on all of the other elements.

(ii) We add to the concept of an architecture, that of an infrastructure, which is key to the deconstructive efforts necessary to understand and construct a morphology. We all look at networks as a holistic entity, as an infrastructure, and it is argued that only through the deconstruction of this infrastructure can we truly understand the underlying morphological structures.

(iii) The morphological elements are developed in detail. The development is based upon the techniques developed over the past two hundred years in plant and animal taxonomy. If we focus on plants alone, the need exists to separate the plants at the highest level, and to do so with the grossest characteristics. Similar sets of characteristics or morphological elements are developed in this effort.

(iv) Taxonomy builds on morphology. With a morphology we can describe, uniquely, any network. Then using this set of unique descriptors, the taxonomical approach then attempts to differentiate them into smaller and smaller classes. The clustering into classes or taxa is the task of taxonomy. In this paper, we shall begin the process of proposing a taxonomy, but this is but a beginning.

(v) Finally, we present the applications of our taxonomical approach to several current network scenarios, such as the Internet, NREN, Broadband Fiber Communications and several other specific examples. The intent is to demonstrate the developed methodology and to show that the taxonomical approach leads to an ability to look back in an evolutionary perspective as ell as to look forward and determine the evolutionary paths open to network designers.

This approach to network analysis is necessary in light of the expanding types of networks and the need by regulators, policy makers, and economists to better understand the dimensions that they are interacting with. Specifically, having a morphology allows for less ambiguity on definition and having a taxonomy allows for a more rigorous means to consider commonalities.

2.0 Architectures

An architecture has been defined elsewhere by McGarty as the conceptual embodiment of a physically realizable network concept defined in terms of its essential elements, bounded by the available technology, based upon the currently accepted schema or world view. Thus the three essential parts of an architecture are the elements, the technology and the world view. In this paper we will focus on the characterization of the elements, alluding only slightly to the technological achievability and to the underlying world view.

The concept of a telecommunications architecture has been a cornerstone in the development of new telecommunications systems. However, the structural elements of these architectures have not played a role in the development of policies. In this section we will develop the concept of an architecture as a means to understand the network as both a market and regulatory entity, and will provide a new set of perspectives for viewing the network in terms of a new paradigms and world views.

An architecture, first, requires that the underlying system be treated in terms of a set of commonly understood elements and that these elements have a clearly demarcated set of functions and interfaces that allow for the combining of the basic set of elements. The way the elements then can be combined, reflected against the ultimate types of services provided, determine the architecture. We show this concept in Figure 1.

An architecture, secondly, is driven by three factors; the elements that make up the architecture, the current set of available technologies and the existing world view. Technology places bounds on what is achievable, however those bounds are typically well beyond the limits that are self-imposed by the designer or architect in their view of the user in their world. This concept of architecture and the use of design elements is critical in understanding the paradigms used in the structure of information systems (See Winograd and Flores, pp 34-50, especially their discussion of Heidegger and Throwness in terms of design). World view is the more powerful driver in architecture (See Kuhn, pp 72-85). We argue in this paper that it is essential to develop a philosophical perspective and understanding of how to view networks. We argue with Winograd and Flores, and in turn with Heidegger, that we must be thrown into the network, to understand the needs of the users, and to understand the structure of the paradigms that are used to construct the world view.

To better understand the importance of an architecture we develop the concept of the historicity of architectures based upon the work of Kuhn and ten that of McLuhan. Kuhn begins his thesis of how scientific revolutions occur by the introduction of the concept of paradigms. He defines these as (see Kuhn p. 175);

> "...the term paradigm is used in two different senses. On the one hand, it stands for the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community. On the other, it denotes one sort of element in that constellation, the concrete puzzle-solutions which, employed as models or examples, can replace explicit rules as a basis for the remaining puzzles of normal science, The first sense of the term, call it sociological, ..., "

The concept of a paradigm is in essence the collection of current experiments or examples that clearly demonstrate the view that either leads to a world view or confirms the current broader world view.

New paradigms result from new technologies that are embodied in new examples. New technologies allow for the placing of the elements together in new ways. Kuhn, then goes on to demonstrate that the world view, that is how we view ourselves and our environment is based upon the our acceptance of these paradigms, as either collections of techniques and technologies or as collections of embodiments of these techniques and technologies in "examples". We then end to accept this as the way things are and should be. Then Kuhn argues, as the technologies change, changes in the paradigms do not occur in a continuous fashion but almost in quantum leaps. The new paradigms build and congeal until they burst forth with new world views. It is this model that we ague applies to the evolution of broadband. It is this philosophical view, almost Hegelian in form, that is essential in understanding the underlying and formative changes in paradigms that will change our world view.

As a second perspective of the impact of technology as a dominant driver, we can refer to McLuhan and his development of the concept of media. Drucker has referred to the presentation of McLuhan's doctoral thesis and McLuhan is quoted as follows (See Drucker, p. 250):

> "Movable type, rather then Petrarch, Copernicus, or Columbus was the creator of the modern world view.. "Did I hear you right," asked one of the professors as McLuhan had finished reading, "that you think printing influenced the course s the universities taught and the role of the university, altogether?" "No, sir, " said McLuhan, "it did not influence; printing determined both, indeed, printing determined henceforth what was going to be considered knowledge."

This concept later evolved into the medium being the message. In our context it is the fact that both Kuhn and McLuhan recognized, albeit in differing fields and in differing ways, that fundamental changes in technology and technique, call it paradigm or the medium, will change the world view, also the message. It is the importance of understanding the change in the technology, its function and evaluate the possible change that this will have in the world view.

Thus, architecture is the combination of three parts; the common elements, the underlying technology and the world view. In Figure 2, we depict the conceptualization of architecture as the amalgam of these three elements. We shall develop this construct more fully as we proceed.

The concept of a world view is an overlying concept that goes to the heart of the arguments made in this paper. To better understand what it implies, we further examine several common views and analyze the implications of each. If we view our world as hierarchical, then the network may very well reflect that view. If we further add to that view a bias towards voice communications, these two element will be reflected in all that we do. The very observations that we make about our environment and the needs of the users will be reflected against that view. As an external observer, we at best can deconstruct the view and using the abilities of the hermenutic observer, determine the intent of the builder of the networks. (See Gadamer's interpretation as discussed by Winograd and Flores, pp 27-30. Also see the historical context of the hermenutic approach in the sciences as discussed by Greene in Depew and Weber, pp 9-10).

Take, for example, the use of twisted pair, pairs of copper wire, to transport telephone traffic. For years it was implicitly assumed that this transport medium was limited to 4,000 Hz of bandwidth, that necessary for an adequate quality voice signal. Specifically the world view was that of a voice network that was to be used for voice traffic only. Ten years ago, this was a true limitation, since the transmission was forcefully limited to 4,000 Hz by inductive loads or coils on the telephone lines, assuring that you could do no more than the 4,000 Hz of bandwidth. Then, there was a short period in the mid 1980s, when Local Area network manufacturers found that you could transmit 1.544 Mbps over the common twisted pair, and that data was viable in what was assumed to be a voice only medium. What had been almost religiously believed to be a limit was found to be untrue. Then with the introduction of digital switches, the old "inductive loads" were returned with the switch now limiting the data to 4 KHz or 64 K samples per second. The world view of a voice only network took hold again, but this time in the context of a data rate limitation, rather than a bandwidth limitation. In the early 90's there is another attempted break out of the world view and to put 100 Mbps on twisted pair, so called FDDI circuits. Again, due to the limitations on the part of the network as a voice dominated system, the world view keeps this high data rate capability on the customer's premise only, and not the network.

We describe this transport world view evolution in Figure 3. Here we indicate the two dimensions of information transport, bandwidth and data rate. The designer of the transport facility may limit the data rate by selection of signaling format or delimit bandwidth by filtering. Twisted pair actually has a bandwidth-datarate profile as shown in Figure 3. It encompasses a large capability of either providing bandwidth or data rates to the user. The two limiting world views are indicated as two solid lines, one at 4,000 Hz and one at 64 Kbps. Both are voice only world views. We can readily see, that with optical fiber superimposed the same issue of architecture dominated by world view may result. In the fiber case, the result may be a segmenting of the architecture along selected data rate lines, again formed by the voice world view.

A paradigm, therefore, is simply the specific example or sets of examples that are at the essence of the current understanding of the specific phenomenon. For example, the discovery of the structure of DNA by Watson and Crick, not just the discovery of DNA itself, led to a new paradigm, or experiment to define nature. The gene and its place in human existence has changed from that day in Cambridge.

The new paradigm sets a change in the world view as we have discussed. It is the world view that sets down the limits and signposts for our understanding and interpreting. Linneaus had developed a taxonomy based upon outward morphology of plants. In contrast, using the DNA methodology of gene mapping, new morphologies develop that are less dependent on the essentialist school and more dependent upon the school of empiricism. The same can be said for a telecommunications taxonomy as we progress.

Thus, **architecture can be defined as the conceptual embodiment of a world view, using the commonly understood set of constructural elements, based upon the available set of technologies.**

For example, Gothic architecture was a reflection of the ultimate salvation in God in the afterlife, in a building having a roof, walls, floors, and windows, and made of stone and glass. Romantic architecture was, in contrast, a celebration of man, using the same elements, but some employing a few more building materials. The impact of the differences in world view are self evident in the embodiments of the architecture. (See the discussions on the impact of world view on architecture in Wolfe. In addition see the cultural or world view impact on the Gothic architectures in Jantzen and in Toy.)

Let us consider a second example of the impact of world view on architecture, specifically the difference between the ISDN architecture and the architecture embodied in Local Area Networks, LANs. ISDN is an architecture consistent with a voice dominated, hierarchical world view of single points of control. LANs are architectures of world views that reflect both end user self empowerment and the environment of a data driven utility.

Figure 4 depicts the LAN embodiment as well as its extension in the CATV architecture of voice communications using a LAN world view. This evolution in thought is critical to understand the impact of world view. The LAN is an embodiment of empowerment of the individual view, developed in the context of the 1960's and 1970's. The LAN concept, originating at such locations as XEROX PARC, was driven by the developers needs to enable and empower the end user with computing capabilities heretofore unavailable. Out of this view came the LAN architecture of a fully distributed system, using a coaxial transport mechanism to do nothing more than provide bandwidth. The transport mechanism is a broad enabler. The actual implementation of the details is done at the users terminal in hardware and software. This is in sharp contrast to ISDN, where the ISDN central switch does the enabling. In ISDN, bandwidth is not provided, rather it is a voice based data rate, 64 Kbps or multiple thereof. Consider this contrast in terms of how cable TV companies provided voice communications in the early 1980's. Both Cox and Warner, using variations on LAN technology, delivered a voice, video, and data service over the coaxial transport medium, by empowering the end users terminal, not by regimenting the transport network, as shown in Figure 4.

Technology also plays a very pivotal role in telecommunications. Alfred Kahn (1971, p 300), indicates that in the pre-divestiture period of the Bell System, the arguments for the needs of both vertical integration and need for monopoly control were based on technology. Specifically, there was a contention made by the Bell System that a single point of control to the network was essential. Also, it was argued that an adequate scale economy was attained only through a single monopoly. Indeed, given the state of technology of that time, the argument may have held. For in point, the loaded copper transmission capabilities allowed only limited transport, namely one voice channel per twisted pair. However, as we shall demonstrate, the underlying technology has provided a dramatic change in the underlying system. Functions now provided by the network, may be more efficiently provided by intelligent Customer Premise Equipment (CPE). The question to be posed is; what is the role of the network, and how do we provide the dimensions of creative freedom to allow these new roles to evolve? To effectively approach this problem, we must first develop a canonical structure of a network.

2.1 Elements

There are four architectural elements in the telecommunications network. These elements are the control functions, the transport function, the interconnect function, and the interface function (See Figure 5 where these are generically depicted). We now provide further detail on these functions. It should be noted that these functions have evolved over the years in content and complexity. We view these elements in the context of a communications network that must support the most advanced current concepts in communications. Specifically, the world view adopted in this paper that lead to an interpretation of this architecture are:

(i) End users desire to have interactions in a real time fashion with images and other high resolution information that must be provided in a fashion that meet both time and resolution requirements (See Barlow).

(ii) The end user devices are extremely intelligent and complex and can operate in a stand alone environment.

(iii) The users desire to operate in a totally distributed fashion. Data bases will be a different locations, users are at different locations and input output devices are also at different locations (See Dertouzos and Moses, and de Sola Pool pp 57-59 for details on these directions).

(iv) The network may provide different levels of service to different users. There is no need to provide universal service of full capability to all end users.

This view of the network will significantly influence how extensively we defined the elements and in turn will impact the combination of those elements in an overall architecture. All of these assumptions on the world view are different then before, in an all voice world. In this paper, we define **a network as an embodiment of an architecture, in all of its elements.**

The architectural elements are control, transport, interconnect and interface. In Figure 5, we depict the overall architecture of the element interrelationship and the elements of the functions of the separate elements. The details on each are described below:

o Control: Control elements in an architecture provide for such functions as management, error detection, restoral, billing, inventory management, and diagnostics. Currently, the voice network provides these functions on a centralized basis, although in the last five years there have evolved network management and control schemas and products that allow for the custom control and management of their own network. Companies such as IBM, AT&T and NYNEX have developed network management systems that move the control from the network to the customer (McGarty, 87). On the sub-network side, companies such as NET, Timeplex, Novell, 3-COM and other have done similar implementations for local area networks, data multiplexers and other elements. Centralized network control is now longer necessary and in fact it may not be the most efficient way to control the network.

What is important, however, is that network control providing the above functions is an essential element for either a public or private network. Thus as we consider network evolution, this element or set of function must be included.

Control has now been made to be flexible and movable. The control function is probably the most critical in the changes that have been viewed in the context of an architecture. All buildings need windows, for example, but where one places the windows and what one makes them of can yield a mud adobe or the cathedral at Chartres. The same is true of the control element. In existing networks, the control is centralized, but in newer networks, the control is distributed and empowered to the end users. The users can now reconfigure, add, move, and change their network configuration and capacity

Let us briefly describe how the control function can now be distributed. Consider a large corporate network consisting of computers, LANs, PBXs and smart multiplexers, as well as a backbone fiber transport function. Each of these elements has its own control facility for management and restoral. Each has the capability to reroute traffic from one location to another, and the routing systems are programmed into the system as a whole. On top of these sub element control functions is built another layer of control that views the network as a holistic entity. This form of control has been termed a manager of managers. It monitors all of the sub net elements and takes control if necessary. It is embodied in several independent controllers, each having the capability of taking control from a remote network. This form of organic network control has evolved in recent years and is now common in many corporate networks. In addition, this concept of the organic network was described in detail by Huber in the DOJ report to the U.S. Justice Department during the first Triennial Review of the MFJ (See Huber).

o Transport: The transport element is provided by the underling transport fabric, whether that be twisted pair of copper, fiber optic cable, radio or other means. Transport should not be mixed or confused with other elements of the network. Transport is merely the provision of physical means to move information, in some form such as digital, from one point to another. At most it is expressed in bits per second and at best it is expressed in bandwidth only. Bandwidth as a transport construct is the most enabling. Transport does not encompass the need to change the information or to do any other enhancement to the information.

In the early regulatory cases such as the Above 890 Decisions in the microwave systems that were the precursors to MCI (See Kahn (II p12)), the Bell System argued that the technology of transmission limited the transport to only those companies that had the transport, interconnect and control. MCI on the other hand recognized that the customer was able and willing to differentiate these elements of the architecture and would segment them in a more economically efficient fashion. Specifically, in the early days of MCI, customers in the mid west would select multiple transport paths and would do the control function on their own premises. In addition, the customers were willing to accept lower quality of service for a lower cost of service. The lower quality was reflected by possibly a higher outage time.

It could then be recognized that the horizontal scale economies of all of the network elements, including but not limited to transport, were actually diseconomies of scale in the market. (See Fulhaber for a discussion of a more detailed view of scale diseconomies in terms of the new architectural elements) Fragmentation and segmentation along architecture elements allowed for the growth and efficiency of MCI. The emphasis should also be made on the statement of the FCC Examiner in the MCI case who stated (Kahn II p 134), "MCI is a shoestring operation ... the sites are small and the architecture of the huts is late Sears Roebuck toolshed." It is prescient to note that the examiner used the term architecture for the microwave repeater sites when indeed MCI was changing the architecture of the network. This remark is more than just an embodiment of a metaphor.

In the current network environment, the issue of transport and its enabling capacity has again arose. This has been the case with the introduction of fiber. Fiber may be segmented for the user in terms of data rates or in terms of bandwidth. In the NREN, the three steps are all focused along the lines of increasing data rates, from 1.5 Mbps to 45 Mbps to Gbps. As we have discussed, bandwidth is the more enabling dimension, leaving the choice of data rate and data structure to the end user. This capability is best deployed by using a dark fiber network. Consider the two networks shown in Figure 7. The top network is a standard fiber network with repeater at periodic intervals. In current technology limitations these are necessary because of the losses in fiber transport. However, with the current state of the art technology, fiber can be strung for many tens of miles without such repeaters and still maintain adequate transmission capacity.

Thus the repeaters are not there solely as a result of fiber constraints on transport. They are also there because they enforce the voice regime of the voice based world view. Namely, the repeaters do not repeat data rates, they also repeat framing sequences based on 64 Kbps voice frames. Thus any work station must use 64 Kbps as the underlying data fabric. As an extreme example, NREN in its Phase 2 will provide 45 Mbps to the users. Regrettably, there is no 45 Mbps modem. That is, direct access to 45 Mbps is not achievable. It must be sub multiplexed to the equivalent of voice grade digital circuits. Thus the world view is pervasive in this design. The same is true as SONET protocols are used in upgrades to broadband ISDN, especially over an ATM switch (See Fleming for a discussion of broadband switching and the voice paradigm).

In contrast, dark fiber is the provisioning of an optical fiber to be used as the end user sees fit. It is the world view analog of the LAN. The LAN provides co-axial bandwidth of several hundred MHz whereas the fiber provides the bandwidth of GHz to TeraHz.

o Interconnect: The interconnect element of the architecture describes how the different users are connected to one another or to any of the resources connected to the network and is synonymous with switching. Interconnection assumes that there is an addressing scheme, a management scheme for the addresses, and a scheme to allow one user to address, locate and connect to any other user.

Interconnection has in the past been provided by the Central Office switches. As we shall discuss latter, this implementation of an architectural element was based on certain limitations of the transport element. With the change in the transport element of structures allowing greater bandwidth, the switching needs have changed. Specifically, distributed systems and scale economies of the distributed architectures allow for interconnectivity controlled by the CPE and not the Central Office. As we shall show later, the advent of Local Area Networks and CATV voice communications are ones using distributed interconnectivity elements.

Again, Alfred Kahn noted (II, p 127),

> "We have already alluded to the technological explosion in communications after World War II,...The case for a national telecommunications network monopoly has the following aspects..Aggregate investment costs can be minimized.. if the planning for the installation and expansion is done with an eye for the total system....Since any one of the 5 million billion possible connections that the system must stand ready to make at any point in time may be performed over a variety of routes....justifies the interconnection...completely dependent on its own resources alone."

This argument for interconnection, combined with transport and control (namely horizontal integration) was valid in 1970. It however is not valid today. They are separable functions and scale economies are in the hands of the CPE manufacturers not the network providers. In effect, there exists no monopoly in interconnect as a result of these technology changes. This is a dramatic change from 1971 and Kahn's analysis.

There are three general views of interconnection that are valid today; the Telcom, the Computer Scientist, and the User. The Telcom view is based on the assumption of voice based transport with universal service and the assumption of the inseparability of interconnect and control. The Computer Scientist view is based upon the assumption that the network, as transport, is totally unreliable, and that computer hardware and software must be used in extremis to handle each data packet. Furthermore the Computer Scientist's view of the network is one where timeliness is secondary to control. The Computer Scientists view has been epitomized in the quote, "Every Packet is an Adventure". This is said with glee, in that each data packet is set out across the network and it is through the best of hacking that the Computer Scientist saves the packet from the perils of Scylla and Charybdis. The third view is that of the user, who is interested in developing an interconnect capability that meets the needs and minimizes cost. This is minimization of both obsolescence and cost strategy. Figure 8 depicts the challenge to the User view of interconnect. Processing cost or capacity is declining every year. Thus an investment must try to follow the curve. In a hierarchical view of interconnect, such as a large centrally switched network, the changes occur once every few years. Thus the lost cost or performance efficiency can become significant. In contrast, in an end user controlled environment, with a fully distributed architecture, the lost efficiency is minimized as technology advances.

o Interface: The interfaces are the end users connection to the transport element. The interface element provides for the conversion from the end user information stream and the information streams that are used in the transport form of the network. For example, the telephone interface for voice is the analog conversion device.

Interfaces were originally called "Alien Attachments". In Kahn (II p. 140-145,) he discusses the history of the interface leading up to the Carterfone decision. The most significant position in CPE control was the Hush-A-Phone debate from 1921 to 1946. The Bell System at that time took total and full control over the quality of the delivery of the service of voice. The Hush-A-Phone company provided a mechanical cup device that could be placed over the mouthpiece of the telephone to assist in making the conversation more private. AT&T took the position that it interfered with the network and the quality of service and battled this for 25 years. Such is not the case today. CPE computer equipment has proliferated and the current costs for 9,600 bit per second modems are comparable to high end voice telephone devices. Clearly, this fourth architectural element is separate and apart.

We have divided the network elements into these four categories to demonstrate that there are clearly four distinct and separable areas for growth and policy formation. Issues of regulation, due to potential monopolist control are always a concern, but it will be demonstrated that in all four there are economies in market disaggregation.

2.2 Architectural Alternatives

Is there a natural taxonomy for the set of network architecture alternatives? Do these present limitations on what can be done or are they extensive? Is there a natural limitation in the existing architectures that prevent the new technologies from introducing the new paradigms to the communications world? We address these issues in the context of several existing network hierarchies.

o Hierarchical: The current network architectures are structured in a hierarchical fashion. As we have already indicated, there are historical and technical reason for this architecture. We show in Figure 6 a sample design of such a network. Specifically, we see the set of transmission schemes connecting from a lower level to higher ones. A path may or may not go horizontally. It may go vertically, all controlled by a single control at the highest level.

o Centralized: A centralized architecture is similar to a hierarchical system in that the control function is centralized. However, the transport elements are not in a hierarchical format. This is shown in Figure 7. The hierarchical structure is no longer present, but there is a single point of control. The control element covers all other elements in the system. A typical example of this type of network is that of a large bank in a metropolitan area. Part of the network is the local ATM (Automated Teller Machine) network and the voice network for the bank. Each are separate but the bank controls both from a single point of control.

o Distributed: The distributed system has distributed control, distributed interconnection and flat transport alternatives. This is shown in Figure 8. Here we first note the reduction in concatenated switch and transmission elements. The network is much less dense and the switch is actually co-located with the interface. The LAN networks are typical example of distributed designs.

o Segmented: A segmented network is really a hybrid. Each segment uses a sub architectures that meets the requirements of the existing system but the networks are interconnected through standard interfaces. This is shown in Figure 9. In this case we show that this network architecture is an amalgam of the first three. What is still common, however, is the partitioning into local and long distance nets. A typical example of this network is that of a large corporate network. Part of the network can be for the voice circuits, controlled at a single point and based upon use of both local and inter-exchange carrier circuits. The second part of the network is the data network, again using both local and long distance carriers, and control from a separate location.

o Partitioned (Local and Long Distance combined in a community of interest): In all of the above, we have assumed that local and long distance transport are separate. This is a world view dominated by the regulatory environment. We can see the segmentation along community of interest lines rather than along these more traditional lines. Thus one community of interest is a network for financial service companies and a second for a network providing service to the residential user. These each have all of the local and long distance services, but are now segmented by the user market or the community of interest. The sub architecture may be any of the above. This is shown in Figure 10. The major difference in this system is that we have segmented several overlay networks, each containing elements of the above four. This architecture allows for local and long distance in separate partitions. It says that you can segment the network by users not just by function. Had the MFJ understood users rather than functions, the results could have been dramatically different. An example of a Partitioned network would be that for American Express or Sears. It contains the set of local and long distance networks as well as subnets for specific distributed applications. However, each of these companies may have access to a separate public switched environment.

Understanding that there are several varying architectural designs allows one to better understand that each reflects not only connectivity but also the world view.

2.3 Impact of Technology on Architecture

We have just discussed the elements of the architecture and the embodiments of design that these elements may lead to. We shall later discuss the details of the technology evolution but it is appropriate at this stage to make several observations about the current impact of technology on architecture.

In the current telephone system, the interconnect element of the architecture is provided by the Central Office Switch and the physical interconnection of the wires from the street to that switch. The point a which the many wires from the street meet the switch are at a device called the Main Distribution Frame (MDF). The Frame must be able to connect any incoming wire to any outgoing wire. The MDF, as it is called, has been the same for over fifty years. It is a manually connected system , where the craft person must connect each incoming telephone wire to a corresponding location on the switch, each time a customer moves or changes their phone number. In computer systems, this is all done in an electronic fashion.

In contrast, the central processing unit in computers goes through changes once every two years. The standard processing capacity curves show a doubling of processing capability in the same two year period, as shown in Figure 8. Computer users have a more rapid turnover of technology because they generally work in an environment with no regulation, shorter depreciation schedules and a focus on meeting specific business needs.

In terms of a national network, this then begs the question, should not the network, as infrastructure, be nothing more than a broadband transport of open single mode fiber and let all other functional elements be provided by the end user.

Consider what was written by a Bell System polemicist in 1977 at the 100th anniversary of the Bell System at MIT. The author was John R. Pierce, Executive Director at Bell Labs, who stated:

> " Why shouldn't anyone connect any old thing to the telephone network? Careless interconnection can have several bothersome consequences. Accidental connection of electric power to telephone lines can certainly startle and might conceivable injure and kill telephone maintenance men and can wreak havoc with telephone equipment. Milder problems include electrically imbalanced telephone lines and dialing wrong and false numbers, which ties up telephone equipment.
>
> An acute Soviet observer remarked: "In the United States, man is exploited by man. With us it is just the other way around." Exploitation is a universal feature of society, but universals have their particulars. The exploitation of the telephone service and companies is little different from the exploitation of the mineral resources, gullible investors, or slaves." (de Sola Pool Ed, Pierce, pp 192-194).

The readers should note that this was written nine years after the Carterfone decision and five years before the announced divestiture. Pierce had a world view of an unsegmentable telephone network. This paper has the view of a highly segmentable communications system. The world view of the architecture has taken us from "slavery" of Pierce to the freedom of the distributed computer networks of today. Kuhn has described technologists as Pierce as the "Old Guard", defenders of the status quo. They defend the old paradigms and are generally in controlling positions for long periods of time.

2.4 Architecture versus Infrastructure

Let us redefine the concept of infrastructure. In our context, an infrastructure is a shareable, common, enabling, enduring, resource, that has scale in its design, and is sustainable by an existing market, and is the physical embodiment of and underlying architecture. Specifically;

o Shareable: The resource must be able to be used by any set of users in any context consistent with its overall goals.

o Common: The resource must present a common and consistent interface to all users, accessible by a standard set of means. Thus common may be synonymous with the term standard.

o Enabling: The resource must provide the basis for any user or sets of users to create, develop and implement any and all applications, utilities or services consistent with the underlying set of goals.

o Enduring: This factor means that for an infrastructure to be such, it must have the capabilities of lasting for an extensive period of time. It must have the capability of changing incrementally and in an economically feasible fashion to meet the slight changes in the environment, but must meet the consistency of the world view. In addition is must change in a fashion that is transparent to the users.

o Scale: The resource can add any number of users or uses and can by its very nature expand in a structured form to ensures consistent levels of service.

o Economically Sustainable: The resource must have economic viability. It must meet the needs of the customers and the providers of the information product. It must provide for all of the elements of a distribution channel, bringing the product from the point of creation to the point of consumption. It must have all of the economic elements of a food chain.

o Physical Embodiment of an Architecture: The infrastructure is the physical expression of an underlying architecture. It expresses a world view. This world view must be balanced with all of the other elements of the infrastructure.

An infrastructure is built around the underlying architecture. An infrastructure is in essence the statement of the architecture which in turn is the conceptual embodiment of the world view.

Infrastructures as physical embodiments of architectures must, to have economic lives that are meaningful, be developed when the world view, technology and user needs are stable. If any of these three are in states of significant flux, the infrastructure may soon not meet the change in the world view and then become obsolete.

2.4.1 Types of Infrastructure

It is important to distinguish between architecture and infrastructure. We have extensively defined architecture in terms of its three parts; elements, world view and technology. Infrastructure unfortunately has been reified in terms of some physical embodiment. The discussion of NREN being an infrastructure is viewed by many as being a determinate thing. Kahin has, however, de-reified the concept in terms of it being an embodiment of a concept or set of common goals. **We expand that and state that an infrastructure is an enabling capability built around a common construct.**

There are four types of infrastructure views that are pertinent to the current discussions of networks. These are of particular import to such networks as NREN since they will lead to the policy directions that it will take. These four infrastructure types are as follows:

o Physical: This is the most simplistic view of an infrastructure. It requires a single investment in a single physical embodiment. The old Bell System was such an infrastructure. The National Highway system is such an infrastructure. We show this in Figure 11.

o Logical: This network may have separate physical embodiments, but all users share a common set of standards, protocols and other shared commonalities. All users have access through an accepted standard interfaces and common higher level transport facility. IBM had attempted in their development of SNA in the mid 1970's to develop a logical infrastructure in data communications. **This was expanded upon by the ISO OSI seven layer architecture, selecting a specific set of protocols in each layer. We show this in Figure 12.**

o Virtual: **This type of infrastructure is built on intermediaries and agreements. It provides shared common access and support interfaces that allow underlying physical networks to interconnect to one another. Separately, the individual networks may use differing protocols and there are no common standards.** The standards are at best reflected in the gateways to the interconnection of the network. Thus this infrastructure is a loose binding through gateways. It is in many ways what is the INTERNet today, **if we include all of the subnets. This is shown in Figure 13.**

o Relational: **This type is built on relationships between the network parties and the establishment on higher level accessing** and admission. Specifically, a relation infrastructure is based on agreements on sharing addresses, not necessarily common addressing, and on the willingness to share data formats and types. It is an infrastructure based on shared common interests but not shared common access. **This type of infrastructure is what in essence exists in most cases today. Users can move from network to network through various gateways. The difficulty is the fact that the interfaces are cumbersome and may requires sophistication on the part of the users. However, more intelligent end user terminals and interfaces will reduce this cumbersome interface problem. This is detailed in Figure 14.**

We show the relationship of these four infrastructures in a diagrammatic fashion in Figures 11 through 14. Our conclusion is that understanding the type of infrastructure that the coalition of users want, will also impact the architecture, based upon an imputed world view. Arguably, a physical infrastructure leads to maximum hierarchical control and the resulting impacts that such control leads to. This is a critical issue for networks such as NREN, since by choosing infrastructure and architecture may not be as uncoupled as desired. In particular, the selection of Gbps capability may really be GHz capability and is best suited to a Virtual or Relational infrastructure.

2.4.2 Current Infrastructure Options

There is a considerable amount of effort to define and implement an information infrastructure. In this section we describe some of these current proposals, many of which a still quite formative and lack substance. In some case we shall try to place them in the context of the constructs that we have developed in the preceding sections. In order to fully describe these infrastructures, it is also necessary to deconstruct the work of the authors, understanding their meanings in the contexts of what they are saying and taking an approach that blends the hermenutics of Gadamer with the semiotics of Levi-Strauss. We now address several of the more current views of infrastructures. In each case, we describe as best can be done the concepts of each of the individuals, and then attempt a deconstruction in terms of their underlying architectural assumptions, their view of infrastructure and more importantly their world view of information and information networks.

(i) Dertouzos Infrastructure

This is the most widely discussed of the information infrastructures having been proposed by Professor Dertouzos who is a Computer Scientist and the Head of the Laboratory for Computer Science at MIT. Simply put, he defines the information infrastructure as:

> " Common resource of computer-communications services, as easy to use and as important as the telephone.."

Dertouzos states that there are three elements to his vision of an information infrastructure. These are;

o Flexible Transport: This includes bandwidth on demand, flexible pricing and security and reliability.

o Common Conventions: This includes his concepts of E Forms and Knowbots. The former is a set of standard for formats and the latter are intelligent agents for the movement and processing of data.

o Common Servers: This is a set of common file servers or generalized servers to provide directories, text/image translation, data base access and active knowledge.

In Figure 15 we depict all of these elements.

(ii) Kahn Infrastructure: The vision of Bob Kahn, of CNRI is one of a broad band research backbone, loosely coupled, with dark fiber and as high a bandwidth as possible, read data rate. This proposal, frequently confused with the Gore infrastructure, is generally more open and flexible. However, it too lacks any economic underpinnings.

(iii) Gore Infrastructure: Gore, the Senator from Tennessee, son of the initiator of the Federal Highway system, and presidential contender, has argued for a single network, government directed and funded, hierarchical in fashion, that allows everyone to have access to every bit. Consider his comparison of data bits to corn kernels;

> " Our current national information policy resembles the worst aspects of our old agricultural policy, which left grain rotting in storage silos while people were starving. We have warehouses of unused information "rotting" while critical questions are left unanswered and critical problems are left unresolved."

He believes that every bit is a good bit. He further has no value concept of information. His definition is clearly the one of quantity and not value. Researchers are not necessarily starving for lack of bits. Quite the contrary, there is a need for coherent data reduction. He further states;

> "Without further funding for this national network, we would end up with a Balkanized system, consistent of dozens of incompatible parts. The strength of the national network is that it will not be controlled or run by a single entity. Hundreds of different players will be able to connect their networks to this one"

He is somewhat contradictory. On one hand he states that there will be one network and not many on the other hand he has all the separate networks connecting to this one. In this case, his world view comes through clear as well as a lack of understanding of architectures and infrastructures. He wants a hierarchical or at most centralized architecture as well as a physical architecture. The proposal lacks the flexibility of a economic entity.

(iv) Heilmeier Infrastructure: Heilmeier, the new President of Bellcore, the R&D arm for the Bell Operating companies on the regulated side, advocated a hierarchical, BOC controlled, network intensive, monolithic network. This is not surprising considering his extensive stay in Washington as a government bureaucrat. He further argues for control of both wire based and wireless networks. He is quoted as saying;

> "I'd like to see a bona fide information infrastructure rather than a fragmented world of different systems for everything."

Networks are currently fragmented and as a result of this fragmentation local economic optimization has occurred. In contrast to the hierarchical, centrally controlled view of Heilmeier, also formerly head of DARPA, wherein he views the need for a single point of control and direction, the world of communications networks and information networks have grown through the increased power of the end user interfaces and interconnected distributed throughout the network. In addition growth has resulted from less control in the network and less centralization. The work of the author (McGarty 1990 [1], [2], 1991 [1],[3]) has shown an architecture for a distributed multimedia environment that has been built and is still in operation that uses a mix of communications channels and thrives on those channels that have the least functionality. Specifically, dark fiber transport is the most enabling and empowering of any communications channel.

2.4.3 Proposed Infrastructure

Infrastructures are enabling entities. As we have discussed, an infrastructure does not have to be a single centrally controlled, managed, and funded entity to be effective. In fact an infrastructure on the loosely constructed basis of a relational infrastructure is just as effective as the extreme of a physical infrastructure. We make the following observations, and based on the prior developments in the paper propose an alternative direction for infrastructure development.

(i) Technology is rapidly changing and will continue to do so. The directions in technology are towards increased processing capability per unit workstation and increased capacity in performing both complex processing tasks while at the same time handling sophisticated protocol procedures. We depict this change in Figure 16.

(ii) User terminals are expanding in a network multimedia environment that is empowering the end users to both use many new media types as well as dialog in a conversational basis with other users in the same network. The extremes in this environment are depicted in Figure 17

(iii) End users are becoming more pervasive and training of users based upon strict confines of computer languages are disappearing. The end user is empowered to act and to use information system with no training or education. Citibank, in it development of the ATM network has ensured that the systems have minimal need for human intervention or training. In addition, the Citibank home banking product, the most widely used of any home banking products on PCs, is almost instruction free. The Apple MAC computer is also another example of end-user empowerment through intimidation free end user interfaces. The relationships between these are depicted in Figure 18.

(iv) Successful technology development in a productive fashion has best be effected within the constructs of entrepreneurial small companies that allow for the creation of new ideas judged by the dynamics of a free market. Large centralized technology development organizations have time scales that are much longer than the time scales of the underling technologies. The development in the computer industry of today are prime examples.

(v) Users are not only empowered to use systems in a variety of ways but they are also able to select from a wide variety of systems, interfaces and data sources. To quote A.G. Fraser of Bell Laboratories:

> "Every standards body seems to be churning out protocols left, right and center. We may already have passed the point where we can all come together." (Coy, 1991)

Thus, distributed networks, interfacing with disparate other networks, through gateways is already a reality.

These observations then indicate that with a changing base of customers, a changing set of needs and an already progressing infrastructure that is relational at best, that to continue to maximize our technical creativity it is best to match the information infrastructure to our cultural paradigms. Thus it is argued that the proper evolution of an information infrastructure should be along the relational model. That, in fact, the physical extreme is counter to the trends of user empowerment and economic efficiency. It further could provide a roadblock to technical creativity.

3.0 Network Morphological Elements

In order to develop a taxonomy and in order to provide a Key for the taxonomy in determining which network fits where, it is first necessary to identify the morphological elements. Consider the work of Linneaus in characterizing plants. After many centuries of naturalists identifying differing plants it became quite clear that there were several key characteristics that were used for the identification and differentiation of plants. These characteristics were related to the morphology or appearance of each species. Thus for plants, we look at the leaves, the flowers, the fruits, the shoots, the roots, and the seeds. These represent the elements necessary for the morphological structure.

In this paper, we attempt the same step that Linneaus had taken but for communications network. Our ultimate goal is to use these elements as the basis of a dichotomous key system frequently used in a botanical identification tract. A dichotomous key is a method to classify a plant based upon the layered set of identifiers about such elements as the leaf or the flower. We depict these concepts in Figure 19.

In describing any network we have the following four major elements; control, interconnect, interface and transport. They are like the elements in plants of flower, fruit, seed, shoot and root. Each may have added subtleties in their structure but they represent the first high level differentiators of the network morphology. We now define these elements in detail. We then proceed to further differentiate these elements to a depth adequate for the development of a taxonomy for segmentation.

Control: Control functions in a network describe all of those functions necessary for the operations, administration and maintenance of a network. It includes such functions as network management, network restoral, billing, inventory management, network reconfiguration.

Interconnect: The interconnect functions describe all of those functions that are necessary for the identification, selection, processing and support of all user to user connections on a network. Interconnection assumes an addressing scheme, a management scheme for the addresses, and a means for one user to address and connect to any other user including the determination of where that user is and how to locate them.

Interface: The interfaces are the connection between the end user and the transport element. The interface includes all of the functionality necessary for the user

Transport: This element characterizes the physical and electronic means of transporting the information from one location to another. Transport focuses on the point to point means of the network.

We add a fifth element, namely the user as a means to help differentiate the ultimate use of the network as a means to allow for partitioning along the lines of use. Thus:

User: This is the end user of the network. The user may or may not be a human and as a user has needs to be met in terms of the network structure. For example, the user may be a software process which may be configured in a client server mode and as such the set of users may be the clients and a single server.

We now begin to detail each of these areas out in further detail. Our approach is to develop a morphological structure that provides detail on general structural elements leaving the specific choice of the element to the lowest level. A morphology has no repetition of low level element choices. Each is independent. In addition, each choice is descriptive and is not exclusive, that is saying it is not something.

The morphological approach is as follows. Each element, E.k, has a set of sub elements, E.k.j. In turn each of these may be sub divided into other elements, E.k.j.n, until the final step is a descriptor of a sub element. A descriptor, D.k.j.n is a positive, inclusive statement of that sub element. For example a flower may have sepals, petals, stamen and pistil. The sepals have venation. The venation may be parallel, pinnate or palmate. The characteristics or descriptors are parallel, pinnate or palmate. They are positive statements. It is unacceptable in a morphology to have parallel and non parallel. The latter must be descriptive and inclusive in a class.

In a morphology, a complete classification is the set of all descriptors, {D.k.j.n:k=1,..K, j=1..J,n=1..N}. We must be certain that the set partitions the space of all known networks into classes that are separate. That is only the same network may have the same descriptor set. The details of this morphological definition are shown in Figure 20.

3.1 Users

We begin the development with the user division since in many cases it is the end user who ultimately defines the network. For example, the current focus is on the users being processes, processors, or data files. rarely in the current environment do we see the human being a specific user. In the current developments of networks, there is a stronger trend to the user being the main user of the network.

The elements that further define the set of users is as follows:

o Type: The type of users characterizes the nature of the end user or end user set. The end user may be a human, a data file, a process or a processor.

o Time: The time element describes the nature of the connection as perceived by the end user. Depending on the user, the time element may have multiple options. The descriptors for this type are as follows:

  o Simultaneous: All users are communicating at the same time.

  o Displaced: Some users are not at the same time frame and moreover, there is a disparate set of these time frames.

  o Shifted: Time frames are equally shifted.

o Transaction: This element describes the nature of the interaction between the users. Specifically it may be:

  o Shared: All users may randomly access the services.

  o Sequenced: A protocol of control from one to another exists.

  o Directed: Control is forced from a single point.

o Set: The set of users may be homogeneous or inhomogeneous. If the set is homogeneous then the descriptor of type is definitive. If the set is inhomogeneous, then the descriptor of type must be expanded.

Thus the User element can be fully characterized by the descriptor set;

$$\{D.1.1.n_1, D.1.2.n_2, D.1.3.n_3, D.1.4.n_4\}$$

where D.i.j characterizes the specific descriptor sequence and the n_k characterizes the specific dichotomous ending. These details are shown in Figure 21.

3.2 Interconnect

Interconnect in the broadest sense describes the totality of how the users are brought together in a shared community for the purpose of communicating. As we stated before, communications is the ability to change the state of one user or another in the linkages of the total process. Interconnection is the establishment and maintenance of the infrastructures that are required for the maintenance of these path.

In a similar fashion, we can describe the interconnect sub elements as follows;

o Location: The location of the interconnect agents or elements are the first item in the morphology deconstruction in this area. The location reflects the nature of the network as well as the world view of the designers. The following are the specific descriptors.

o Fully Distributed: Each user of the network has access to and control over its own interconnect facility, which in turn may act autonomously in the network.

o Intra Netted: Interconnecting is don on a clustered basis with a collection of users in a closed and geographically compact community having access to a server that facilitates in an autonomous fashion all of the network connections.

o Regional: Interconnecting is performed on the basis of a closed user group that is loosely connected geographically. A system provides a local switching node that is itself autonomous.

o Centralized: In this configuration, the interconnecting is performed by a single element, that controls and directs all switching.

o Hierarchical: A hierarchical network is one in which the interconnection or switching is hierarchically distributed, in that each element may switch to a certain degree, possibly locally, but that the broader the reach of the switching, the higher in the network switch levels the switching or interconnection goes. The current public switched network is an example.

o Addressing: This is a key factor in the overall operations of the interconnect function. Specifically, addressing permits the naming of any node and the location of that node or user for access of the interconnect function. Addressing has two characteristics. The first is the geographical nature of addressing that states where, physically in the network, the addressing may be used and effected. The second in the temporal factor of addressing that relates to the issue of whether the addresses themselves are static or dynamic. Specifically, with dynamic addressing we change the address from time to time. Adaptive addressing changes addresses based upon other factors.

(i) Physical Addressing

o Local: This type of addressing allows for addresses to be local to a select user group. There is now way to address a foreign user entity.

o Universal: This allows for global addressing of any user on the network.

o Serialized: This approach allows for addressing of groups, then sub groups and then ultimately down to selected end user communities.

(ii) Temporal Addressing

o Static: In this addressing system all addresses are kept constant with time.

o Dynamic: In this scheme, addresses are changeable with time occurring to some prearranged system or protocol.

o Adaptive: Adaptive addressing goes beyond dynamic addressing in that it responds not only to time and place but also to other exogenous factors in the end user or network operating factors. An adaptive addressing scheme may

o Selection: This element of interconnect focuses on the issue of how the interconnect process is managed. Specifically, there are two currently observed descriptors; random, that is on a basis of algorithmic but arbitrary, and assigned or deterministic interconnect tables.

o Random: This system is based upon a algorithm or protocol but the result depends on factors that are random.

o Assigned: This is a preassigned system, where knowing the state of the network at any one time determines the connection path.

o Performance: The performance determinant addresses the issue of the quality of service delivered. The quality may be judged along several axes. The following are the current set of determinants.

o Time: This factor relates to the time of setup or other such factors.

o Signal: This relates to the quality level of the voice signal or the data or image signals.

o Delay: This is the characterization of the delay in the network.

o Blocking: This is the characterization of the blocking in the interconnect.

o Links: The link element or descriptor of the interconnect function relates to the types of interconnect that are employed. Specifically, is the interconnect a physical interconnection, a virtual interconnection or a relational one. The reader is referred to Tannenbaum for the full detail on these approaches. At a higher level these are described below.

    o Physical: This is a defined and measurable physical path between all interconnections and users.

    o Virtual: This is a path that is created on the basis of signaling vectors between all of the users. Although not a physical path, it is an algorithmically defined path that is reconstructable at any instant from the state of the network.

    o Relational: This is a fully random path built upon relations between users in the network. It depends upon states of the users and the network, unlike the virtual path that depends solely upon the state of the network.

o Setup: This is the final descriptor of the interconnect element. It represents the nature of the interconnect signaling, as separate from or a part of the communication channel from user to user. The two forms are as follows:

    o In Band: All signaling in in the same path as the user to user communications in all layers of the communication channel, physical or logical.

    o Out of Band: Signaling takes different physical and/or logical paths.

We show the details of this break in Figure 22.

3.3 Interface

Interface describes the nature of the interaction between the user and the interfaces and transport. Interface describes the elements that allow for the users to take maximum advantage of the others users interface needs.

There are five descriptors of the interface level. They are described below.

o Modality: This descriptor describes the nature of the information flowing from or into the user. There are the following types;

    o Video

- Voice
- Text
- Data
- Image

In addition to the above simple descriptors, there are a set of compound descriptors that reflect a multimedia environment. We develop those through a concatenation of the above descriptors.

o Multiplicity: This descriptor indicates the nature of the number of end users connected to a single interface. Simply stated there may be one or many. Thus;

- Single
- Multiple

o Integratability: This descriptor indicates the temporal, spatial or logical nature of the interface. In the simple temporal case, we can envision the interface operating in a synchronous mode with timing shared amongst al of the users. In a spatial synchronous mode, we can envision all of the users sharing a common virtual spatial reference, even though all of the users may have different screens with different aspect ratios and other such factors. Logical synchronicity describes the ability to assure the cohesiveness of the information presented in the display interface. In a similar fashion, asynchronous integrability reflects the fact that the there is no overall timing of the events and that they follow a system of one to one arrangements. The third level is sub synchronous wherein some may be synchronized while others are not. Thus we have;

- Synchronous
- Asynchronous
- Sub Synchronous

o Conversationality: This describes the nature of the interface and the users as regards to the nature of the sessions that may be created on the network. They may range from the shared or party line method, to the conversational systems common in multimedia communications, into a private line and finally into a fully secure link. Thus;

- Share

o Conversational

o Private

o Secure

o Links: This descriptor indicates the number of links that are supported per interface. Specifically;

o Single

o Multiple

We show the details of this in Figure 23.

3.4 Control

Control is the broadest element in the morphology of networks. The control may span the issue of who owns and operates the network to specifically how the network is managed as a living and operating entity.

o Management: The management element describes the specifics of who owns and operates the network. It is in essence the legal control part of the network.

o Users;Direct: Each user has direct control over the network.

o Users;Indirect: Each user has an influence on the network but the control is indirectly applied.

o Shared: Users share in a pooling fashion the control over the network.

o Public: There is a publicly accepted control point for the network. Such is the case for the public switched network.

o Private: This is a network provided in a privates basis. Control is in the hands of the private entity.

o Maintenance: The maintenance element describes the philosophy to the real time control of the network. It describes how the network is managed as a operating entity. Several possible, and currently recognized descriptors are possible;

o Centralized: Controlled by a single entity.

o Sectored: Broken into segments that are controlled by separate entities divided by geography, or function or some other such factor.

- Distributed: A fully distributed and autonomous function.

o Scope: The scope element describes the breath of elements that are performed by the network as it is functioning in its operational management role. The functions may include some of the following descriptors.

- Inventory
- Maintenance

These are the major descriptors of the control function. All too often designers have not focused on the control descriptors as an element in the network morphology. In this paper, we have presented several key control descriptors and there may be more discovered as control becomes a more significant factor in the design of a network.

We show the details of this effort in Figure 24.

3.5 Transport

Transport is the set of elements that relate to the underlying means of movement of the communications signals from one point to another. In its simplest sense, it represents the media of movement and the specific signals that are used to make that movement possible. In the context of the ISO model (Tannenbaum) these represent the lower three levels, Levels, 1 to 3.

o Medium: The medium characterizes the lowest level of transport, referring to the specific transport vehicle. In the following list we refer to fiber, radio and other specific means of transport. The following are typical descriptors;

- Fiber
- Coax
- Copper
- Microwave
- Satellite
- Radio

o Method: This represents the method or means of transporting the signal. There are two general descriptors, that in turn have more specificity. They are;

- Analog

- AM
- FM
- PM

- Digital
  - PSK
  - FSK
  - ASK

- Mode: This represents the characteristics of the Layer 3 elements of keeping links in the network in operation. The two major ways of doing it to date are synchronous and asynchronous. Thus we have;

  - Synchronous
  - Asynchronous

We show the details in Figure 25.

3.6 Morphology Applied

A morphology is useful if and only if it can be applied to any network and an adequate descriptor of that network is produced. Moreover, as we proceed to taxonomies, a morphology is useful as long as it leads to a set of descriptors that classifies sets of networks in consistent groups. In the current morphological paradigm, we may have not included a set of elements that may become more important in latter stages. For example, in morphological studies of plants in the 1930s, the use of the DNA or proteins generated were not considered as a morphological factor. These factors, may in the next hundred years become the dominant morphological factors for taxonomical classification, however, today they do not play that role.

In this section we take three current networks and deconstruct their morphologies.

In Figures 26 and 27 we depict the relationship between taxonomy and morphology and then extend it to the relationship between networks. Specifically, we show the ISO relationships.

The approach in this paper follows the work of many taxonomists and tries to merge that method of classification with communications networks. As we have been developing the concepts, there still are some fundamental issues that need be resolved. The most important is that of a species of network. The species concept has had a great deal of study in Biology and Mayer has spent much of his writings in this area. However, there are two other requirements that are critical and that may not be in the current set of descriptions. First, the categorizations that we develop must have some sense of uniqueness. Namely, there are flowering and nonflowering plants. Second, as we develop categories we must have some implicit distance measure to show how close or how far away one species is from another. DNA gene mapping is one such means but even there it is disputable from an evolutionary stand. We can only approach the task by means of examples as did Linneaus.

3.6.1 Internet

The Internet is the evolution of the early ARPA Net that was first conceived of in the late 1960s. It is a collection of many networks that currently provides access to many sub networks. Quarterman provides a detailed description of the current Internet. In this section we apply the morphological analysis that we have developed to this network.

3.6.2 Public Switched Network

The Public Switched Network is the result of an evolutionary process that had given rise to the Bell System and has resulted in the current structures under the Modified Final Judgment (MFJ) strictures (Coll; Geller; Kraus and Duerig). The network is based upon a set of technologies that require massive investment in capital assets to allow for the interconnection of many users to each other. The system requires massive switching infrastructures since the underlying transport facilities, the classic copper cables called "twisted pairs", have very limited information carrying capacity.

The public switched network is built around a hierarchical architecture that makes several assumptions of its environment and the customer base. These assumptions are (See von Auw for the insider Bell System view, pp 334-398; see Toffler for the external consultants vision of where the Bell System could have gone):

o Bandwidth is a costly commodity so that it is necessary to provide for concentration of circuits on trunks and tandem lines. This concentration leads to the need for multi layered switching centers, a Class 5 Central Office being the lowest level.

o Voice is the primary means of communications and all circuits are to be considered multiples of voice circuits. In addition the voice is to be sampled at a rate of 8,000 samples per second and the number of bits per sample may be from 7 to 8.

o Universal service is necessary in order to meet the needs of the state regulatory bodies, This means that telephone service must be structured to cover the gamut of the rural home to the large corporation.

o Quality of service is to be as high as possible with overall system availability to exceed 99.95%. This implies redundancy, disaster recovery systems, and a trained workforce that will permit as near as real time restoral as possible. New York telephone has in twenty years responded to crises that would have sent other US corporations reeling in chaos. Their response allowed restoral of services in extreme conditions of distress (See the recent paper by Bell discussing the fragmentation of the telephone network).

o The focus is on operations, namely keeping the network service up to the performance standards set, and this implies that the work force must have the capability to deal with complex operations requirements in multiple positions. All people should be cross-trained to meet the level of service expected by the consumer of the service.

These assumptions make the local telephone company an infrastructure entity. The telephone company as the local operating company has a highly redundant, high quality of service, with a highly integrated work force.

If we look at this network in terms of our architectural elements we see the following:

o Control: The control is highly centralized. The control emanates from a set of methods and procedures, flows through the overall control mechanism for the network and is integrated to the maintenance and restoral efforts.

o Interconnect: This is a truly hierarchical interconnect. It is based upon the Central Office Switch, which is designed to conserve bandwidth at the trunk side. It provides a level of common access based on a single voice channel.

o Transport: The basic transport is the twisted pair to the end user. There is fiber in the loop and some fiber to the user, specifically those users in the higher data rate category.

o Interface: Generally the interface if the telephone handset. More recently, the interface has been expanded to include data sets.

In contrast to the ongoing performance levels of the Regional Bell Company, the interexchange carriers (IECs) do not have to meet the same levels of service. The recent AT&T service outage in New York with their Class 4 and Class 3 switch outages showed how the level of service has dropped for the IEC level (See Bell p. 36). Specifically, the IECs have recognized that a level of service may be priced on a differential basis. This is in contrast to the pricing structures for the local operating companies whose service levels are more closely controlled by the state Public Service commission. It is of question if there is to be a divergence in service levels over time, between these two types of carriers.

There has been great discussion on the threat to the local carriers from the bypass carriers. The bypass carriers have had some impact but has not been as serious as expected. The true competition has typically been from the changes in technology. Specifically the user has in the past used a set of single voice circuits not having the capability to multiplex them over several higher data rate lines. With the introduction of T1 or DS1 (1.544 Mbps) circuit, now it is possible to get 24 voice circuits for the cost of 8. In addition it is also possible for customer to get DS3 or 45 Mbps circuits for 8 times a DS1. Thus the technological innovations in multiplexed circuits are the internal competitors to the existing single voice circuits.

The current evolutionary thinking in the public switched network takes it from ISDN to Broadband ISDN with ATM switching. It is an evolutionary path that is built on the world view of the nineteenth century system of hierarchical switches and the need for universal service. It is driven by a need to provide the same data transport, at almost the same time, to business customers as to the residential customer. It does not readily admit the flexibility of multiple overlay networks, allowing for segmentation of service. It is predicated on the assumptions of high per user capital investment and allocation of costs in a rate based world. Much of this thought process is, however, driven by responding to a Public Service Commission demand on a state by state basis for equality of service.

The question may be asked as to why the local operating companies have not taken a more active role in the development of the regional networks. There are several obvious answers and those not so obvious. Clearly, in the case of most regional networks, NYSERNet being one, inter LATA transport is necessary. New York Telephone took a key role in the early stages, however it had to deal through Rochester Telephone to legally work with the NYSERNet efforts. In fact, it is even considered in violation of the MFJ to manage an inter LATA network. Thus, for MFJ and other regulatory reasons, the local operating companies are wary of involvement. A second reason is the general voice focus of the Regional Phone Companies. The emphasis on data in the networks of the type such as NREN go beyond the general network infrastructure supported by the local operating companies. A third reason is the questionable economic viability and extensibility of such academic networks. These are shown in Figure 28.

3.6.3 CATV

CATV networks have evolved over the past thirty years from a simple local distribution service for off the air television transmissions to highly complex communications networks with a centralized architecture. In the early 1980s the CATV carriers were required to make all of the cable systems have the capacity to carry two way transmissions and it was implemented in 1980 by the Warner Cable company in the now classic QUBE system (See McGarty 1982, 1983 for a technical description of the system and Couch, McGarty and Kahan for the market structures). Two way cable was further expanded to provide for both data and voice transmission. The first data circuits were provided in 1982 by Warner in Pittsburgh, providing 1.5 Mbps data communications to Westinghouse in a metropolitan area network. In 1983, Cox Cable (see Tjaden) implemented, with the assistance of MCI, a fully switched voice communications system over the cable network. In 1983, Warner Cable reached 100% penetration of optical fiber in its backbone trunks, from hub to head ends, in the large Metro systems. In late 1983, Warner Cable developed, and field tested a full motion video, on-demand, videotex system in a joint venture with Bell Atlantic, Bank of America, Digital Equipment Corporation and GTE. After determining that the time was not appropriate this trial was canceled (See McGarty and McGarty, 1983). However, GTE took the Warner developed technology and further developed for its cable trials in California. Unfortunately the GTE trials lacked a market driven partner and they too failed. Despite the failures, these trials showed that the cable industry, almost a decade ago, had developed, tested and marketed systems that are still to be implemented in the telephone network. This limit is not a technical or market limitation, it is clearly a limit of judicial mandates on market expansion.

Thus in many ways the cable industry was far ahead in meeting the needs of all classes of users as compared to the telephone companies. Much of this was a direct result of the lack of regulation and willingness on the part of the customer to infer the existence of and agree to an underlying price-performance curve.

The CATV networks are structured to provide for the distribution of entertainment to the home. These networks are centralized in form an as shown in Figure 20 they have a head end that operates the local area, a set of hubs that are distribution points and possibly sub hubs for local regeneration. The systems are generally one way broadcast but have a two way capability. The one way may be 50 MHz or more and the return channel is 50 Mhz or more. The systems are primarily coaxial cable, although they are being expanded to include fiber. Some of the existing systems have a fiber backbone

The architectural elements for the CATV networks are as follows:

o Control: The control is generally from a central facility in the network. The systems are broadcast only and thus distributed control of the network is limited.

o Transport: The transport is very passive. The coaxial cable used in these systems is a limiting factor. It has repeaters along the route and and these are limiters to the cable design. With the introduction of fiber in the CATV local loop, however, this will change and the cable transport will have the capacity for any bandwidth. Even in the current systems, there is not the segmentation as in copper. Cable could provide any user in the reverse path with any part or all of the reverse 50 Mhz of bandwidth today. In fact, in several of the Warner QUBE systems, this was commonly used for commercial data circuits. Thus the CATV systems are dramatically different than Telco system in that ability to assign and allocate full capacity on transport to any user.

o Interconnect: The interconnect capability of a cable system is fully distributed. In the QUBE system, a polling scheme was used which was centralized. In the Cox INDAX system, the scheme was a CSMA-CD system that was fully distributed. Thus in CATV both extremes have been used. In fact, CATV used the first version of the IEEE 802.6 protocol in the CSMA-CD designs, this being the basis for SMDS systems.

o Interface: Cable allowed a wide variety of interfaces, ranging from TV converters, to PCs and video games. This is dramatically different from the limitations on Telco networks.

The cable systems have a natural monopoly in their underlying franchise licenses. These licenses are awarded on a municipality basis and generally assure the local governments a certain percent of the gross revenues from the system. Thus it is of immediate gain to the local governing bodies to maximize the revenue from the cable systems to achieve the greatest revenue source from the cable operator. The current law limits this implicit tax to 5 %.

The evolution of the CATV networks has been based on the assumption that the CATV operators will assume the massive capital investment risks with the opportunity to attain an adequate return on their investments. That return has for the most part, been focused on the use of the transmission medium for the almost exclusive purpose of entertainment distribution. The fact that the current cable business passes almost 80% of the US homes and has about 50% penetration, thus providing service to 40% of the US households. In contrast however, even at the current rates of service, the revenue for the CATV industry as a whole is only $18 billion, comparable to one RBOC, there being seven, plus GTE. The total RBOCs plus GTE equal the interexchange carriers in revenue, including AT&T, MCI, Sprint and the other IECs. Thus the total CATV industry is about one sixteenth or 6%

of the telecommunications transport business for voice and data. Such a position is not one of any market dominance in the network area. However, as has been noted, this industry has a network in place with both existing capabilities and new transport capacity that greatly expands what the the RBOCs have in all their networks. The difference is driven by both the unregulated nature of cable plus the fact that cable is not forced to be the transmission provider of last resort. That is cable is not required to provide "Life Line" services below cost.

CATV companies now find themselves in an environment where the RBOCs are potential alternative carriers competing with CATV (See Carnavale). Specifically, the RBOCs have indicated their intent in providing local loop fiber transport. That transport would have the capability to provide transport for CATV systems. The large capital intensiveness of these systems, however, will slow their installation. The inertia of local governments, the true regulators and customers in this market, will probably, for the short term, maintain the status quo. It does however allow for the CATV companies, as they progress to fiber based transports to themselves become the alternative carrier. If the CATV companies, in the current rebuild cycle that will occur in the 1990s, position their rebuilds in fiber, then they are in the position to have the transport base for transmission to the home. It is then possible, in extremis, for the RBOCs to become leasors of transport service from the CATV companies who will have fiber passing the majority of homes, and not vica versa. It will be an issue of who will be at the home first with the transport facility and then it will become an economic decision. We detail the CATV network in Figure 29.

4.0 Network Taxonomy

Having developed the morphological concepts in networks, in this section we plan to develop the concept of taxonomies using these morphological elements. As with any taxonomical development, the choice is somewhat arbitrary, especially as we begin at the highest level. The works os Sokal and Sneath in taxonomical classification may be referred to and it is this work that has influenced the current approach. If we recall plant taxonomies, the partioning is first along the lines of seed bearing and non seed bearing plants. Then the partition in the seed bearing branch are those with fruit (flowering plants) and those without (conifers). The same issues are present with networks. What factor do we start with that is as important as seeds and then flowers or fruits. The issue of taxonomy based on highest level of morphological partitioning is critical. We show this in Figure 30.

4.1 Taxonomical Alternatives

In the development of a taxonomy, we begin with the available morphologies and generally attempt to generate taxa based upon the highest level of differentiators. As we have discussed before, we have presented architectural variants and infrastructure variants. These were developed at the highest level without any benefit of the morphology that we have also developed.

4.2 Current Network Examples

Before proceeding we begin with several examples of current networks.

4.3 The Development of Genera and Species

The concept of Genera and Species in plant taxonomy is a statement that says that there are sets of common elements that are in collections of different networks and that this collection is commons to sub classes of such network. In this section we develop the concept and define several classes of networks and **demonstrate the structure that they have with respect to one another.**

4.4 The Evolution of Networks

Networks have evolved over time and some types no longer exist. Most step by step voice networks are out of existence at this time. They have been superseded by cross bar and then electronic switching systems. The question may be asked what is the evolutionary past of the local area network. The reason for this set of questions is to not only understand the past but recognizing that the past is the prologue to the future, to project possible network evolutionary trends.

4.5 The Relationship of Networks in Taxa

As in plant taxonomy, there is a set of hierarchical relationships amongst networks. The collection of networks at lower levels, such a genera an species, can be concatenated upwards into the taxa. We will develop some of these concepts in this section.

5.0 Conclusions

In this paper we have developed a first step in characterizing a network morphology and taxonomy. The approach take is similar to that used in plant taxonomy. It recognizes that it is first necessary to characterize the network in terms of elements and the element characterization must not reach the level of final detail until the elements are adequately exhaustive. This approach is in sharp contrast to other techniques which try to characterize networks in tree clades, specifying all of the characteristic as the depth of the tree continues. In contrast, the approach taken in this paper is morphological, laying out characteristics, allowing for classification and then taking the morphological base as the source of the taxonomy. The use of morphological approaches allows for different taxonomical classifications, whereas the former approach has the taxonomy embedded in the description.

We have been able to further develop the concept of network genera and species and from this we can relate network types in consistent morphological groupings. In addition, this approach also allows for the determination of evolutionary trends and relationships.

It should be stressed that the current approach is at best an initial attempt that must be tested against its utility in describing any and all networks that may be developed. As Linnaeus had discovered, taxonomies and morphologies are always subject to changes as we learn more about them.

6.0 Glossary

Architecture: The conceptual embodiment of a world view constructed of the system elements utilizing the available technology.

Benefit: An unexpected positive influence, of a monetary or non monetary nature, that is attained by a user of a service.

Centralized: A system philosophy that ensures the overall operations of a system based upon a single and centrally located point of control and influence.

Control: The means of monitoring, managing, adapting, and reconfiguring all information network elements to ensure a consistent level of service delivery.

Data Base: A device or set of devices that stores and retrieves data elements on one or many types.

Distributed: A system that has a fully disconnected and independent set of elements that separately or together provide for all of the elements necessary for the support of the full service.

Distribution Channel: The complete and uninterrupted set of tasks and functions necessary to ensure the economic viable flow of information goods and services from the source to the consume of those services.

Hierarchical: A system with a single point of definition, development, management and control, with reporting relationships of all elements that flow ultimately upward to a dominant control point.

Infrastructure: A sharable, common, enabling means to an end, enduring in a stable fashion, having scale of design, sustainable by an existing market, being the physical embodiment of an underling architecture.

Interconnect: The ability to and systems necessary to effect that ability to provide the connection between any viable set of entities in a network.

Interface: The layers of protocols, tools, development mechanisms that enable an end user to achieve the maximum use of all resource available to them on the network to which it is attached.

Logical Infrastructure: An infrastructure wherein the commonality is based upon the agreements on single set of protocols that operate on differing physical elements that may be under disparate control and management.

Market: The collection of users who create an economically efficient and effective set of transactions for information.

Multimedia: The use of multiple sensory data and inputs by human end users that allows for the interaction of the sensory data with the user.

Multimedia Communications: A multimedia environment consisting of multiple human users in a conversational format in a temporally or spatially based environment.

Need: The creation of a sustaining economic imperative based on consistent benefits to a user.

Network: A transport mechanism combined with the interconnect and control functions.

Paradigm: A specific example, experiment, or physical test case that is used by a large group to explain a broad set of phenomena that are directly or indirectly related to the underlying physical example. A typical set of examples are the use of the Apple MAC icon screen to redefine human interface, the Watson and Crick view of DNA as the coding mechanism for life or waves used by Maxwell to describe light.

Physical Infrastructure: A fully integrated, centrally controlled and defined and regulated physical embodiment of an architecture.

Process: An embodiment of a set of procedures in a software program to effect a set of well defined changes to input.

Processor: A physical device that is used to run a process.

Relational Infrastructure: An infrastructure that is the loose coupling of totally independent sub infrastructures. The interfacing is built upon agreements to interface and sharing of internal standards in each sub infrastructure.

Segmented: A structured partition between two tightly controlled subnetworks.

Transport: The movement of physical information from a set of points to another set of points.

User: Any entity or agent that uses resources on the network.

Value: An economic measure of the effectiveness of the use of information.

Virtual Infrastructure: An infrastructure that is based upon common but disparate sets of protocols that are agreed to on the basis of group decisions.

World View: A philosophy, either explicitly or implicitly, adopted by the system designer, owners, or managers, that reflects the accepted limitations of the prevailing paradigm.

7.0 References

Arms, C., Campus Networking Strategies, DIGITAL Press (Maynard, MA), 1988.

Avery, J.E., VAN, The Regulated Regime, Telecom and Posts Div, Dept of Trade and Industry, UK, Conf on Communications, IEE, pp 78-81, May 1986.

Barlow, W. The Broadband Revolution, Info Tech and Pub Policy, Vl 8, No 1, pp 6-8, 1989.

Bell, D., The Coming of the Industrial Society, Basic Books (New York), 1973.

Bell, T., Technical Challenges to a Decentralized Phone System, IEEE Spectrum, pp 32-37, Sept., 1990.

Bernstein, J., Three Degrees Above Zero, Scribner's(New York), 1984.

Blackwood, M.A., A. Girschick, Theory of Games and Statistical Decisions, Wiley (New York), 1954.

Bostwick, W.E., Program Plan for the National Research and Education Network, Dept. Of Energy, May, 1989.

Brealey, R., S. Myers, Principles of Corporate Finance, McGraw Hill (New York), 1990.

Carnevale,M.L., "Untangling the Debate over Cable Television", Wall Street Journal, p. B1, March, 19, 1990.

Coll, S. The Deal of the Century, Atheneum (New York), 1986.

Copeland, T.E., J.F. Weston, Financial Theory and Corporate Policy, Addison Wesley (Reading, MA) 1983.

Couch, S., T.P. McGarty, H. Kahan, QUBE: The Medium of Interactive Response, A Compendium for Direct Marketeers, Direct Mktg Assn., pp 162-165, 1982.

Depew, D.J., B.H. Weber, Evolution at a Crossroads, MIT Press (Cambridge, MA), 1985.

de Sola Pool, I., Technologies Without Barriers, Harvard University Press (Cambridge, MA), 1990.

de Sola Pool, I., The Social Impact of the Telephone, MIT Press (Cambridge, MA), 1977.

Dertouzos, M.L., et al, Made in America, MIT Press (Cambridge, MA), 1989.

Dertouzos, M.L., J. Moses, The Computer Age, MIT Press (Cambridge, MA), 1979.

Dorfman, R.A., P.A. Samuelson, R.M. Solow, Linear Programming and Economic Analysis, Dover (New York), 1986.

Drucker, P., Adventures of a Bystander, Harper Row (New York), 1979.

Dugan, D.J., R. Stannard, Barriers to Marginal Cost Pricing in Regulated Telecommunications, Public Utilities Fortn., vol 116, No 11, pp 43-50, Nov 1985.

Egan, B.L., Costing and Pricing of the Network of the Future, Proc of International Switching Symposium, pp 483-490, 1987.

Egan, B.L., T.C. Halpin, The Welfare Economics of Alternative Access Carriage Rate Structures in the United States, Telecom Journal, Vol 54, No 1, pp 46-56, Jan 1987.

Fleming, S., What Users Can Expect From New Virtual Wideband Services, Telecommunications, pp 29-44, October, 1990.

Fruhan, W.E., Financial Strategy, Irwin (Homewood, IL), 1979.

Fulhaber, G.R., Pricing Internet: Efficient Subsidy, Information Infrastructures for the 1990's, J.F. Kennedy School of Government, Harvard University, Nov. 1990.

Gawdun, M., Private-Public Network Internetworking, Telecommunications, Vol 21, No 11, pp 49-58, Nov 1987.

Geller, H., US Domestic Telecommunications Policy in the Next Five Years, IEEE Comm Mag, Vol 27, No 8, pp 19-23, Aug 1989.

Harvey, P.H., M.D. Pagel, The Comparative Method in Evolutionary Biology, Oxford (Oxford), 1991.

Henderson, J.M., R.E. Quandt, Microeconomic Theory, McGraw Hill (New York), 1980.

Hills, J., Issues in Telecommunications Policy- A Review, Oxford Surveys in Information Technology, Vol 4, pp 57-96, 1987.

Huber, P.W., The Geodesic Network, U.S. Department of Justice, Washington, DC, January, 1987.

Hudson, H.E., Proliferation and Convergence of Electronic Media, First World Electronic Media Symposium, pp 335-339, 1989.

Irwin, M.R., M.J. Merenda, Corporate Networks, Privatization ans State Sovereignty, Telecommunications policy, Vol 13, No 4, pp 329-335, Dec 1989.

Jantzen, H., High Gothic, Princeton University Press (Princeton, NJ), 1984.

Jardine,N., R. Sibson, Mathematical Taxonomy, Wiley (New York), 1971.

Kahin, B., The NREN as a Quasi-Public Network: Access, Use, and Pricing, J.F. Kennedy School of Government, Harvard University, 90-01, Feb., 1990.

Kahn, A.E., The Economics of Regulation, MIT Press (Cambridge, MA), 1989.

Kirstein, P.T., An Introduction to International Research Networks, IEEE Int Council for Comptr Comm, Ninth International Conf, pp 416-418, 1988.

Kohno, H., H. Mitomo, Optimal Pricing f Telecommunications Service in Advanced Information Oriented Society, Proceedings of International Conf on Info Tech, pp 195-213, 1988.

Konsynski, B.R., E.W. McFarlan, Information Partnerships - Shared Data, Shared Scale, Harvard Business Review, pp. 114-120, September-October, 1990.

Kraus, C.R., A.W. Duerig, The Rape of Ma Bell, Lyle Stuart (Secaucus, NJ) 1988.

Kuhn, T.S., The Structure of Scientific Revolutions, Univ Chicago Press (Chicago), 1970.

Lawrence, P.R., D. Dyer, Renewing American Industry, Free Press (New York), 1983.

Luce, R.D., H. Raiffa, Games and Decisions, Dover (New York), 1985.

Mandelbaum, R., P.A. Mandelbaum, The Strategic Future of Mid Level Networks, J.F. Kennedy School of Government, Harvard University, Working Paper, October, 1990.

Margulis, L., K.V. Schwartz, Five Kingdoms, Freeman (New York), 1988.

Markoff, J., Creating a Giant Computer Highway, New York Times, Sept. 2, 1990.

McGarty, T.P., B. Pomerance, M. Steckman, CATV for Computer Communications Networks, IEEE CompCon, 1982.

McGarty, T.P., Business Plans, J. Wiley (New York), 1989.

McGarty, T.P., Financial Data Networking and Technological Impacts, INTELCOM, 1980.

McGarty, T.P., G.J. Clancey, Cable Based Metro Area Networks, IEEE Jour on Sel Areas in Comm, Vol 1, No 5, pp 816-831, Nov 1983.

McGarty, T.P., Growth of EFT Networks, Cashflow, pp 25-28, Nov. 1981.

McGarty, T.P., L.L. Ball, Network Management and Control Systems, IEEE NOMS Conf, 1988.

McGarty, T.P., Local Area Wideband Data Communications Networks, EASCON, 1982.

McGarty, T.P., M. Sununu, Applications of Multi-Media Communications Systems to Health Care Management, HIMSS Conference, San Francisco, Feb. 1991.

McGarty, T.P., Multimedia Communications in Diagnostic Imaging, Investigative Radiology, April, 1991.

McGarty, T.P., R. Veith, Hybrid Cable and Telephone Networks, IEEE CompCon, 1983.

McGarty, T.P., S.J. McGarty, Impacts of Consumer Demands on CATV Local Loop Communications, IEEE ICC, 1983.

McGarty, T.P., Multimedia Communications Systems, IMAGING, Nov. 1990.

McGarty, T.P., Multimedia Communications Architectures, SPIE Optical Communications Conference, Boston, MA, September, 1991.

McGarty, T.P., Alternative Networking Architectures; Pricing, policy and Competition, Information Infrastructures for the 1990s, Harvard University, J.F. Kennedy School of Government, Nov. 1990.

McGarty, T.P., S.J. McGarty, Information Architectures and Infrastructures; Value Creation and Transfer, 19th Annual Telecommunications Policy Research Conference, Solomons Is, MD, September, 1991.

McLuhan, M., Understanding Media, NAL (New York), 1964.

McLuhan, M., The Gutenberg Galaxy, Univ Toronto Press (Toronto), 1962.

Muroyama, J.H., H.G. Stever, Globalization of Technology, National Academy Press (Washington, DC), 1988.

Noam, E. M., Network Tipping and the Tragedy of the Common Network, J.F. Kennedy School of Government, Harvard University, Working Paper, October, 1990.

Nugent, P.M., User Objectives in the Development of International Telecommunications Policy, Inf. Age, Vol 7, No 4, pp 200-202, Oct 1985.

O'Hara, S., The Evolution of A Modern Telecommunications Network to the Year 2000 and Beyond, IEE Proc, Vol 132, No 7, pp 467-480, 1985.

Pindyck, R.S., D.L. Rubinfield, Microeconomics, McGraw Hill (New York), 1989.

Porter, M., Competitive Advantage, Free Press (New York), 1985.

Porter, M., Competitive Strategy, Free Press (New York), 1980.

Porter, M., The Competitive Advantage of Nations, Free Press (New York), 1990.

Quaterman, J.S., The Matrix, Digital Press (Maynard, MA), 1990.

Roszak, T., The Cult of Information, Pantheon (New York), 1986.

Rutkowski, A.M., Computer IV: Regulating the Public Information Fabric, Proc of the Regional Conf of the International Council for Computer Communications, pp 131-135, 1987.

S. 898, U.S. Senate Hearings on Telecommunications Competition, Serial No 97-61, June, 1981.

Shubik, M., A Game Theoretic Approach to Political Economy, MIT Press (Cambridge, MA), 1987.

Shubik, M., Game Theory in the Social Sciences, MIT Press (Cambridge, MA), 1984.

Sirbu, M.A., D.P. Reed, An Optimal Investment Strategy Model for Fiber to the Home, International Symposium on Subscriber Loops to the Home, pp. 149-155, 1988.

Spulber, D.F., Regulation and Markets, MIT Press (Cambridge, MA), 1990.

Stace, C.A., Plant Taxonomy and Biosystematics, Arnold (London), 1989.

Tannenbaum, A., Computer Communications, Prentice Hall (Englewood Cliffs, NJ), 1989.

Temin, P., The Fall of the Bell System, Cambridge Univ Press (Cambridge), 1987.

Tjaden, G., CATV and Voice Telecommunications, IEEE ICC, 1984.

Toffler, A., The Adaptive Corporation, Bantam (New York), 1985.

Toy, S., Castles, Heinemann (London), 1939.

Vickers, R., T. Vilmansen, The Evolution of Telecommunications Technology, Proc IEEE, vol 74, No 9, pp 1231-1245, Sept 1986.

Von Auw, A., Heritage and Destiny, Praeger (New York), 1983.

Von Hippel, E. The Sources of Innovation, Oxford (New York), 1988.

Von Neumann, J., O. Morgenstern, Theory of Games and Economic Behavior, Wiley (New York), 1944.

West, E.H., et al, Design, Operation, and Maintenance of a Multi Firm Shared Private Network, IEEE MONECH Conf, pp80-82, 1987.

Wilkes, M.V., The bandwidth Famine, Comm ACM, pp 19-21, Vol 33, No 8, Aug 1990.

Winograd, T., F. Flores, Understanding Computers and Cognition, Addison Wesley (Reading, MA), 1987.

Wirth, T.E., Telecommunications in Transition, U.S. House of Representatives Committee Report, Nov, 1981.

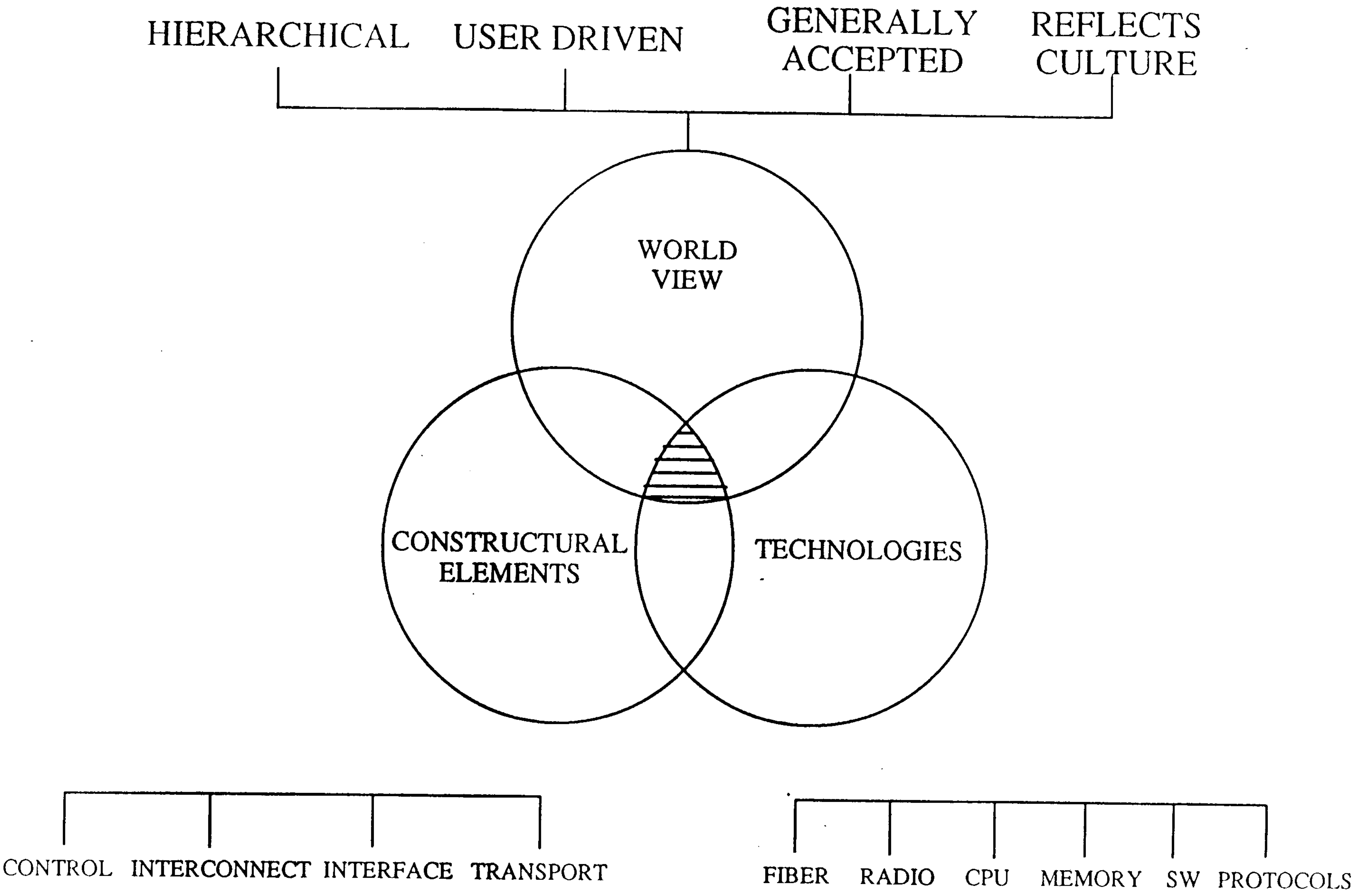
Wolfe, T., From Bauhaus to Our House, Simon and Schuster (New York), 1981.

Zuboff, S., In the Age of the Smart Machine, Basic Books (New York), 1988.

8.0 Figures

27. ISO Morphology
28. Public Switched Network
29. CATV Network
30. Taxonomy Structure

ARCHITECTURE



HIERARCHICAL

USER DRIVEN

GENERALLY ACCEPTED

REFLECTS CULTURE

WORLD VIEW

CONSTRUCTURAL ELEMENTS

TECHNOLOGIES

CONTROL

INTERCONNECT

INTERFACE

TRANSPORT

FIBER

RADIO

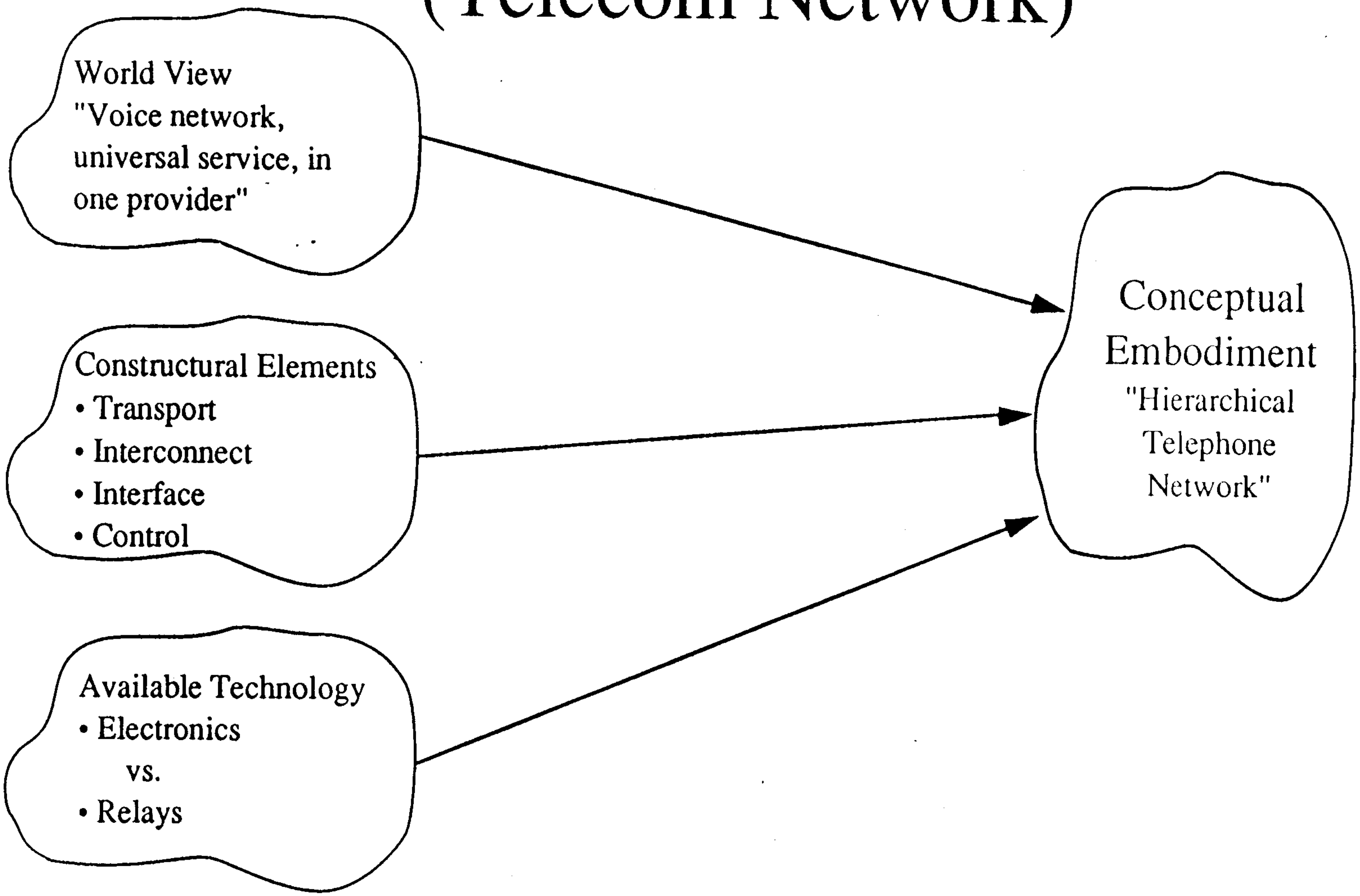
CPU

MEMORY

SW

PROTOCOLS

Architecture (Telecom Network)



World View
"Voice network, universal service, in one provider"

Constructural Elements
- Transport
- Interconnect
- Interface
- Control

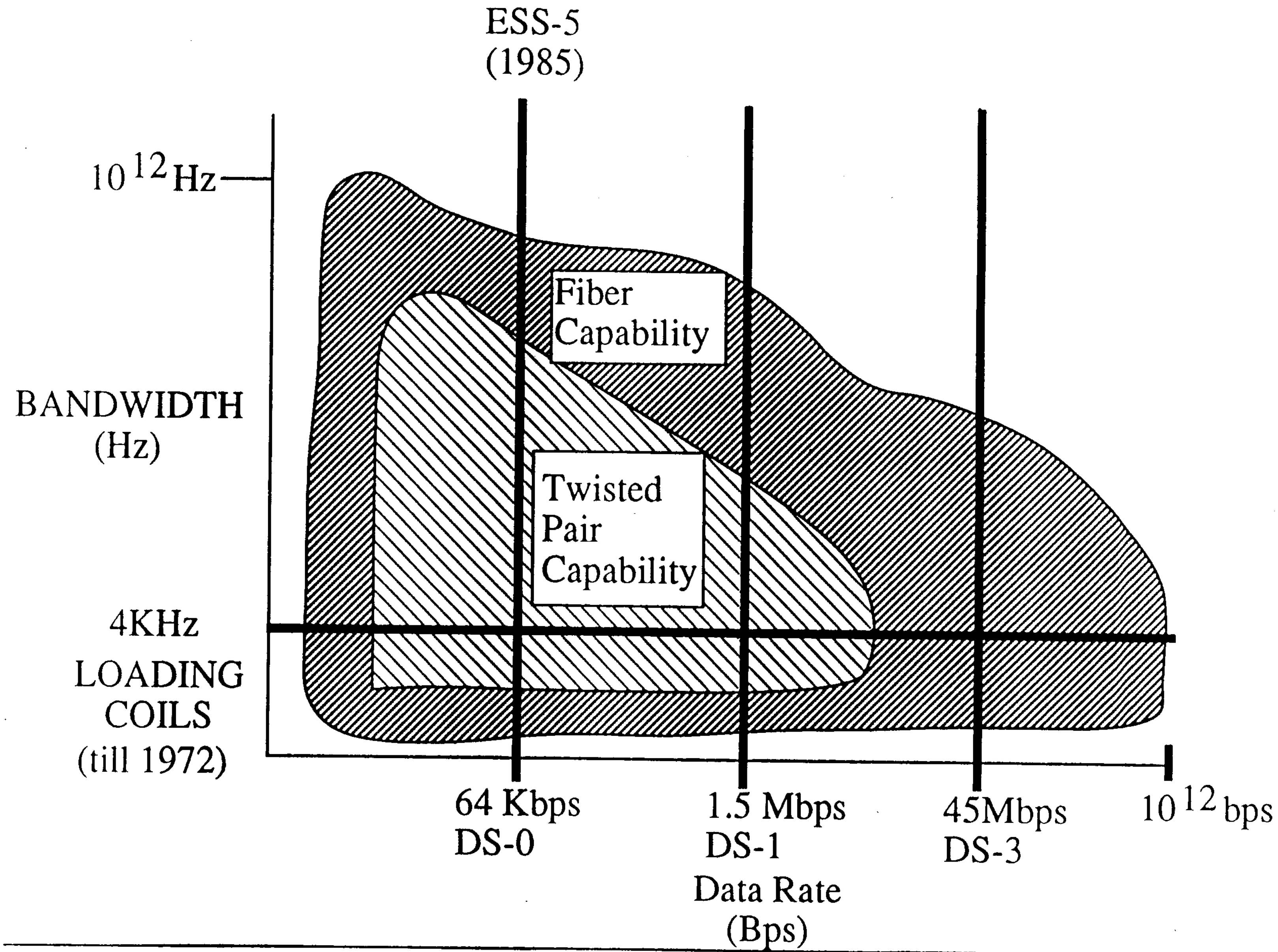
Available Technology
- Electronics

vs.

- Relays

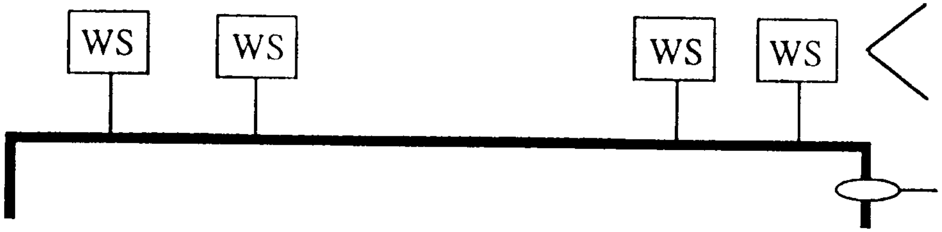
Conceptual Embodiment
"Hierarchical Telephone Network"

FLEXIBILITY, STANDARDS AND REALITY



ENABLING NETWORKS

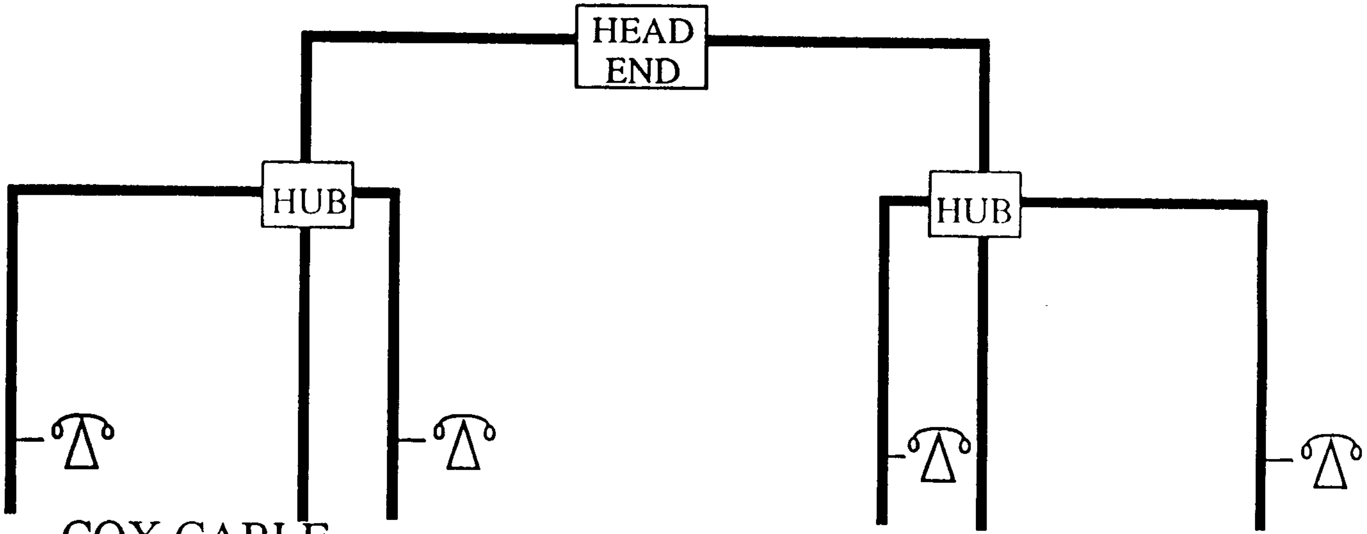
ETHERNET
LANS



INTERFACE
INTERCONNECT
CONTROL

COAX
TRANSPORT ONLY

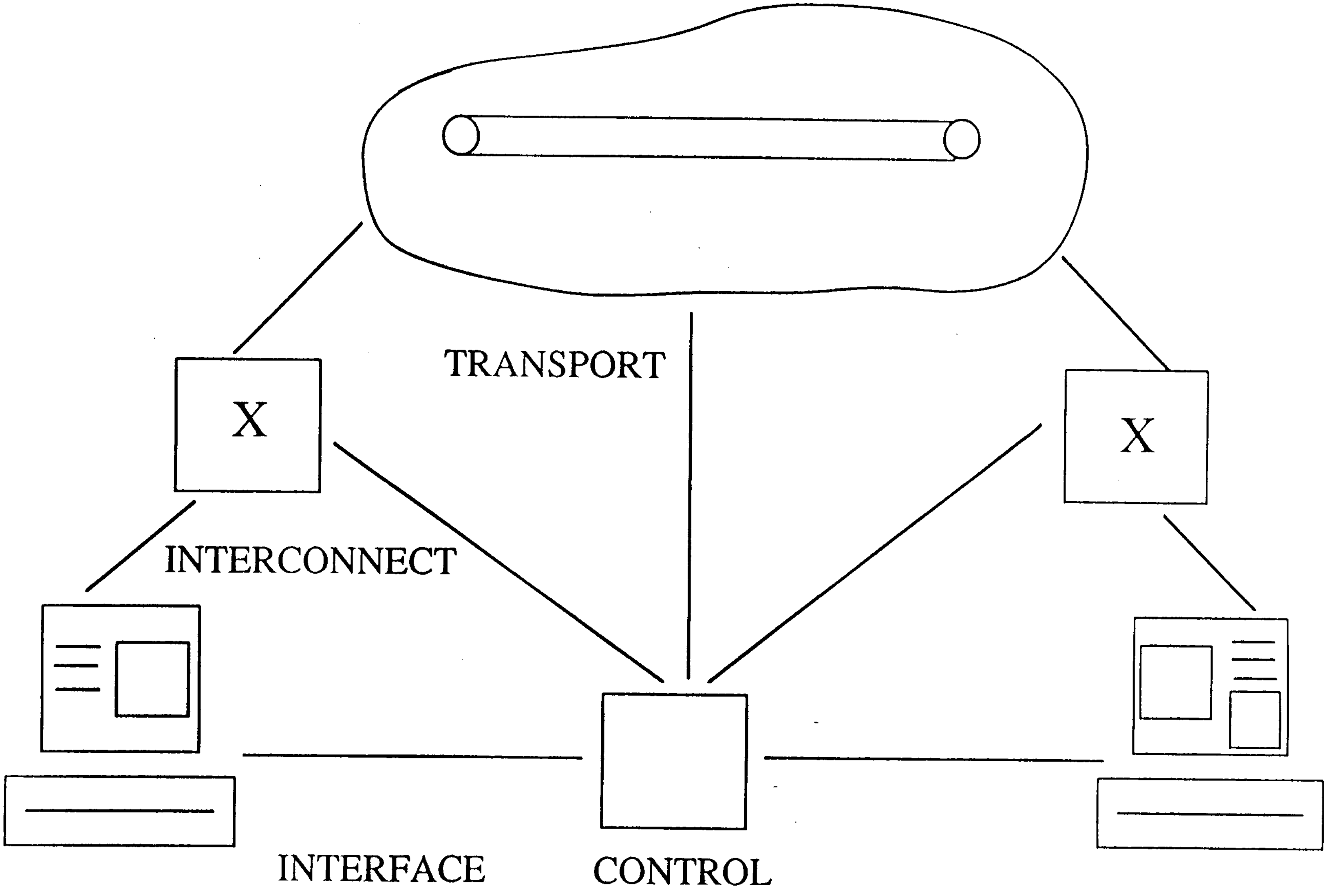
CATV



COX CABLE
(CDMA)
INDAX

WARNER CABLE
(POLLING)
QUBE

ARCHITECTURAL ELEMEMTS



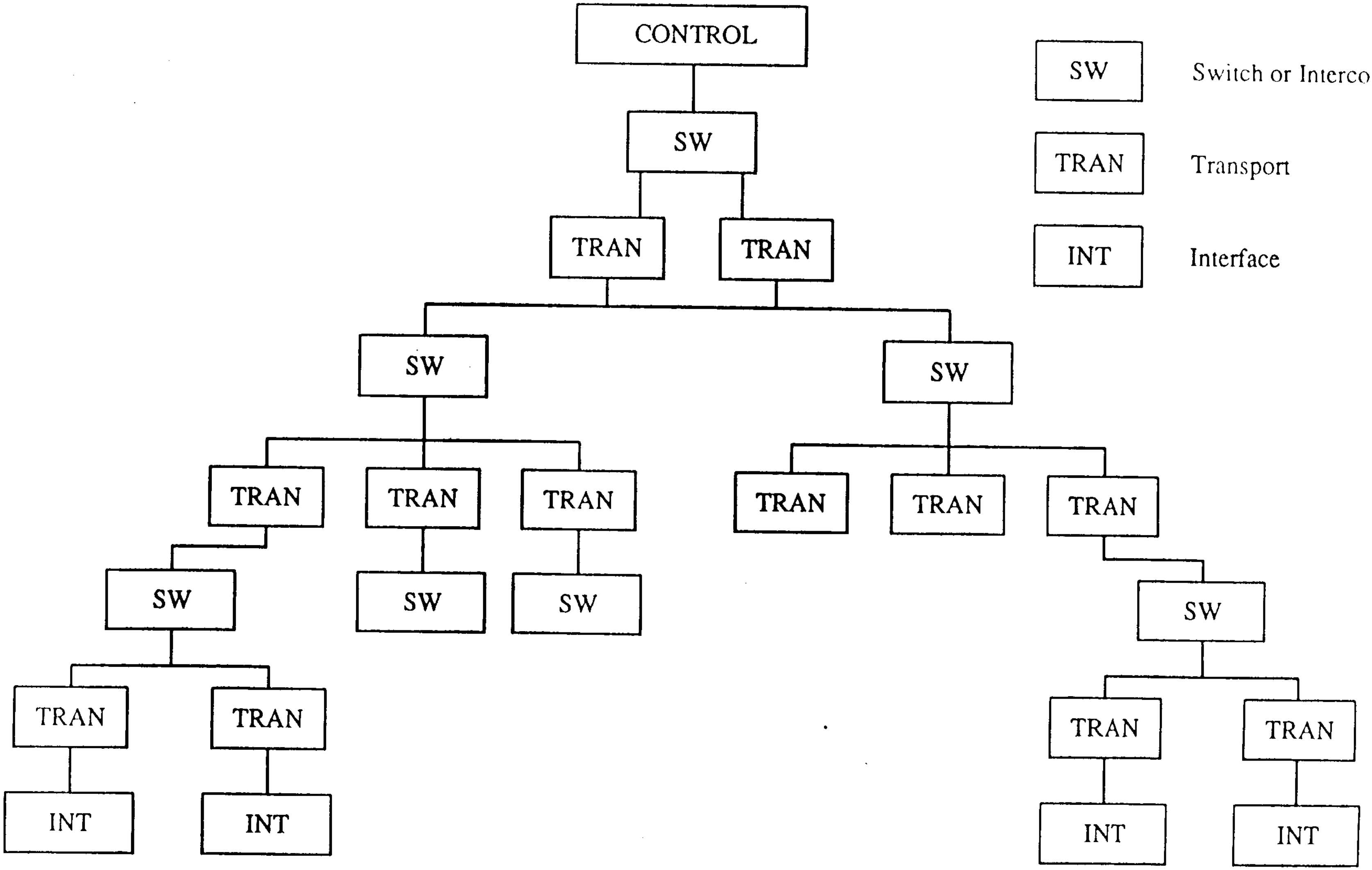
TRANSPORT

INTERCONNECT

INTERFACE

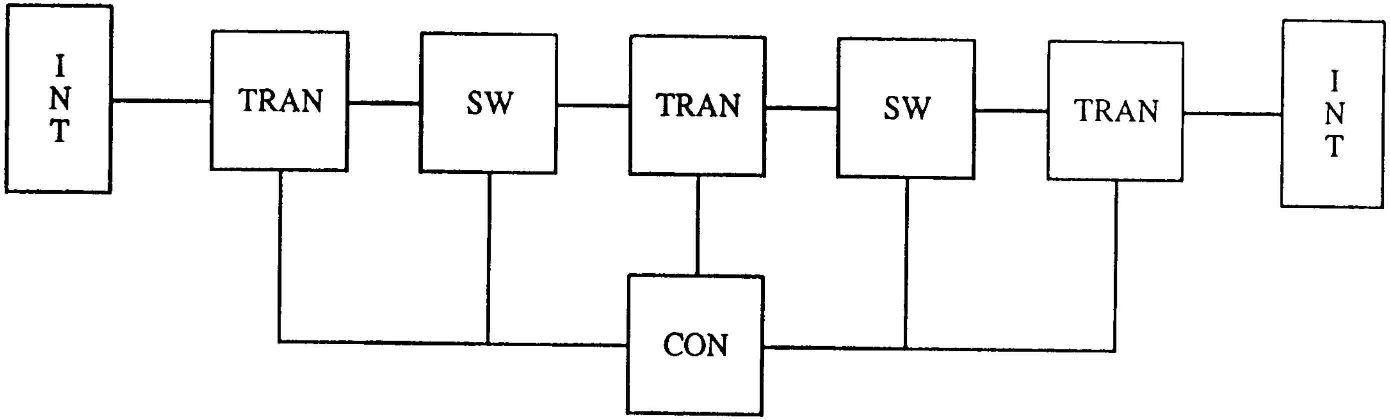
CONTROL

HIERARCHICAL

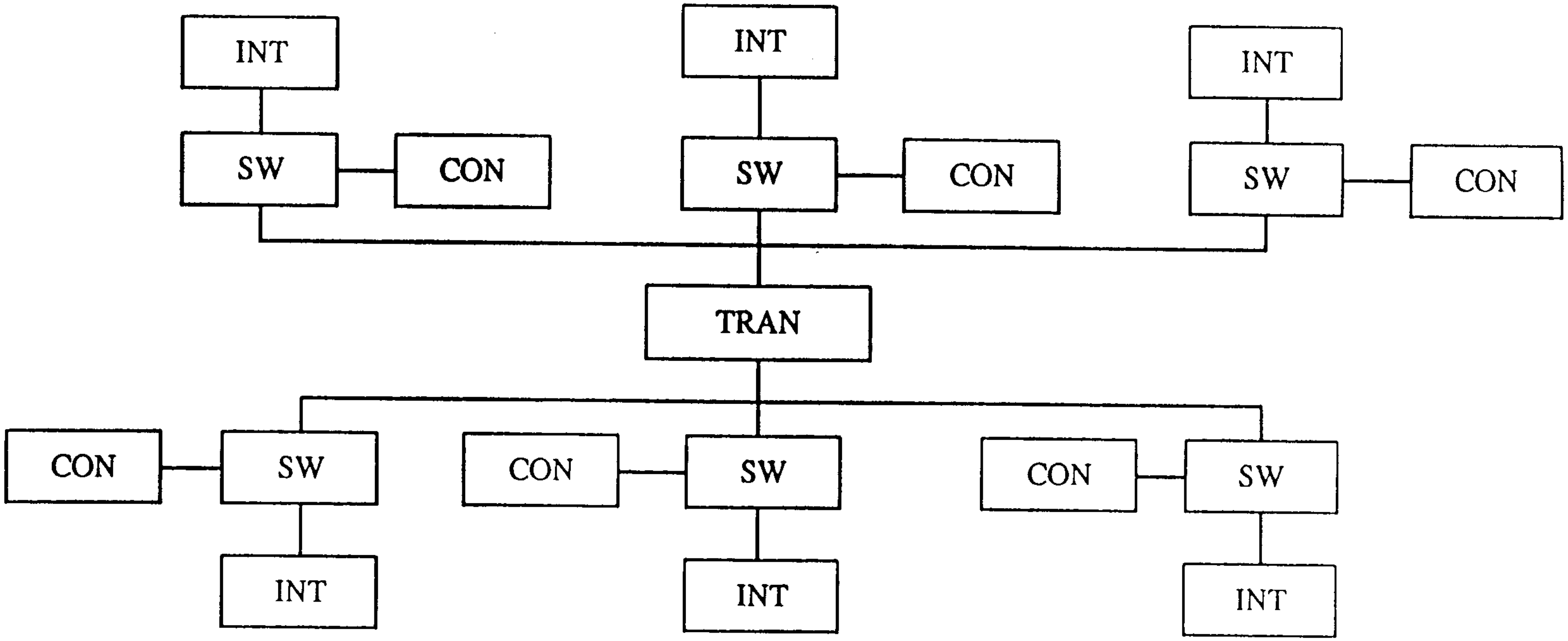


SW	Switch or Interconnect
TRAN	Transport
INT	Interface

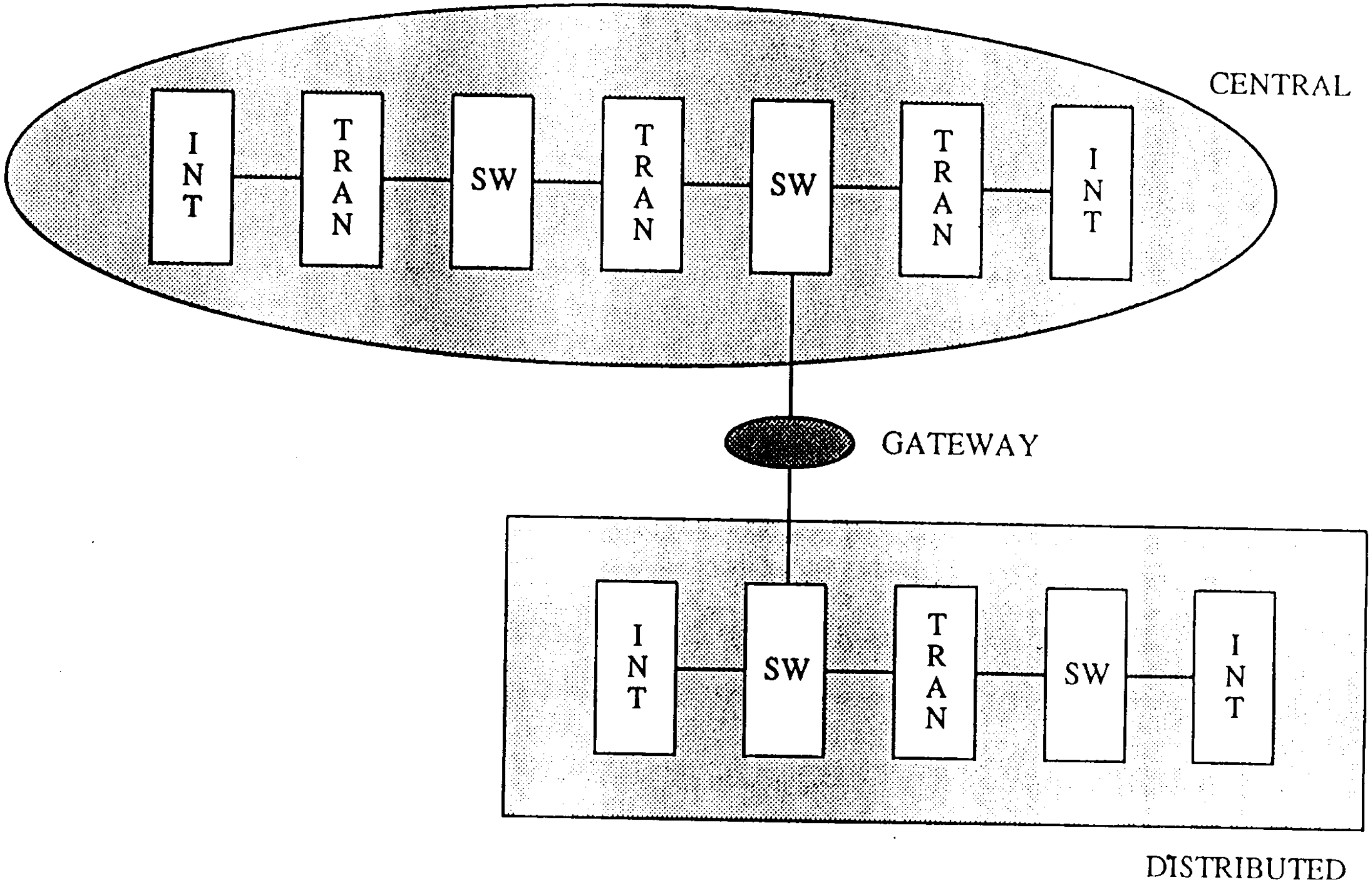
CENTRALIZED



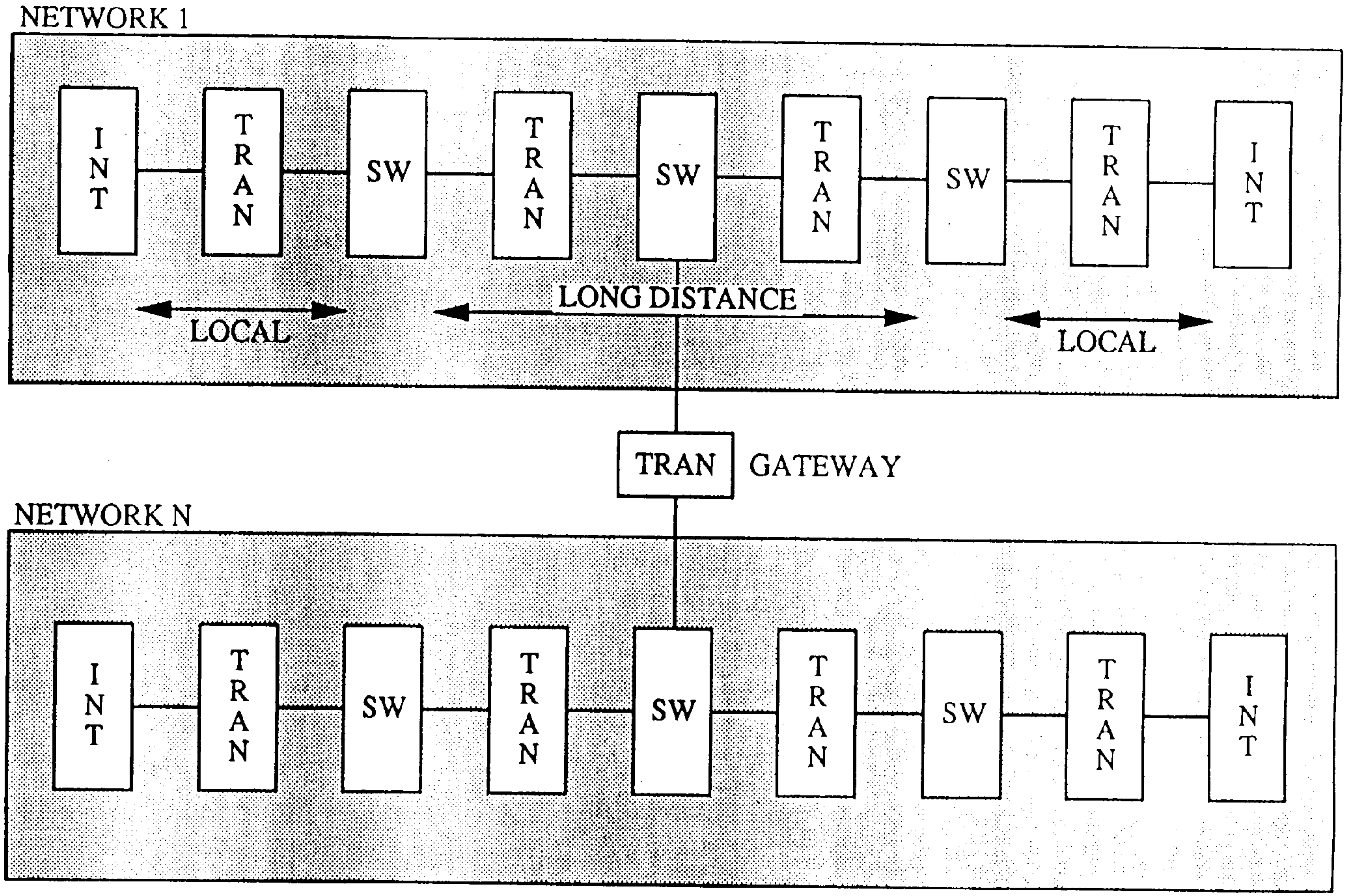
DISTRIBUTED



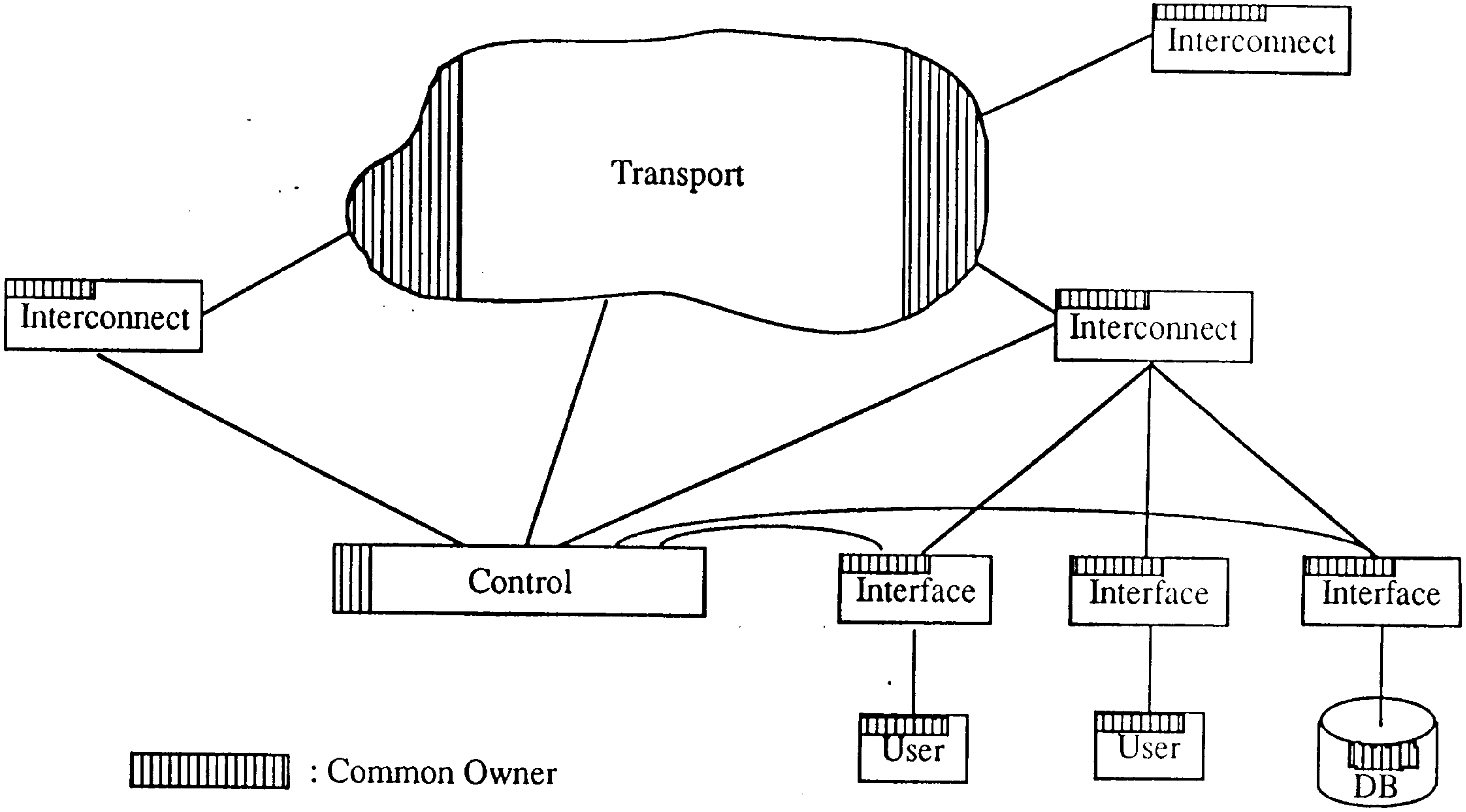
SEGMENTED


INT
TRAN
SW
TRAN
SW
TRAN
INT
CENTRAL
GATEWAY
INT
SW
TRAN
SW
INT
DISTRIBUTED

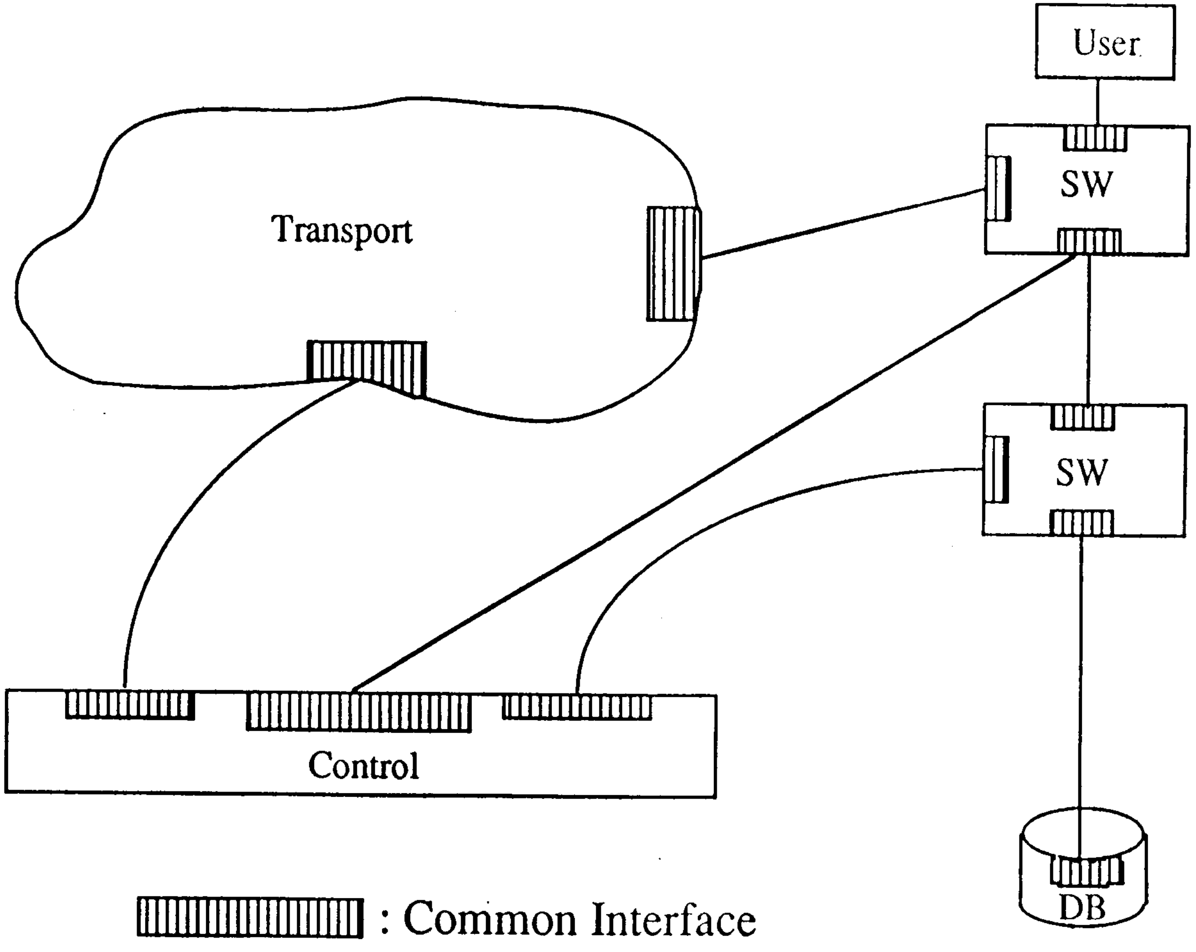
PARTITIONED



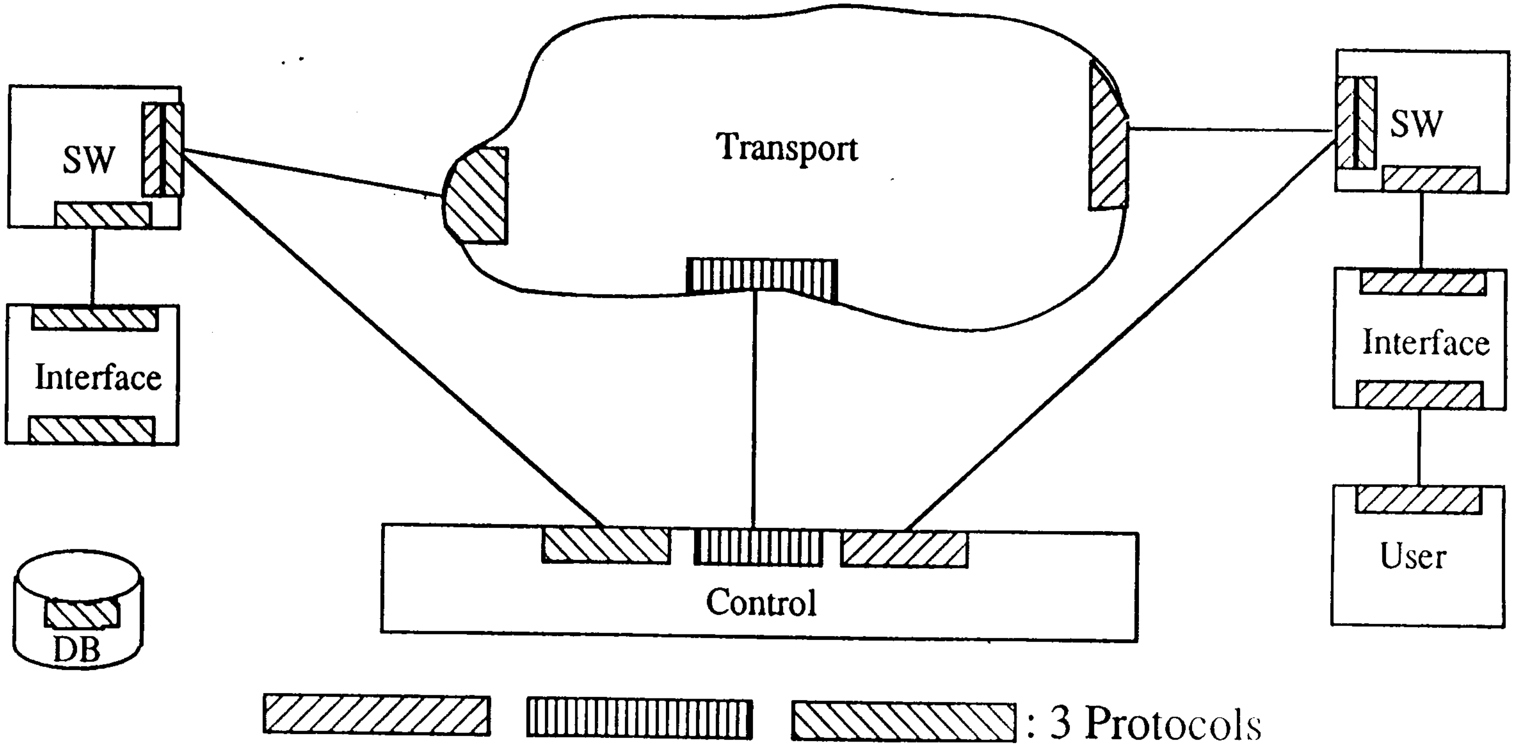
Physical Infrastructure



Logical Infrastructure

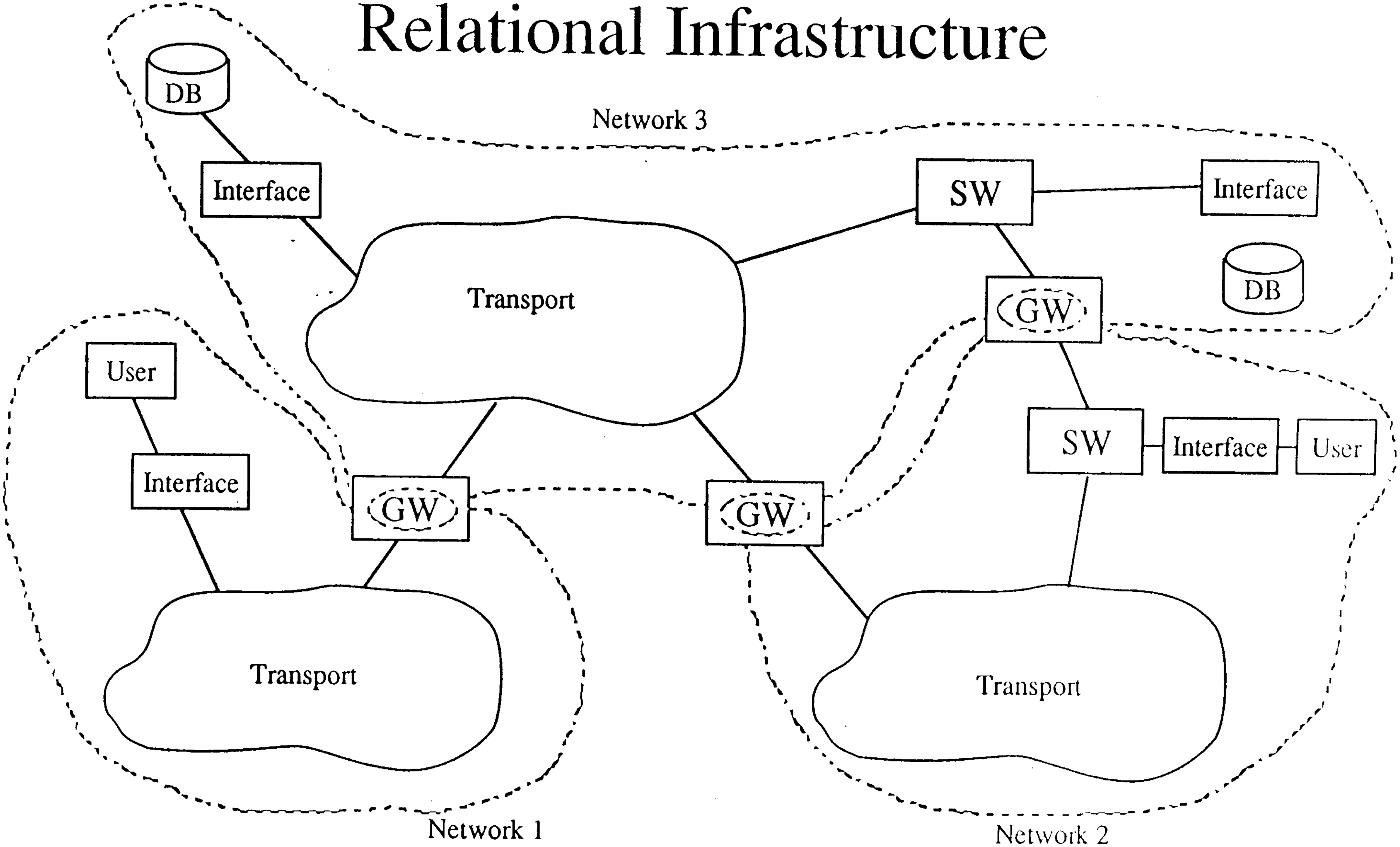


Virtual Infrastructure



▧ ▥ ▨ : 3 Protocols

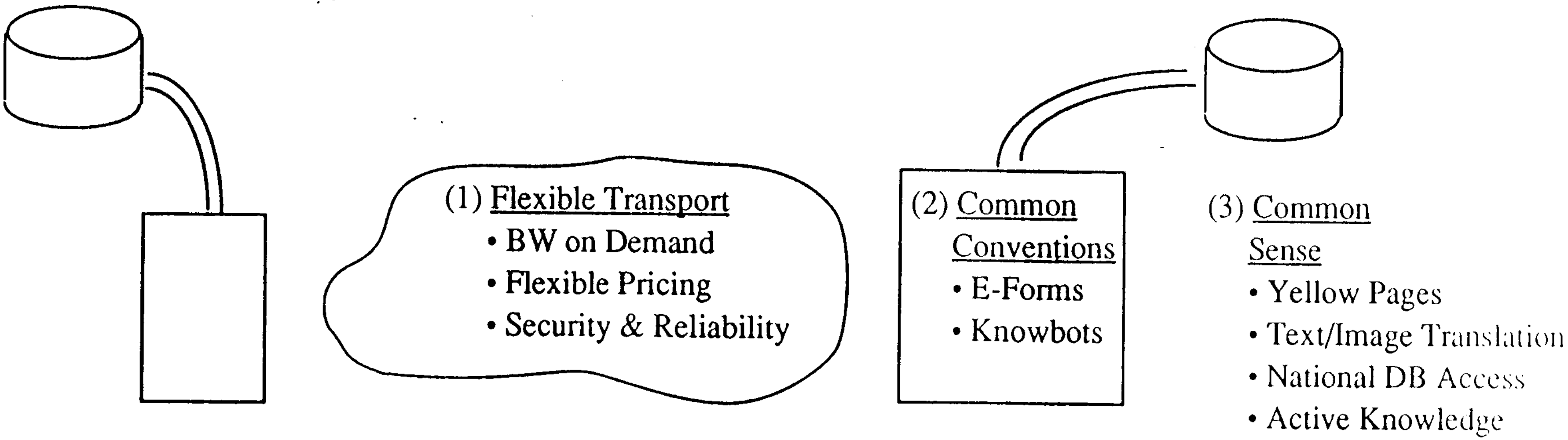
Relational Infrastructure



Information Infrastructure Visions

"Common resource of computer-communications services, as easy to use and as important as the telephone . . ."

(Dertouzos)

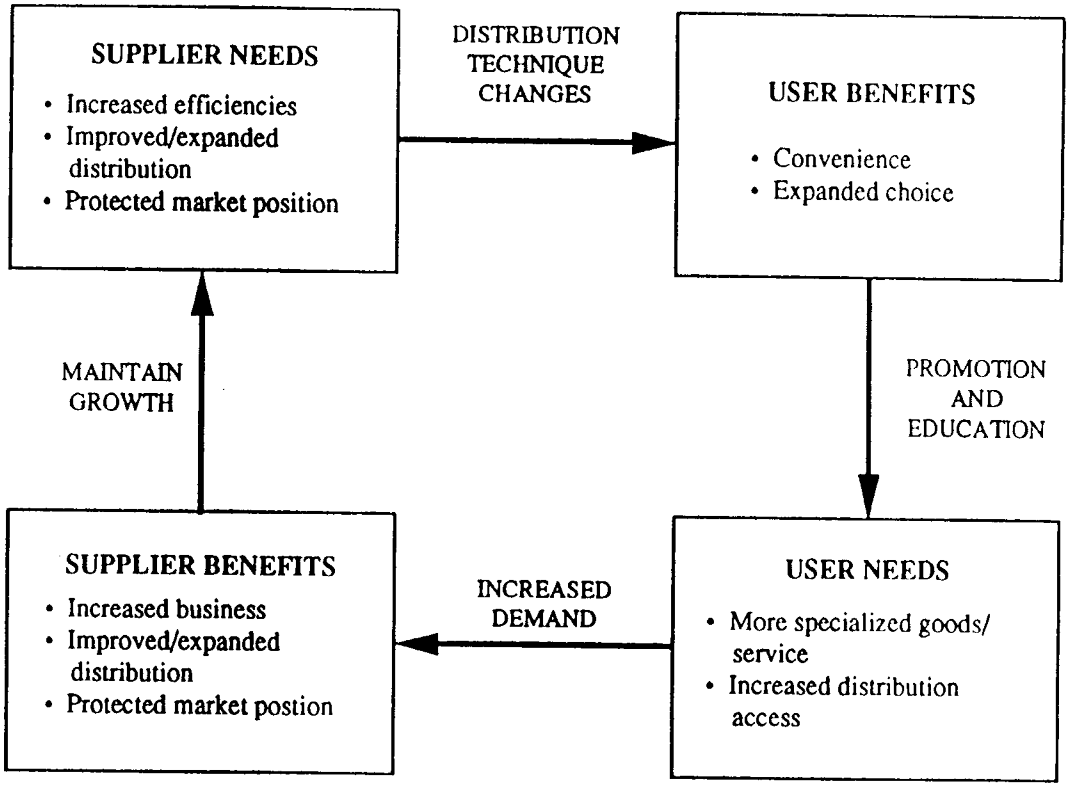


(1) <u>Flexible Transport</u>
- BW on Demand
- Flexible Pricing
- Security & Reliability

(2) <u>Common Conventions</u>
- E-Forms
- Knowbots

(3) <u>Common Sense</u>
- Yellow Pages
- Text/Image Translation
- National DB Access
- Active Knowledge

NEEDS/BENEFIT CYCLE



SUPPLIER NEEDS

- Increased efficiencies
- Improved/expanded distribution
- Protected market position

DISTRIBUTION TECHNIQUE CHANGES

USER BENEFITS

- Convenience
- Expanded choice

PROMOTION AND EDUCATION

USER NEEDS

- More specialized goods/ service
- Increased distribution access

INCREASED DEMAND

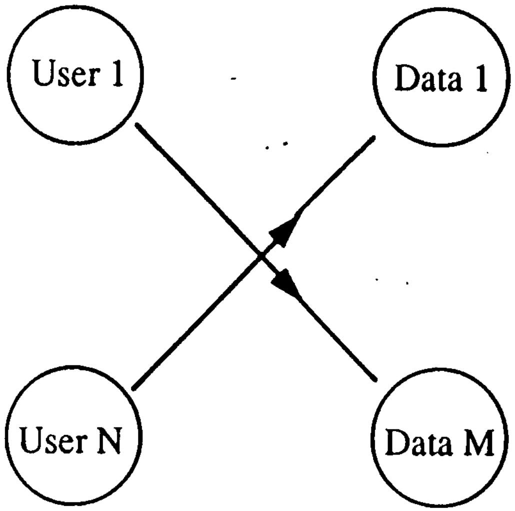
SUPPLIER BENEFITS

- Increased business
- Improved/expanded distribution
- Protected market postion

MAINTAIN GROWTH

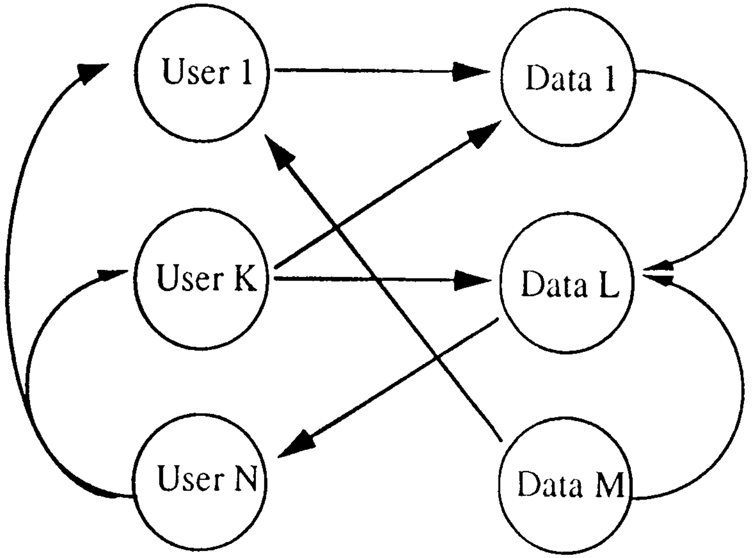
Architecture Evolution

Original



- Identify Data Set
- Establish Connection
- Transfer Data

Proposed



- Interaction
- Change
- Modifications
- Transaction (eg Value Creation)

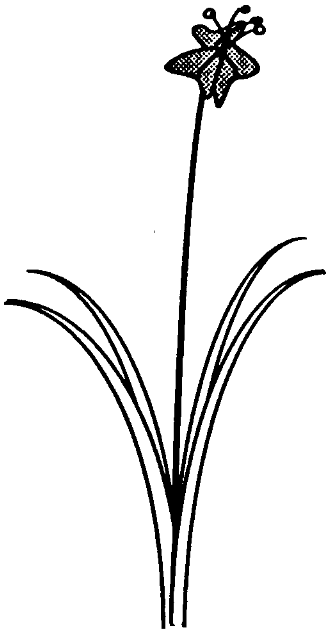
Garden = Collection of Species

Networks

Morphology

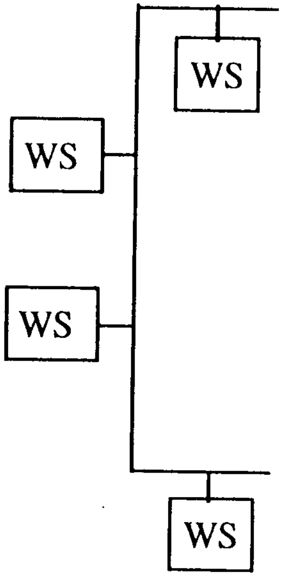
- Ability to <u>uniquely</u> characterize through visible and measurable characteristics

<u>Plant</u>



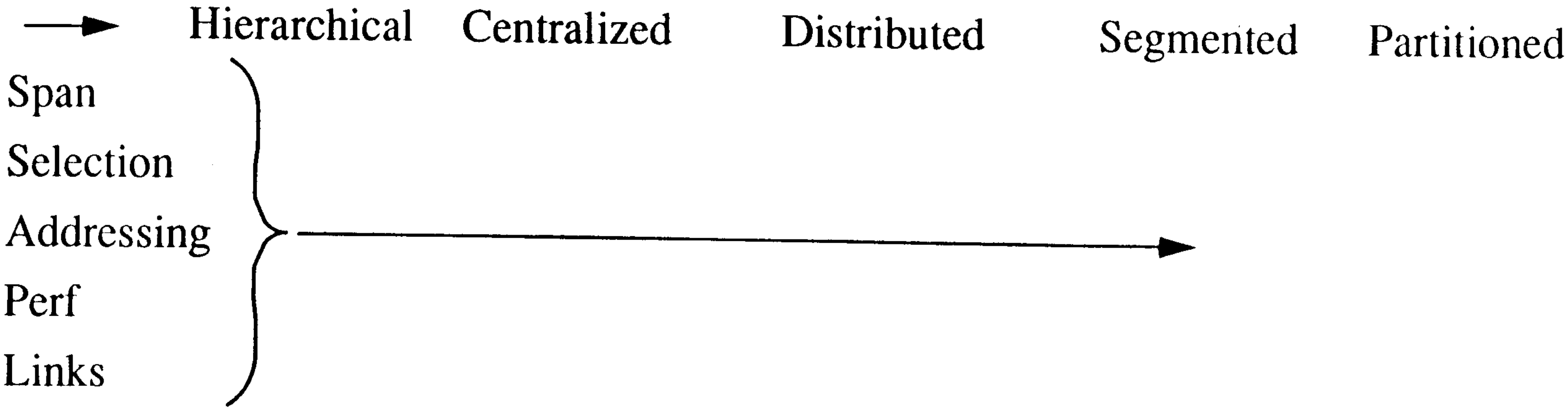
- Covered seed (fruit)
- Flowering
- Single Flower
- Single Leaf
- Parallel veins
- 3 sepals
- 3 petals
- One pistil
- 3 Stamen
- *<u>Hemerocalis</u>*: Species

<u>Network</u>



- Wire based
- Coaxial
- CSMA-ed switch
- Distributed control
- Local
- *<u>LAN</u>*: Species

Interconnect



→ Hierarchical Centralized Distributed Segmented Partitioned

Span
Selection
Addressing
Perf
Links

Interface

- Voice
  - Single
  - Conf
- Video
  - NTSC
  - HDTV
  - D16
- Text
  - Ascii
  - X.11
  - Hi Res
- Image
  - Bit Map
  - Hi Res
  - Variable
- Data
  - Single Stream
  - Multiple

- Multiplicity
- Integratability
- Conversationality
- Links

Control

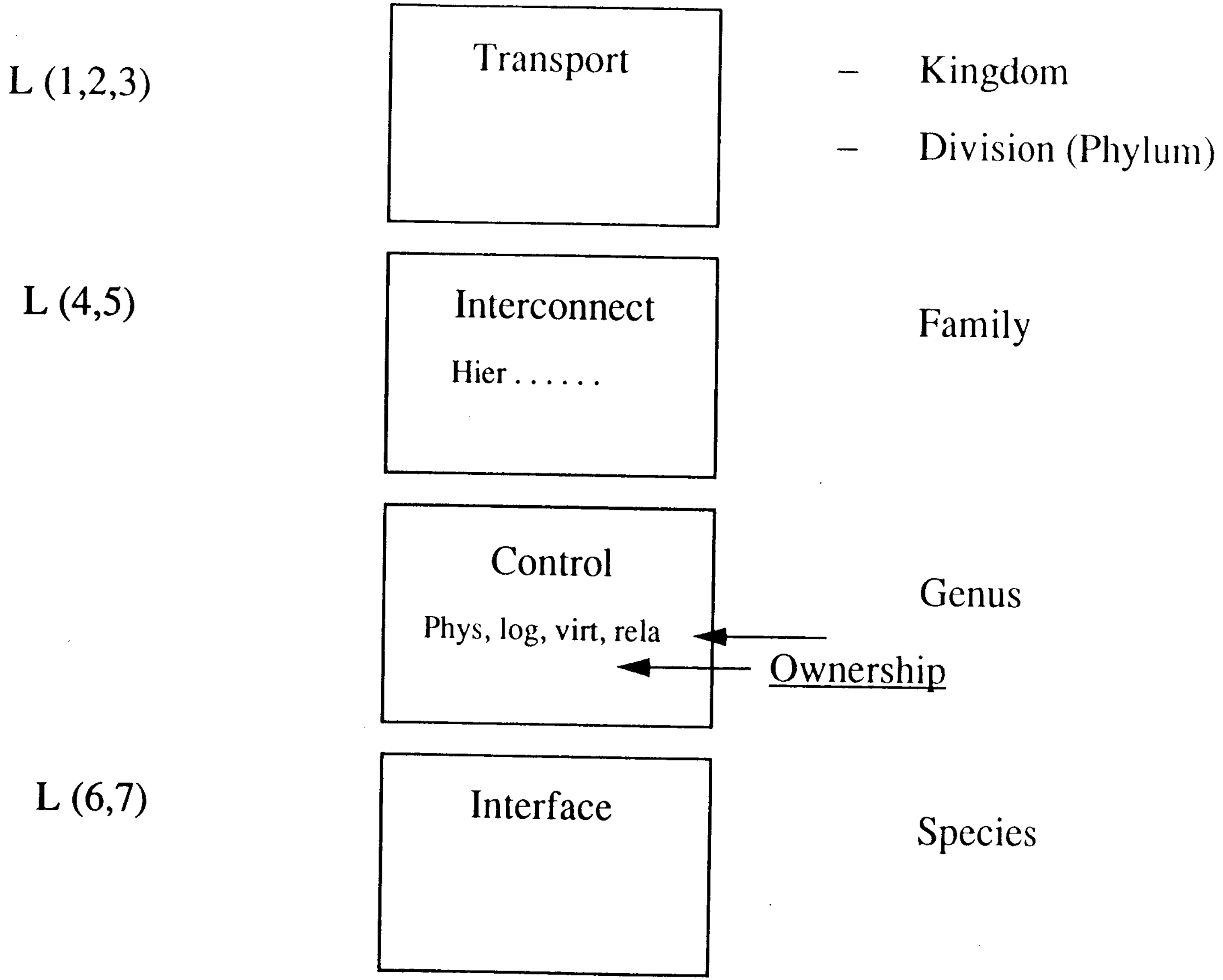
Physical Logical Virtual Relational

- Users
- Maintenance
- Scope (Functions)

Transport

- Wire
  - Copper
  - Coax
  - Fiber
- Wireless
  - Radio
  - Satellite

- Method (Analog/Digital)
- Mode (Synch/Asynch)
- Link (Data Control, Clear)



L (1,2,3)

Transport

– Kingdom

– Division (Phylum)

L (4,5)

Interconnect

Hier . . . . . .

Family

Control

Phys, log, virt, rela

Genus

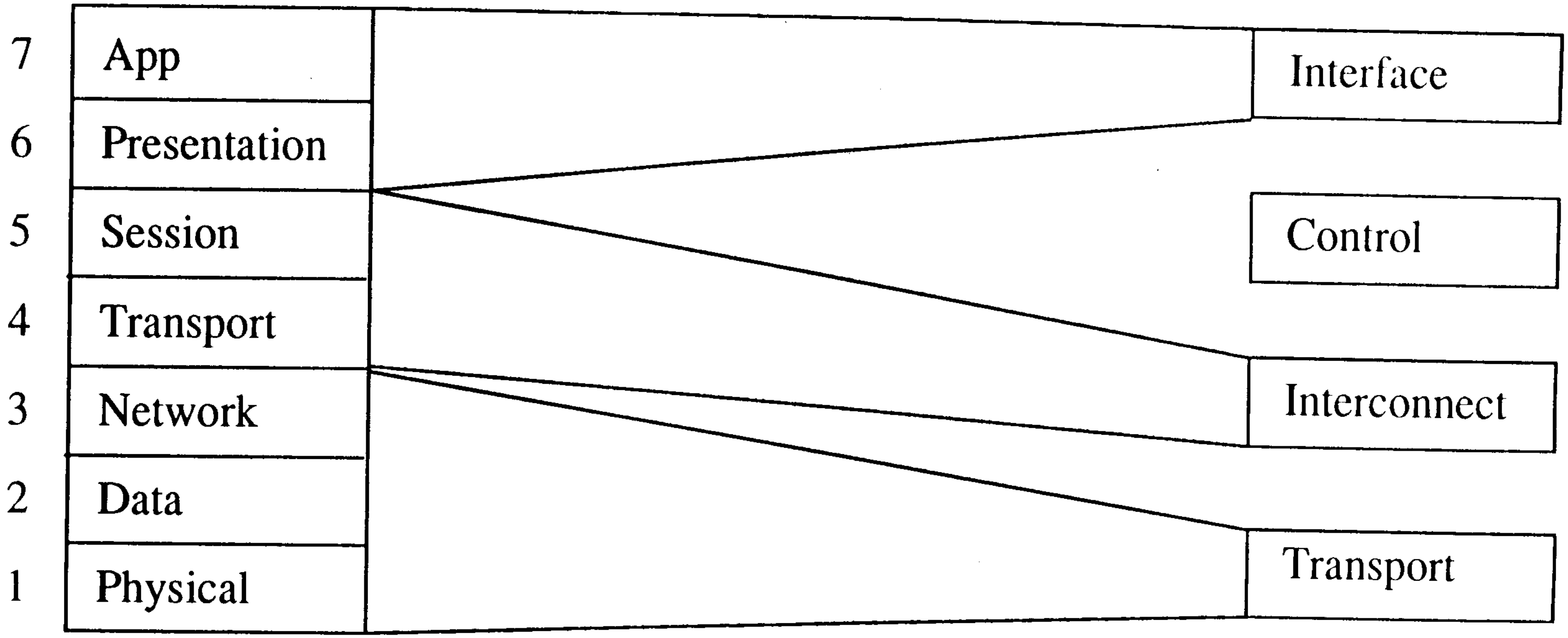
Ownership

L (6,7)

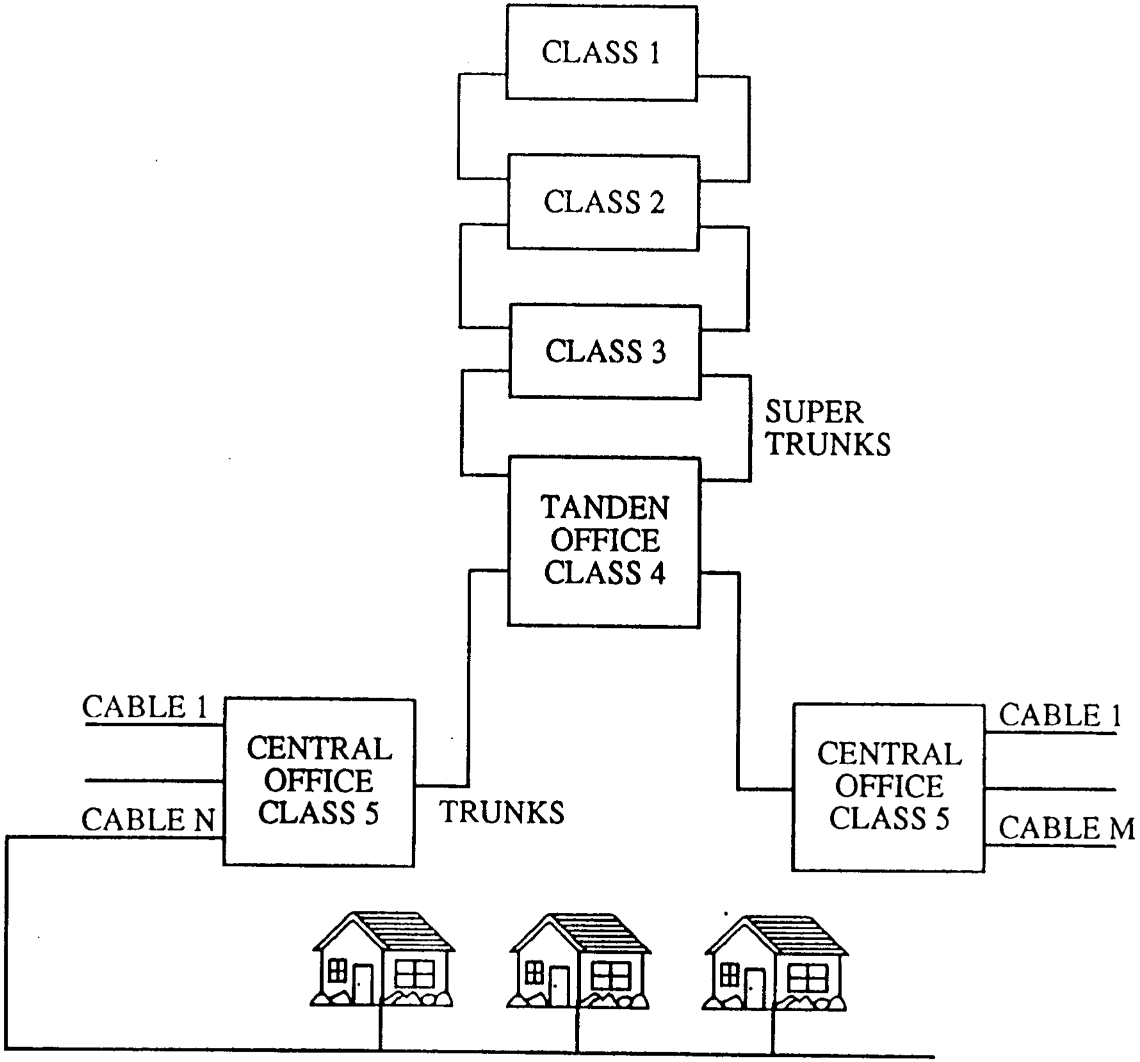
Interface

Species

ISO vs. Taxonomy

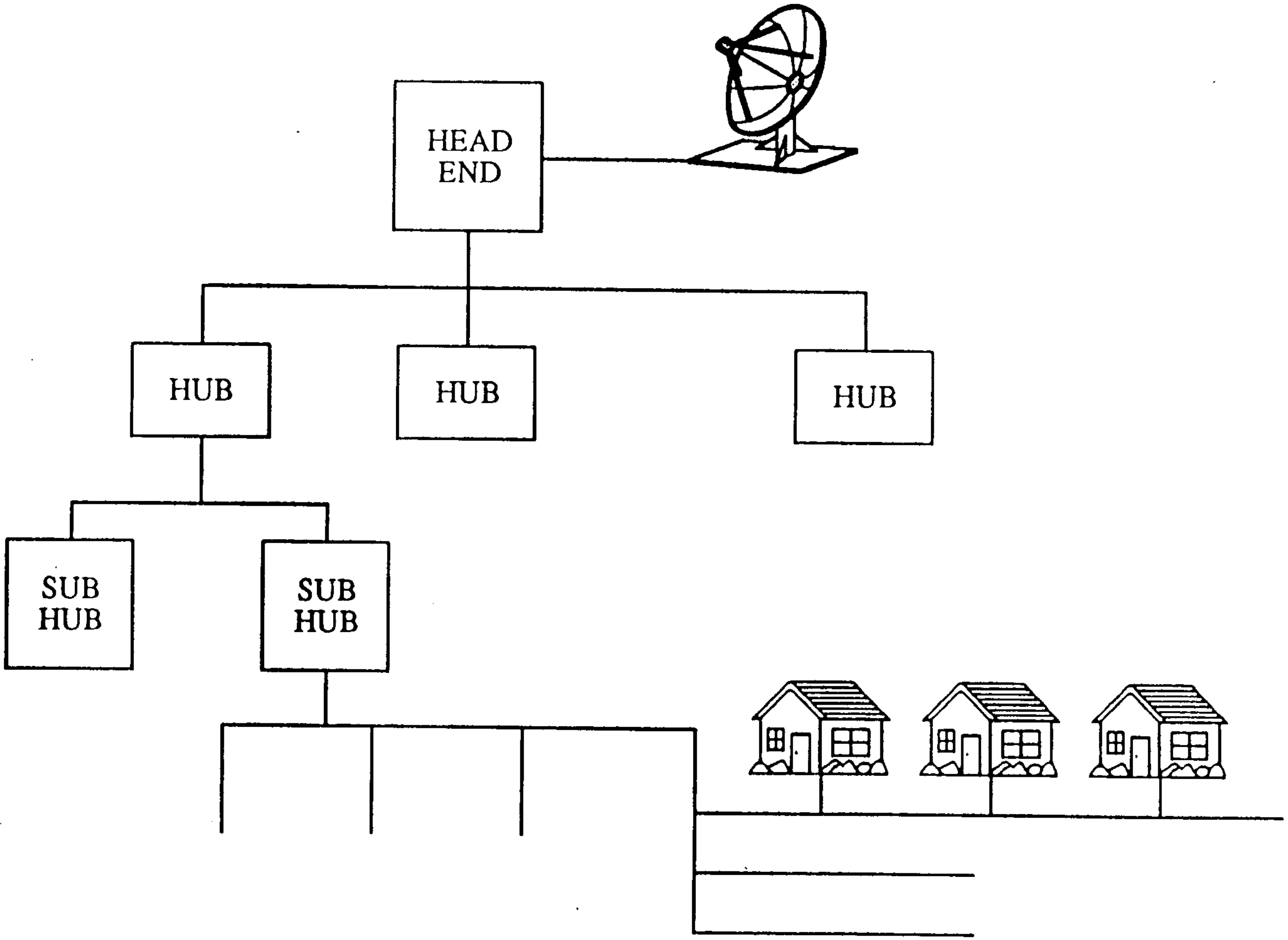


CURRENT SWITCHED NETWORK



28

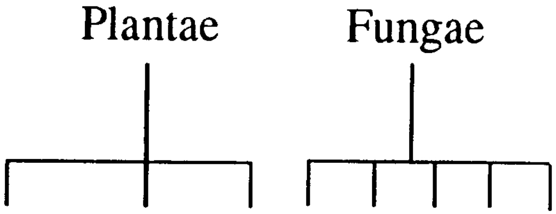
CATV NETWORK STRUCTURE



Taxonomy

- The classification of organisms based on consistent clustering in a hierarchical fashion along a common morphological structure

<u>Plants</u>



<u>Networks</u>