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The Patterns of Interorganizational Networks in the Development of Data Communications Technologies

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ABSTRACT

Technology alliances have been used increasingly in the last few years in the data communications industry. The dynamics of these alliances highlight the dilemma (or strategy) of firms to achieve interoperability with competing product platforms while attempting to differentiate and promote their own products. Using social network analysis, we explore and identify the network patterns of technology alliances in the development of data communications technologies. To attribute meaning to these network patterns, a taxonomy of innovations based on the framework by Henderson and Clark (1990) is created with the help of two well-qualified field experts. Based on 150 sampled firms and 319 technology alliances in the data communications industry from 1985-1996, we observe that the characteristics of core-periphery structure can best describe the patterns of networks in this industry. More specifically, a small number of firms in the core of the network have jointly developed modular innovations which have implications for emerging standards, whereas many other firms have come together for more limited purposes, supporting incremental innovations at the periphery of the network. Several issues are raised on the correlation between core-periphery structure and the nature of innovation and the conditions under which generalizability can be made. Finally, an important managerial implication is that technology alliances are not merely a choice for sharing costs and risks with partners but are instrumental to the standardization and adoption process in the market. The history of technology alliances among competitors within the industry does determine the trends of emerging technologies.

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1. Introduction

Strategic alliances have been used increasingly in many technology-intensive industries since the 1980s (Garrette & Dussauge 1995; Hagedoorn 1995; Hergert & Morris 1988; Mariti & Smiley 1983). Strategic alliances are often depicted as cooperative relationships creating values for partners (Harrigan 1987). According to recent theoretical and empirical literature, firms establish strategic alliances in order to integrate external knowledge (Arora & Gambardella 1995; Hamel 1991; Kogut & Zander 1992), reduce technological and market uncertainty (Mitchell & Singh 1992; Roberts 1985), create synergy between complementary technologies (Olleros & Macdonald 1988; Sinha & Cusumano 1991), and set forth new standards (Axelrod et al. 1995). Hence, from strategic management viewpoint, strategic alliances have important implications for technological innovation.

This paper is focused on the patterns and characteristics of alliances in the data communications industry. It aims to develop an understanding of the industry in which strategic alliances have been employed to combine complementary knowledge among potential competitors. According to the knowledgeable critics in this industry, strategic alliances have effectively influenced the properties of emerging technologies. The study therefore raises several implications for the evolution of technology and organization, which may complement the theoretical and empirical insights arising from the existing literature in technological innovation and strategic management.

A quantitative method that is useful for understanding the patterns of relationships among firms and that has begun to gain acceptance by some researchers interested in technological innovation is social network analysis (Freeman 1991). Social network analysis allows a researcher to identify and to interpret the patterns of relationships systematically by attributes of actors and/or relationships.[1] Since strategic alliances generally reflect the cooperation rather than competition among firms, the network methods which identify cohesive subgroups are employed in the study. Cohesive subgroups imply that actors within each subgroup have stronger ties than do actors between any two subgroups.

In the study, we examine only strategic alliances like licensing and joint development agreements, which had been intended to create new technologies (referred to here as technology alliances). Business alliances that do not have significant technical contributions to the partners are excluded. Examples of business alliances include supplier and customer agreements, marketing and distribution agreements, product bundling, OEM and value-added reselling activities. Standards-setting alliances that accelerate the implementation of specifications, and mergers and acquisitions that eliminate the possibility of interfirm relationships will be omitted also. In order to interpret the network patterns using alliance data, a taxonomy of data communications technologies in terms of radical, architectural, modular and incremental innovations based on the framework by Henderson and Clark (1990) is defined with the help of two field experts. Both experts are involved in the interpretation of the agreements.

Using 150 firms and 319 technology alliances in the data communications

[1] In social network analysis an actor can be an individual or an organization.

industry from 1985-1996, we demonstrate that social network analysis is useful in exploring the network structures related to emerging technologies. The primary findings suggest that firms differ in their roles within the industry network. One central coalition of firms has repeatedly used technology alliances for the development of modular innovations which have implications on industry standards. In contrast, other firms have come together for more limited purposes, supporting incremental innovations at the periphery of the network. The dichotomy of roles can best be described as the core-periphery structure. This structure appears to be very stable over a 12-year period. The findings further raise an intriguing question on the relative importance of technologies emerged from the industry network occupied largely by the incumbents, versus those from the new entrants outside the network.

The organization of the essay is as follows. Section 2 briefly outlines the objectives of studying interorganizational networks. This is followed by a description of the data communications industry in section 3 and the research method in section 4. Both sections 5 and 6 present the findings of social network analysis. Section 7 presents the discussion and the principal conclusions of the findings. Finally, directions for future research are suggested in section 8.

2. The Objectives of Studying Interorganizational Networks

Over the last several years a growing body of literature on interorganizational networks has been published in some top academic journals for business management (see Table 1).[2] These studies have explored the patterns of production networks in various industries, including automobile, biotechnology, computer, and fashion (Barley, Freeman, & Hybels 1992; Lincoln, Gerlach, & Admajian 1996; Saxenian 1994; Uzzi 1997). However, a brief review of the literature published from 1990 until June 1997 reveals two difficulties related to the study of interorganizational networks. First, the analyses based on diverse methodologies and definitions of interorganizational networks have made the comparison of network characteristics across industries difficult (Jones, Hesterly & Borgatti 1997). Second, the difficulty in collecting time-series network data has constrained researcher ability to use longitudinal analysis. Hence, researchers across disciplinary training have begun to seek a more quantitative technique to study networks.

Table 1. Selected Journals with Articles on Interorganizational Networks[3]

Journal	1990-1997	Before 1990
Academy of Management Journal	6	0
Academy of Management Review	1	4
Administrative Science Quarterly	5	7
Organization Science	2	-
R&D Management	4	0
Research Policy	19	0
Strategic Management Journal	3	3

Recently, technology management scholars have called for the use of social

[2] Three excellent volumes of network studies are available: a collection of essays on networks and organizations edited by Nohria and Eccles (1992), a special issue in Research Policy (1991, vol. 20, no. 5) dedicated to the topic of "Networks of Innovators", and a recent special research forum on alliances and networks in the Academy of Management Journal (1997, vol. 40, no. 2). Using ABI database in Lexis/Nexis, we searched for article titles with the word "networks" in several refereed journals. Many articles were retrieved but we counted only articles related to networks of firms, as shown in Table 1. The oldest articles went as far back as 1977 in AMR.

[3] Many studies on interorganizational networks can also be found in journals like American Sociological Review, Annual Review of Sociology, and Californian Management Review. A more thorough search

network analysis to identify regularity and characteristics of interorganizational networks in the development of technological systems (DeBresson & Amesse 1991).[4] By using social network concepts and methods, researchers are able to explore and formulate hypothetical behaviors of firms participating in industry networks. The technology management literature in fact shows that social network analysis has long been employed in diffusion studies (Abrahamson & Rosenkopf 1997; Burt 1980; Coleman, Katz & Menzel 1957; Czepiel 1975) and in communications studies related to problem solving (Allen 1977; Freeman 1978; Stork 1991). However, how interorganizational networks evolve and how technological development shapes and is shaped by the evolution of these networks remain among the important questions for technology and strategic management scholars (Freeman 1991; Rosenkopf & Tushman 1994). In the last few years, many scholars have addressed these questions by examining networks from a social network perspective (Barley, Freeman & Hybels 1992; Clarysse, Debackere & Dierdonck 1996; Liebeskind, et al. 1996; Powell, Koput & Laurel 1996; Walker, Kogut & Shan 1997). These studies have so far been done mostly in the biotechnology industry.

Given the usefulness of social network analysis in studying interorganizational networks, the purpose of this essay is twofold. The first is to identify the patterns of interorganizational networks driven by technology alliances in the data communications

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including the abstracts will be considered for future literature review.

[4] More than a decade ago, Aldrich and Whetten (1981) urged organization theorists to study interorganizational relations from a social network perspective. Although social network theory and methods have been widely applied in social science research, most of the empirical studies were done at the individual level. Some network studies published in the 1970s and 1980s were based on local communities (Gray, 1990). Two early review articles on the use of social network methods for organization studies are Tichy, Tushman and Fombrun (1979) and Fombrun (1982).

industry. The second is to identify and interpret the characteristics of innovations specific to particular firms or grouping of firms in the industry. An attempt is made to integrate the findings within the well-cited innovation framework by Henderson and Clark (1990). The understanding of the data communications industry network that is driven more by technology rather than science would provide an interesting contrast to existing studies in the biotechnology industry. Since longitudinal data on technology alliances in this industry are accessible from public databases, the study can trace the evolutionary patterns of networks which would otherwise be difficult using cross-section data alone.

3. The Data Communications Industry

3.1 Technologies and Markets

The data communications industry began to amplify the power of the computer in the late 1970s with a revolutionary technology--local area network (LAN), which connects multiple devices such as computers, printers and file servers by a physical medium in order to provide distributed processing capability for the end-user.[5] In 1977 Datapoint Corporation implemented the first commercial LAN technology (ARCnet). Several competing technologies followed immediately and were aggressively promoted by some dominant firms in the industry. The LAN standard-setting committee IEEE 802

[5] Although data communications between mainframes and terminals began in the 1950s, the birth of the data communications industry is defined herer by the year 1977 in which the first LAN technology was commercially available in the market. Appendix A provides a synopsis of local area network standards and technologies.

finally approved Xerox's Ethernet and IBM's Token-ring networks as industry standards in 1981.[6]

Many early entrants in the industry during the late 1970s were established firms from other related industries. In 1982 GE targeted the factory automation market with a LAN product called GEnet that complied with the IEEE 802 LAN standard. By 1985 AT&T was positioned to compete with IBM on the LAN front with the introduction of its UNIX-based Starlan. By 1991, however, many independent networking vendors finally started delivering interoperable technologies across multiple networking platforms.[7] For example, DEC who had been a key player in Ethernet announced its first token ring products and Apple Computer unveiled its first gateway for system network architecture (SNA), the proprietary network architecture of IBM.

Since 1992 intranet and internet activities--connectivity between LAN segments distributed geographically, have become the main thrust of growth and competition in the data communications industry. From 1993 to 1996, we see the emergence of mature standards in networking hardware with various transmission speeds and greater bandwidth, enabling applications to be built independent of hardware platforms and network architectures.[8] There are switched Ethernet, Fast Ethernet (either 100Base-X or 100VG-AnyLAN), switched Fast Ethernet, Gigabit and switched Gigabit Ethernet. Token-ring comes in 4- and 16-Mbps (megabit per second) options, as well as a switched

[6] Ethernet technology was invented by Robert Metcalfe at Xerox in the 1970s. The technology was later jointly promoted by Xerox, DEC and Intel from 1976 until about 1981.
[7] PC Week, February 10, 1992
[8] MIS Week, January 1, 1990

version. There are also FDDI and switched FDDI, and ATM in 25, 100, 155 and 622 Mbps.[9] Modems, ASDL and ISDN are other technologies for remote access, allowing users to connect to their corporate computer systems from homes or office branches.[10]

These new technologies are expected to drive the worldwide LAN market from $20.5 billion in 1996 to $37 billion in 2000 (see Figure 1a and Figure 1b).[11] In U.S. 80% of the companies with more than 100 employees have a LAN and 85% of the employees in those companies have PCs connected to the LAN.[12] However, 90% of LAN users remain on Ethernet or Token-ring networks and have not migrated to high-speed technologies such as 100Base-T and ATM.[13]

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[9] FDDI (Fiber Distributed Data Interface) is a high-speed token-ring networking technology designed to run over optical fiber at the rate of 100 megabit per second. ATM (Asynchronous Transfer Mode), another high-speed technology that is designed to be a fast, general purpose transfer mode for multimedia transmissions.

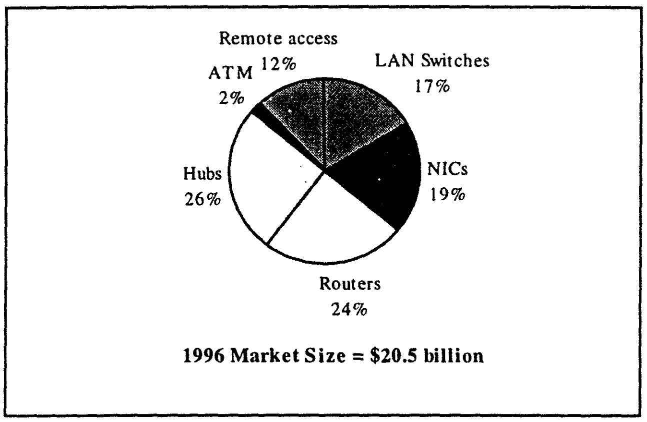
[10] ADSL (Asymmetric Digital Subscriber Line) transmits megabits over twisted-pair telephone lines that already exist. ISDN (Integrated Services Digital Network) is an older technology that provides greater speed and bandwidth over regular telephone lines.

[11] Doyle Lee, "Global LAN Market: Key Trends and Influences, 1996 to 2000," International Data Corporation (IDC) Report, No. 12715, December 1996.

[12] Ibid.

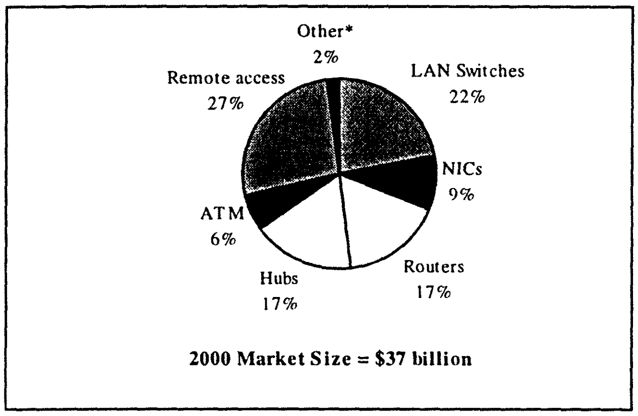
[13] Corporate users can deal with the high demand for internet bandwidth by segmenting their networks via LAN switching technology and installing high-speed LAN backbones.

Figure 1a. Worldwide LAN Market Revenues by Segment, 1996



Source: IDC Report, see footnote 10.

Figure 1b. Worldwide LAN Market Revenues by Segment, 2000

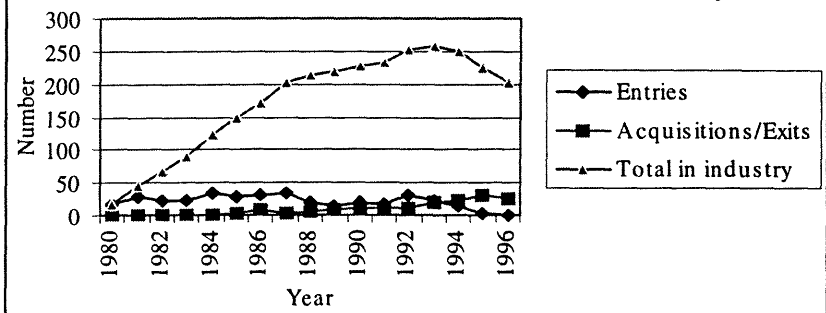


*Other includes Gigabit Ethernet and other new technologies.
Source: IDC Report, see footnote 10.

3.2 Data Communications Firms

We compiled the list of firms in the U.S. data communications industry using the CorpTech directory which has been published yearly since 1986.[14] The CorpTech directory consists of the profiles of all public and private firms involved in technology-intensive industries by product types. Figure 2 below shows the distribution of firms founded in the industry between 1980 and 1996. The number of new entrants during this period is 362. The number of firms founded before 1980 in other related industries like computer and telecommunications approximately accounted for another 134 entrants.

Figure 2. Number of Entries and Exits by Year in the Data Communications Industry



Source: CorpTech Directory (1986-1997) and Lexis/Nexis (1997)

While collecting information from public sources, we also found that the number of mergers and acquisitions was increasing in the 1990s. The number of acquisitions per year is included in Figure 2. The total number of firms in the industry by 1996 is 496 and the total number of acquisitions is 168, almost 34% of the firms being absorbed within the industry.[15]

Besides acquisitions, dissolution and bankruptcies were checked using the

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[14] The CorpTech Directory, Corporate Technology Information Services, Inc. Woburn, MA. Internet:http//www.corptech.com.

[15] Based on recent industry reports in Dow Jones Wires, the number of acquisitions is rising in this industry. The actual number of acquisitions could be higher since many small acquisitions are not widely reported in news announcements.

Directory of Obsolete Securities and the bankruptcy database in Lexis/Nexis.[16] Only two bankruptcies were detected. Two reasons may account for the low outcome of this search. First, information on private firms is not well covered in the bankruptcy databases and there are about 250 private firms in the industry. Second, many firms that entered the industry but left within the first three years were not published in the CorpTech directory in the first place. Therefore, the number of exits in Figure 2 basically reflects the number of acquisitions in the industry.

4. Research Method

4.1 Social Network Analysis

Social network analysis is focused on uncovering the relational patterns of interaction among individuals or organizations. Most social network analyses can be simplified into three steps. The first is to generate some structural patterns from the relational data. Then the characteristics of these patterns are identified and interpreted using additional information such as attributes of actors and their relationships.[17] Finally, implications are drawn as to how the specific patterns and their meaning advance our insights into the relevant field of research. The following sections explain in details the methods applied in the first and second steps. The findings and their implications are discussed in Sections 5 and 6.

[16] Directory of Obsolete Securities, 1991 Edition, Financial Information, Inc. Jersey City, NJ.
[17] Actors are referred to as individuals or organizations.

Step 1: Representation of Network Structures

Two general techniques can be applied to represent network structures, i.e. relational and positional methods (Dimaggio 1986; Mizruchi & Galaskiewicz 1993; Wasserman & Faust 1994). Relational methods identify cohesive subgroups within a network based on specific properties of ties between actors. Depending upon the hypothetical social processes, the properties of ties impose certain restrictions on the network structures. For example, we can formulate the patterns of information diffusion through intermediaries by specifying the number of intermediate ties between any two actors. In contrast, positional methods partition actors based on the similarity of their ties to all other actors and stress competition among actors within a structural position. Two actors are said to be "structurally equivalent" if they have identical ties to and from all other actors in the same network. These two actors may or may not have direct ties with each other but they are competing for resources provided by their identical partners.

Since technology alliances in the data communications industry reflect the development of highly inter-dependent technologies, relational methods are conceptually more sensitive to identifying clusters of cooperative relationships. Furthermore, the resulting cohesive subgroups can be interpreted in the second step by the substantive contents of their partnership agreements. Various graph theoretic techniques are available to identify cohesive subgroups but many of them require the properties of ties to be specified beforehand (Wasserman & Faust 1994). Since the organizing concepts and underlying dimension of the industry network is not known *a priori*, we employ a less restricted approach, i.e. multi-dimensional scaling (MDS), to display the proximity of firms in the network graphically.

The use of MDS to represent the relative distance and closeness of actors within a network is typical of social network analysis (Coxon 1982; Schiffman, Reynolds & Young 1982). Based on some measure of pairwise proximity among actors, such as the geodesic distance between each pair of actors, MDS will compute a set of estimated coordinates among pairs of actors.[18] In a two-dimensional spatial map, MDS represents "similar firms" as coordinates close to each other whereas "dissimilar firms" as coordinates distant from each another. Tables B-1, B-2 and B-3 provide examples of the output in generating the MDS map by UCINET, a software program for social network analysis.[19]

Step 2: Interpretation of Network Structures

The interpretation of an MDS map is twofold. First, we look for significant patterns in the MDS configurations, i.e. detect structures that are not simply arbitrary artifacts of the scaling procedure but are stable characteristics of the original data. Then we ascribe a meaning to these structures using additional information such as properties of firms and their relationships with others.

[18] In graph theory, a geodesic is a shortest path between two nodes. There could be more than one shortest path between two nodes. The geodesic distance is defined as the length of a geodesic between the two nodes.

[19] Borgatti, Everett and Freeman, 1992, *UCINET IV*, Columbia: Analytic Technologies. Also special thanks to Professor Borgatti for his help and suggestions in the use of the software and social network analysis.

The graphical output of MDS is depicted in this study as a set of firms connected by lines, indicating the presence of alliances between two firms.[20] In addition, thicker lines will be used for any two firms that have relatively more alliances with each other in the network. Three aspects of MDS configurations that have received much attention are: 1) the dimensions (orthogonal axes which span the MDS space), 2) the simple graphical structures (chains, circular and etc.), and 3) the regions (high density of points relatively to low density of points) (Coxon 1982). In the study, regions with varying degrees of density are expected to emerge since firms with more alliances among themselves are likely to cluster in space. For this reason, a network measure called centrality, which highlights the structural differences between firms by their relative locations in the network, would be useful in simplifying the network patterns.

Three different measures of centrality are commonly used in social network analysis, namely, degree, betweenness and closeness. Among the three measures, closeness centrality is more appropriate because it considers how central the firm is with respect to all others in the same network. On the other hand, degree centrality counts the number of direct ties from the focal firm only and betweenness centrality assumes that the importance of a firm is reflected in the firm's potential control over the paths connecting two other firms. Appendix C provides additional information on closeness centrality.

Finally, the contents of technology alliance agreements provide a substantive

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[20] The graphics are generated by the software called Krackplot 3.0, 1995, Krackhardt, D. Blythe, J., & McGrath C., Natick, MA: Analytic Technologies. http://analytictech.com/

interpretation of the network patterns. A conceptual framework defining the nature of innovations is thus necessary for systematic analysis of the contents. The notion that different types of innovations exist has important implications in the studies of technological innovation. In particular, following Schumpeter's (1942) notion of radical and incremental innovations, studies have found evidence of radical innovations destroying existing capabilities and markets whereas incremental innovations enhance existing skills and knowledge (Abernathy & Clark 1985; Christensen 1995; Henderson & Clark 1990; Tushman & Anderson 1986). The following section describes how a taxonomy of innovations in the data communications industry was designed for this study.

4.2 Taxonomy of Innovations

In this study technology alliances involve technological developments in the network environment of the International Standards Organization (ISO) reference model as shown in Figures A-2 and A-3 of Appendix A. These developments commonly reflect a need for hierarchical connectivity among the network components. Each ISO layer defines a particular protocol necessary for data transmission with specific capability. Interconnectivity across layers further ensures that data are translated into appropriate codes handled by adjacent layers. Therefore, technological innovations happen within and across layers in the network environment. A taxonomy of innovations that defines the extent of design changes made in the network environment would be useful for classifying the technology agreements.

Owing to the complexity of networking technologies, an engineer who has been developing products for the network environment for the past three years was recruited to help define the taxonomy. First, he was briefed on the purpose of his tasks and given the literature by Henderson and Clark (1990), Christensen (1992a, b), and Tushman and Anderson (1986) to review the various theoretical frameworks. We then examined the publications available in the International Data Corporation's (IDC) library to explore other possible models employed by industry analysts. Not surprisingly, the IDC industry reports tend to focus on general product features from the end-user's viewpoint. We felt that a conceptual model which addresses the technical implications of interfaces and components separately would be more useful for our purposes.

Given that technical changes involve both ISO layers and their linkages, the framework of component and architectural innovations developed by Henderson and Clark (1990) appears to be applicable, as shown in Figure 3. Four types of innovations are defined: incremental, modular, architectural and radical. The collaborating engineer felt that radical innovations which change the core concepts and redefine the linkages rarely occur in this industry. The first radical innovation in the data communications industry was probably the concept of local area networking itself. In his opinion no technological development in the past 12 years from 1985-1996 can be qualified as a radical innovation.

Figure 3. A Taxonomy of Innovation Adapted from Henderson and Clark (1990)

		Core Concepts of ISO Layers	
		Reinforced	Overturned
Linkages between ISO Layers	Reinforced	Incremental Innovation	Modular Innovation
	Changed	Architectural Innovation	Radical Innovation

Architectural innovation is rearrangement of the way in which component layers relate to each other. The basic purpose of each layer remains unaffected. However, new functionality may be added into the layer in order to support the rearrangement. For example, Ipsilon Networks' IP (Internet Protocol) switching technology is an architectural innovation.[21] Ipsilon Networks claims that the technology resolves the problems of complexity, inefficiency and functionality duplication inherent to the traditional networking approaches.

[21] In essence, IP switching goes against the conventional layered architecture of neighbor-layer opacity and ties up the IP Layer with the ATM (Asynchronous Transfer Mode) Adaptation Layer by defining two new protocols called GSMP (General Switch Management Protocol) and IFMP (Ipsilon Flow Management Protocol). The basic approach is to route IP traffic (Layer 3) on top of ATM Adaptation Layer (Layer 2). The traditional approaches to this end have been LANE (LAN Emulation) defined by ATM Forum, Classical IP over ATM from the IPATM working group of IETF and MPOA (Multiprotocol over ATM) under ballot from ATM Forum.

Modular innovation involves a replacement of protocol or technology for a given ISO layer. This can be viewed as a fundamental change in the technology used in that layer, leaving the other layers unchanged. The entry of ATM (Asynchronous Transfer Mode) technology in early 1990s in the networking industry is an excellent example of modular innovation.[22]

Finally, incremental innovation adds new functionality to existing technologies for one ISO layer and enhances the interface with adjacent layers which use different technologies. Gigabit Ethernet is a good example of incremental innovation. Gigabit Ethernet technology fully capitalizes on the existing installed base of Ethernet technology (IEEE 802.3 CSMA/CD Layer 2 Protocol). The basic limitation of traditional Ethernet technology was limited bandwidth (10 Mbps). Gigabit Ethernet technology uses the same Layer 2 Ethernet technology over Fibre Channel Physical Layer (Layer 1) to achieve bandwidths of the order of 1 Gbps.

The coding of technology alliances based on the above taxonomy of innovation remains a difficult task since a good understanding of the history of technological developments and the technical details is necessary. Although a panel of industry experts would be ideal, owing to the time constraint to complete the study, another expert (Expert 2, E2) was sought to perform the coding in parallel with the first engineer (Expert 1, E1). The main advantage of having independent experts to apply the taxonomy is to resolve

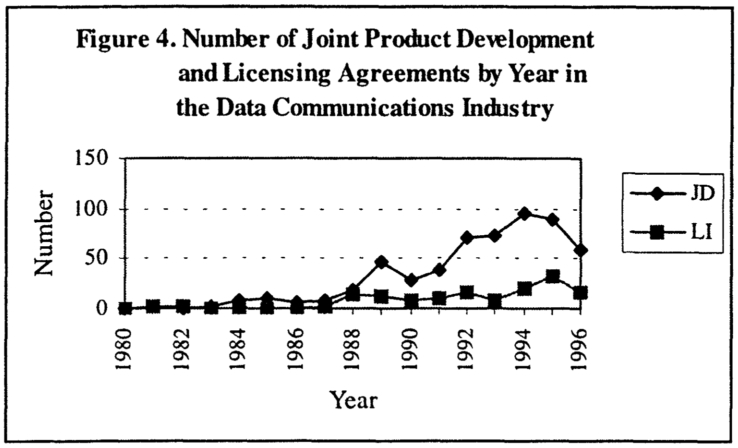
[22] ATM is basically a Layer 2 technology. ATM delivers important advantages over existing LAN and WAN technologies, including the promise of scaleable bandwidths at unprecedented price and performance points and Quality of Service (QoS) guarantees, which facilitate new classes of applications such as multimedia.

any problematic issues arising from coding. Comparison of coding outcomes is made to ensure reliability of scores. Through an interview with a founder and chairman of a prominent networking company in Massachusetts, E2 was identified and recruited to assist. This second expert is most qualified, a Senior Research Scientist who has been developing advanced communications techniques in the M.I.T. Laboratory for Computer Science and is well-known in the industry. He has been actively involved in the development of local area networking technologies since the 1970s and continues to attend many standards meetings and professional conferences in the industry. In addition, he serves as a board member of a networking company.

E2 was briefed on the purpose of his tasks and given the taxonomy of innovations to examine. He did not find particular problems with the various definitions in the taxonomy. He was later told that E1 had assisted in coming up with the definitions and would be coding the alliance agreements independently. Both experts were given Tables D-1, D-2 and D-3 in Appendix D and a total of 61alliance agreements to code.

4.3 Longitudinal Network Data

Technology alliances are used in this study to represent the formal relationships between firms. For each of the 496 firms found previously, full-text descriptions of technology alliance agreements, if any, were retrieved from Lexis/Nexis and Dow Jones Wires. Most agreements included joint product development, licensing and/or cross-licensing agreements. Figure 4 below shows the distribution of alliance agreements established in the U.S. from 1980 to 1996. There are 613 joint product development agreements and 157 licensing agreements. In fact, the total number of agreements should be higher since we omitted agreements that were not publicized, international agreements involving firms outside of U.S., and minority equity investments.[23]



Source: Full-text reports from Lexis/Nexis and Dow Jones Wires, 1997

Figure 4 also shows a downtrend in the alliance activity from about 1995. Three factors may have contributed to this decline: 1) the decrease in the number of new entrants, 2) the increase in the number of acquisitions, and 3) data not yet available on-line in the public databases.

Technology alliances were sparse before 1985 because early technological developments were largely focused on proprietary technologies. For this reason, only

[23] Minority equity investments have been used as an incentive to motivate the invested firms to undertake product development projects that meet the objectives of the investing firms. However, minority equity investment data were not widely reported in public sources for the intended analyses later.

alliance agreements from 1985 to 1996 were examined. All input data to UCINET are in the form of NxN matrices, where N is the number of firms involved in technology alliances and each cell indicates the number of agreements between two firms.

More than 150 firms were detected over the 12-year period. Given the large matrix, the graphical representations of MDS would be extremely difficult for the analyses. Consequently, we split the dataset into three time periods that approximately coincide with the emergence of particular industry standards: 1985-1988, 1989-1992, and 1993-1996. According to various industry sources, 1985 marked the year of market growth with two competing standards, Ethernet and Token Ring, dominating the development of new component technologies. In 1989 one of the first industry standards-setting forums was initiated by competing firms to advance the FDDI STM standard (an improved protocol over token ring networks.) Since then, many large standards-setting forums have been promoted by major industry players rather than the standards-setting bodies like IEEE, ANSI and ITU (see Appendix F for standards-setting forums.)[24]

Finally, 1993-1996 represents the dramatic growth of data communications markets driven by internet and intranet activities. About half of the total technology alliances were established during this period. Although the division into these time periods seems somewhat arbitrary, subsequent analyses based on the variation in the global network patterns will confirm the significance of industry forces such as market growth and standardization in driving technological changes over time.

[24] IEEE is the Institute of Electrical and Electronics Engineers, Inc., ANSI is American National Standards Institute, and ITU is International Telecommunications Union.

For the three periods, there are 32, 127 and 211 firms, and 36, 118 and 207 agreements respectively.[25] However, some of these alliances were non-repeated, dyadic relations between two firms that are isolated from all other firms. Since isolated firms cannot be reached by others, closeness centrality measure will assign zeros to all firms in the network. For this reason, isolated relationships were omitted in the analyses. In the final sample, we ended up with 28, 68 and 117 firms and 34, 89 and 196 agreements in the corresponding periods. Table 2 below gives the distribution of the most recently founded firms by period. Overall, few firms in the sample are less than 8 years old.

Table 2. Number of Most Recently Founded Firms in the Sample by Period

Period	Total no. of firms in the industry founded in this period	No. of sample firms in this period	No. of sample firms founded in this period	No. of sample firms founded in the 4 years prior to this period
1985-1988	113	28	5 (18%)	7 (25%)
1989-1992	82	68	5 (7%)	17 (25%)
1993-1996	43	117	4 (3%)	10 (8%)

Percentages in parentheses are the proportions of sample firms by period.

5. The Characteristics of Network Structures and Memberships

The patterns of the industry networks in three periods are presented in Figures 5, 6 and 7. Each line joining any two firms represents the presence of alliances but a thicker line indicates 2 or more alliance agreements were established in separate years. Since the

[25] The total number of alliance agreements from 1985 to 1996 included in the matrices is 361, which is slightly more than half of the reported number 684 in Figure 3. Two reasons account for the discrepancy. First, those omitted agreements involved largely private firms and some non U.S. parent firms for which we could not obtain sufficient information. We decided to drop these firms in the study. Second, Figure 3 has incorporated the latest results from the second and third searches through Dow Jones Wires, which produced many new agreements not found previously in Lexis/Nexis. Nevertheless, the set of 361 alliances

list of alliance agreements for each period was compiled from public sources, some agreements might have been omitted in the analysis. Despite the omissions, the global representation of the industry networks can be revealing in regard to emerging network characteristics over time.

In Figure 5, the network pattern from 1985-1988 shows three branches intersecting at 3Com (3CO) and Microsoft (MS) in the center of network. Both firms were known to be developing networking software and hardware, such as OS/2 LAN Manager, compatible to the IBM PC platform during this period. Several other notable firms like DEC, AT&T, Intel (INT), and Novell (NVL) occupy positions at the three branches respectively. DEC was developing various technologies including modules connected to baseband Ethernet, broadband Ethernet, and WANs. Novell was implementing connectivity for PC workstations to LAN servers through TCP/IP gateway, whereas Intel was developing Ethernet and ISDN chips for Ethernet and remote access technologies.

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has at least incorporated the prominent agreements in the industry during the last 12 years.

Figure 5. Network of Firms in the Data Communications Industry, 1985-1988

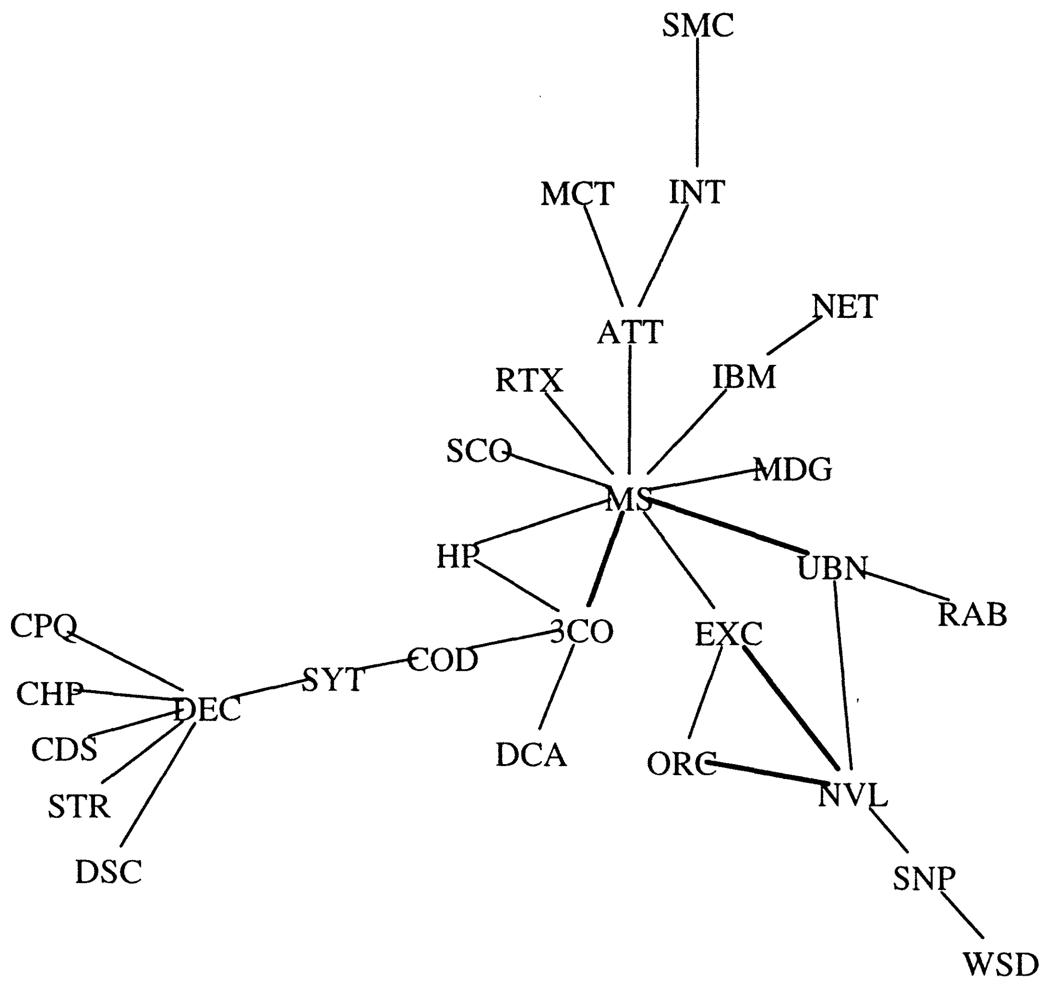
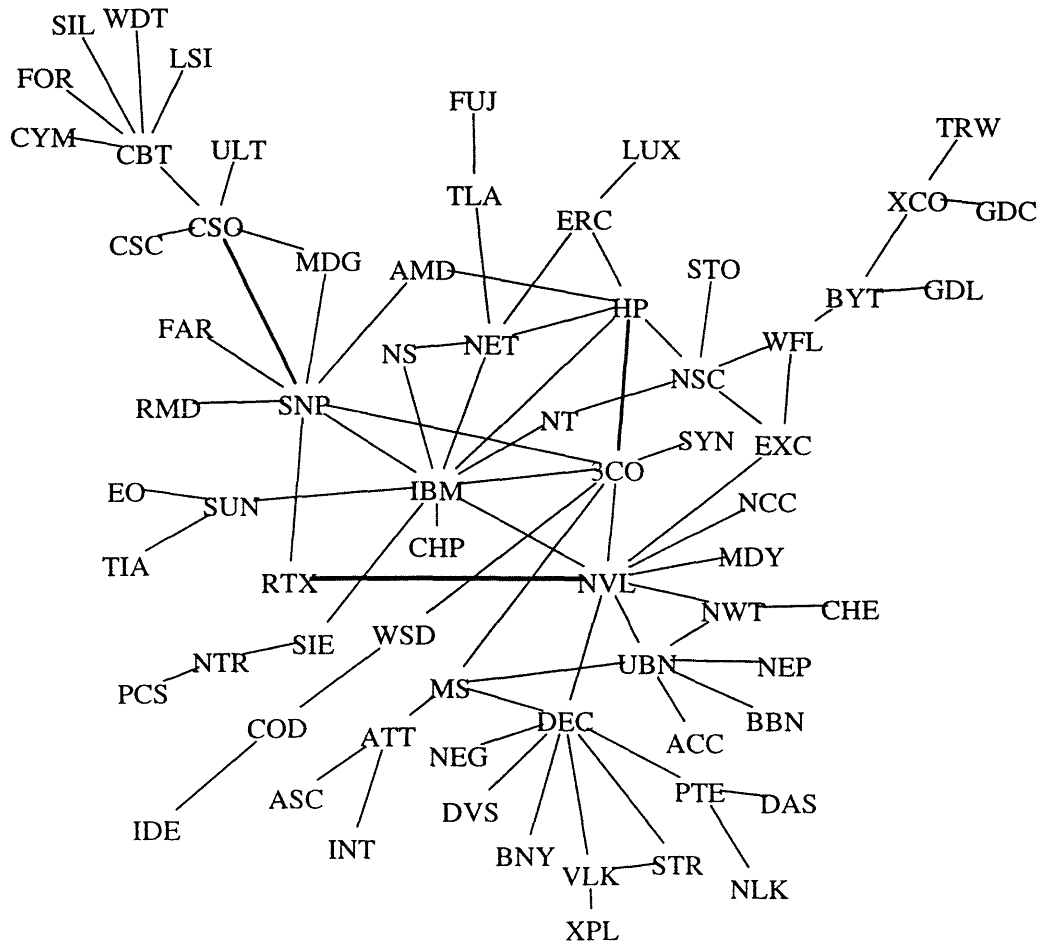
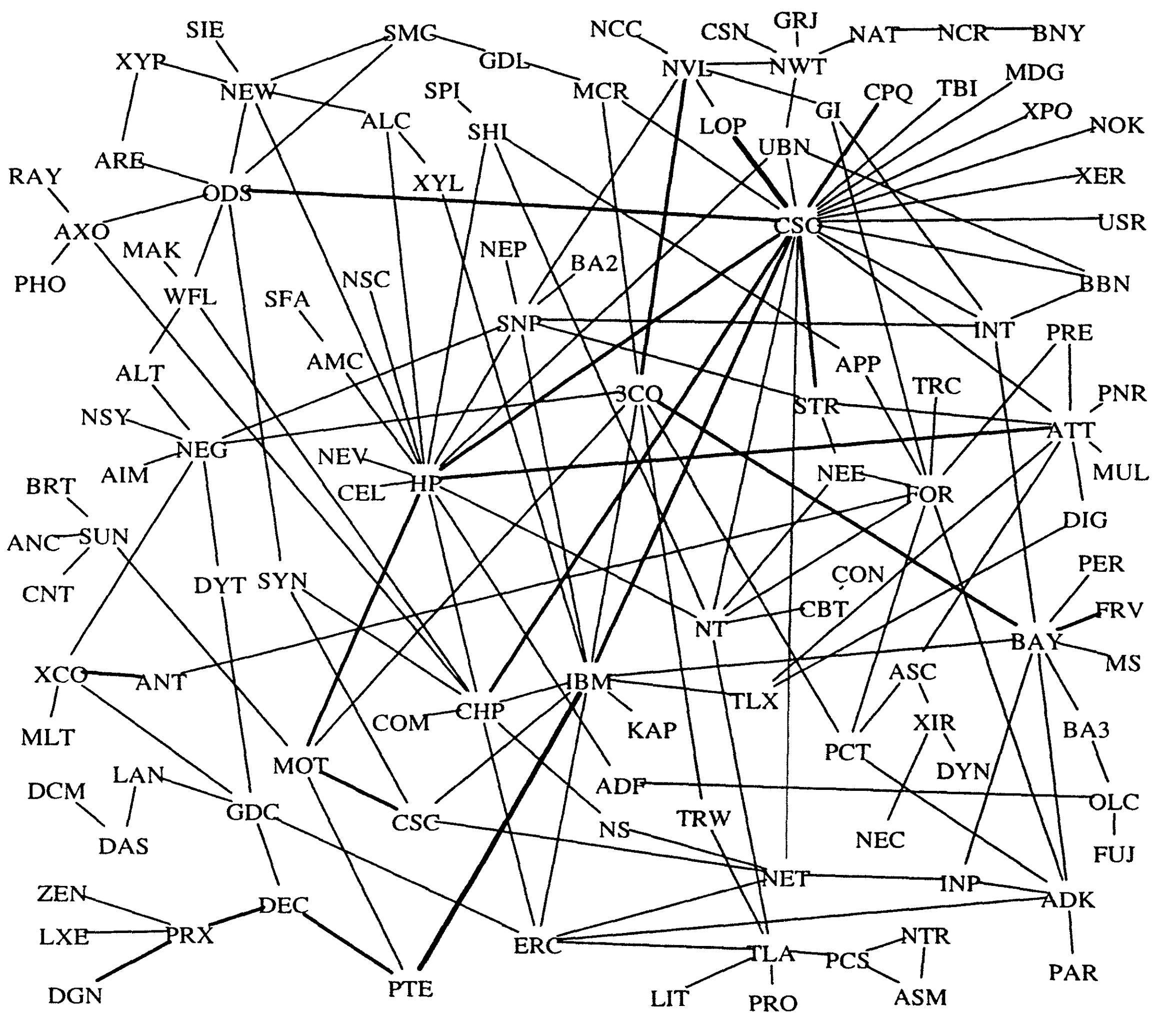


Figure 6. Network of Firms in the Data Communications Industry, 1989-1992



From Figure 5 to Figure 6, however, four significant characteristics of interorganizational dynamics emerged over time. First, the industry network evidently has become denser and more connected among firms. Second, some firms like DEC, HP, Novell (NVL), and SynOptics Communications (SNP) from the branches in the last period have moved closer to the center of the network by forming relationships with other existing firms, especially 3Com that has continued to maintain the central position. In contrast, others like AT&T, Intel (INT) and UB Networks (UBN) have remained in their branch positions. Third, repeated alliances are apparent among some firms from the last period. Finally, new branches have emerged, led by Cabletron Systems (CBT), Cisco (CSO) and Wellfleet Communications (WFL) that did not exist in network before.

Figure 7. Network of Firms in the Data Communications Industry, 1993-1996



Interestingly, Figure 7 reveals some similar network characteristics in the third period. First, even more firms participate in the industry network. Second, 3Com, HP, IBM and SynOptics (SNP) have maintained their central positions by forming more alliances. The exceptions are DEC and Novell (NVL) which appear to have fewer alliances compared to the last period. Third, companies like AT&T, Cisco (CSO), Ericssons (ERC), Intel (INT), NorTel (NT, formerly known as Northern Telecom), and UB Networks (UBN) have moved to the center of the network from their boundary positions, whereas Wellfleet (WFL) and Cabletron have not. Finally, many new branches that are relatively well connected with others along the boundary have emerged. These positions are led by General Datacomm (GDC), Optical Data Systems (ODS), and Sun Microsystems (SUN), and so on.

Further investigation suggests that no obvious firm characteristics like founding age and firm size can be associated with the dynamics of interorganizational relationships. However, some network characteristics like centrality can be useful in summarizing the patterns of network structures. Table 3 shows the characteristics of networks in three periods by closeness centrality and network centralization measures. In each successive period, the size of the network (number of firms) is twice as large and the number of alliances is more than double. The statistical means of the firm-level closeness centrality are almost the same and the standard deviations are low across the three periods.[26] The network centralization index is a group-level measure of variation in

[26] The normalized closeness centrality indices are expressed in percentages by UCINET. Firm-level indices are not shown here except for the statistical mean.

firm-level centrality. The larger the index the more likely that a particular firm is quite central, with remaining firms considerably less central. The network centralization indices here are relatively small and stable (26.83-29.97%).

Table 3. Characteristics of Networks by Closeness Centrality and Network Centralization

Closeness Centrality	1985-1988	1989-1992	1993-1996
Mean at firm-level	26.12%	23.69%	25.87%
Std Dev	5.74%	5.04%	4.88%
Minimum	17.76%	14.50%	14.85%
Maximum	40.30%	36.81%	39.32%
Network Centralization	29.97%	26.83%	27.26%
Number of Firms	28	68	117
Number of Alliances	34	89	196

The high stability of aggregate network properties does not, however, imply a low turnover of network memberships across time (Morgan, Neal & Carder 1996). The distribution of firms participating in the networks is given in Table 4. Only 14 firms (9%) continued to form alliances in all three periods. 33 (22%) additional firms formed alliances in two consecutive periods and 101 (67%) firms participated in a single period only. However, these numbers may be different since 72 firms are right censored in the third period, i.e. no data available as to possible firm activity later than 1996. Overall, we observe a low stability of network memberships.

Table 4. Characteristics of Network Memberships

Period(s)	Number of firms*
The first period only (1985-1988)	8
The second period only (1989-1992)	21
The third period only (1993-1996)	72
The first and second only	4
The first and third only	2
The second and third only	29
All three periods	14
Total	150

* The number of firms participating in specific period(s) only.

Given that the exploitation of external sources of innovation is not limited to alliances, the stability of network memberships can also be affected by the mergers and acquisitions activities in the entire industry. In terms of the relative use of alliance and acquisition strategies from 1985-1996, 8% (42 out of 496) of the firms used both alliance and acquisitions, about 22% (108 out of 496) used alliances alone and 17% (85 out of 496) used acquisitions alone.[27] Slightly less than 50% of all firms in the industry use either or both alliances and acquisitions.

Table 5 indicates that only 18 (11%) firms participating in the networks had been acquired. Of the total 160 acquisitions, 90 (56%) were made by non-members of the networks whereas 70 (44%) were made by 42 members of the networks. From 1989 to 1996, however, the acquisition trend of members (columns 3 and 5 in Table 5) is rising faster than that of non-members (columns 4 and 6 in Table 5), presumably reflecting the larger size of network members.

[27] Note that all the percentages reported in this paragraph could be higher since the total number of 496 firms has not accounted for the number of acquisitions each year.

Table 5. Number of Acquisitions Made by Members and Non-members of Networks

Period	Total no. of firms acquired in the period	No. of non-members acquired by members	No. of non-members acquired by non-members	No. of members acquired by members	No. of members acquired by non-members
1985-1988	22	4	15	1	2
1989-1992	43	10	31	2	0
1993-1996	95	42	39	11	3
Total	160	57	85	13	5

The above results suggest that instead of being an acquisition target themselves, members of the networks have become more likely to acquire non-members. This phenomenon raises two interesting empirical questions. Are non-members of the networks more likely to have better technologies which lead to their acquisitions by others? Are network members more likely to maintain their status quo owing to their prior relationships with others? To examine these questions systematically, more empirical data on non-members as well as the relative motives of acquisitions and alliances are required. More implications of the questions will be discussed in the conclusions of this essay.

To further understand the dynamics of networks, Table 6 below lists the identities of only "high-centrality firms" that have closeness centrality one standard deviation above the statistical means. All 19 firms in the table are early entrants in the industry, even really including Bay Networks, established in 1994 as a result of a merger between SynOptics (1985) and Wellfleet Communications (1986).[28]

[28] In Table 6, the founding year of the firm is stated if it was a new entrant in the data communications industry. In the case of established firms from related industries like computers and telecommunications, we stated the year in which their networking divisions were formed (like AT&T, HP, Ericsson and

Table 6. Subset of High-centrality Firms

1985-1988 (4 firms)	1989-1992 (11 firms)	1993-1996 (15 firms)
1979 3CO* (3COM)	1979 3CO* (3COM)	1979 3CO* (3COM)
1983 HP*	1976 DEC[2]	1983 ATT*
1984 MS[1,2] (Microsoft)	1982 EXC[1,2] (Excelan)	1994 BAY (Bay Networks)
1979 TND* (UB Networks)	1983 HP*	1983 CHP[2,3] (Chipcom)
	1979 IBM*	1984 CSO[2,3] (Cisco)
	1984 MS[1,2] (Microsoft)	1985 ERC[2,3] (Ericsson)
	1983 NET[2,3] (Network Equipment Technologies)	1983 HP*
	1973 NT[2,3] (NorTel)	1979 IBM*
	1983 NVL* (Novell)	1976 INT[3] (Intel)
	1985 RTX[1,2] (Retix)	1977 MOT[3] (Motorola)
	1985 SNP[2,3] (SynOptics)	1973 NT[2,3] (NorTel)
		1983 NET[2,3] (Network Equipment Technologies)
		1985 SNP[2,3] (SynOptics)
		1986 STR[3] (Stratacom)
		1979 TND* (UB Networks)
14% (4 out of 28 firms)	16% (11 out of 68 firms)	13% (15 out of 117 firms)

Note: High-centrality firms here have indices one standard deviation above the corresponding means in Table 3. Year of founding the networking business is given beside each firm. The superscript number indicates the period in which the firm has centrality above the mean. An asterisk shows that the firm has centrality above the mean in all three periods. The bottom row indicates the percentage of high-centrality firms in each network.

15 firms (including Bay Networks in its former identity as SynOptics) were active in at least two periods. 13 firms have made a total of 35 acquisitions, that is 50% of the acquisitions made by all network members over three time periods (see also Table 5). Among these 13 firms, only 3Com, Cisco and Novell have acquired other high-centrality firms, namely, Chipcom, Stratacom and Excelan respectively. The two latter acquired firms had been partners of the acquiring firms prior to acquisitions.[29] Independent sales

Motorola) or some of their first projects related to LAN were announced (like DEC, IBM, Intel and Microsoft).

[29] Among all acquisitions in the industry, a total of nine firms have acquired their former alliance partners. These firms are Bay Networks, Cisco, General Instrument, Network General Corp., Network System Corp., Networth, Novell, Telco Systems and Synernetics. Bay Networks, Cisco and Novell are the only high-centrality firms.

data from 1993 to 1996 were not available for Chipcom, Stratacom, SynOptics, UB Networks and Ericsson. Of the 10 other firms, only NET is not among the top 50 producers in 1994 and 1995 sales revenues ranked by NetworkWorld.[30]

High-centrality firms can be broadly characterized as early entrants and market share leaders in the industry. They are also more likely to make acquisitions compared to low-centrality firms.[31] The above observations lead to an interesting question: do firms with more resources also attract more partners? If they do have more resources than others, what then are the benefits of forming more alliances? The technology management literature has informed us that larger, established firms tend to be less innovative than new entrants. Consequently, alliances and acquisitions may be the best alternatives for these larger firms to gather new ideas so as to complement their internal capabilities.

However, if alliances bring external sources of innovation, why then are not more firms like those with low-centrality forming more alliances? Recall that low-centrality firms are also less likely to make acquisitions. Low-centrality firms either do not have the resources to attract potential partners or they are more innovative in the first place. It is apparent that the factors underlying the choice for alliances, acquisitions and internal development differ between high-centrality and low-centrality firms. All the above questions thus have compelling implications for the evolution of technology. More

[30] NetworkWorld, December 30, 1996. The top 50 firms include many established firms from the telecommunications and computer industries. These firms are involved in other areas of data communications technologies such as software and wireless technologies that are not included in the study.
[31] Low-centrality firms have centrality below the means, whereas others with centrality equals to or above

empirical data related to technology alliances will be analyzed in the next section in order to understand the potential roles played by high-centrality versus low-centrality firms in the industry network.

Despite their differences, high-centrality firms and low-centrality firms are two potential sources of stability in the global network structure. The first source is a set of "core" ties that are relatively stable and have anchored the composition of the network over time. The second source is a set of "peripheral" ties that are relatively interchangeable, rendering the aggregate network properties unchanged. These two sources are not mutually exclusive, so either or both could be a source of network stability.

Three explanations are possible for the above speculation. First, a small number of firms might proactively be using alliances as a strategy for a variety of reasons, acquiring complementary technologies and expertise, speeding up new product development and monitoring emerging technologies. In contrast, most firms are probably using alliances as the best option at the time relative to in-house development. While the benefits of strategic alliances are manifold (Contractor & Lorange 1988; Hagedoorn 1993; Tucci & Cusumano 1994), many firms are still skeptical about forming partnerships with present or potential competitors. Asymmetric attributes of the firms can change the relative bargaining power as well as the relative competitive standing between partners (Hamel 1991; Yan & Gray 1994). Even when such skeptical firms participate in joint projects, these alliances are less likely to be involved in highly

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the means will be high-centrality firms.

sensitive areas of technological innovation.

Second, from the social capital viewpoint (Burt 1992b; Coleman 1990), firms that are more "central" in the network by virtue of maintaining many direct and indirect relationships with all other firms have better access to information leading to potential alliance partners. On the other hand, firms located on the periphery of the network obtain lower information benefits, hence have lower inclination for new relations. Walker, Kogut and Shan (1997) showed that the development and maintenance of social capital have led incumbent firms to reproduce the existing network structure, giving rise to network stability. Similarly, Gulati (1995) found that the social structure of past alliances explains the formation of new interorganizational relationships. The stability of high-centrality firms versus the instability of low-centrality firms in this study is good evidence of the varying opportunities and constraints in information access available to the two types of firms.

Third, with increasing networking experiences, the marginal costs for central firms to form new alliance relations can be assumed to be decreasing. However, the marginal costs are likely to be relatively higher for the boundary firms. From the transaction costs viewpoint, firms are assumed to be opportunistic and the market for technological knowledge is imperfect, thus leading to high contractual costs in technology exchange transactions (Teece 1992; Williamson 1985). On the other hand, reciprocity and trust are important social factors in any bilateral transactions (Bradach & Eccles 1989; Ouchi 1980; Ring & Van de Ven 1992). Richardson (1972) pointed out that firms achieve stability and reliability in their relationships with other firms through qualitative coordination. Closeness of ties, reciprocity and trust can all play a part as a cost-effective monitoring device for firms' deviant behaviors. The ability of central firms to manage a diversity of new and repeated relationships with particular partners in the past certainly reflects the potential trust level in new transactions, hence sustaining the stability of their participation in the network. The relatively few new entrants that participated in the network, as shown in Table 2, may in fact indicate that young organizations require time to build up their reputations and perhaps also their internal capacities necessary to be in the network.

Above all, resource dependency, information benefits and networking experience are potential explanations that support the stability of "core-periphery" structure of the industry network. In the following section, we explore the correlation between core-periphery structure and nature of emerging technologies by using the coding scores from two industry experts.

6. The Link Between Core-Periphery Structure and Nature of Emerging Technologies

Tables D-1, D-2 and D-3 in Appendix D list by period the contents of technology alliances for the subgroups in Table 7. These subgroups were selected randomly from Figures 5, 6 and 7 respectively. Ideally, all alliance agreements should be evaluated.

Unfortunately, the time available from each expert was limited to at most three hours.[32] Hence, the interpretation of alliances associated with the core-periphery structure must be treated with caution.

Table 7. Selected Cohesive Subgroups by Period

1985-1988	1989-1992	1993-1996
1. Chipcom, DEC	1. Cabletron, Cayman Systems	1. **AM Communications**, Scientific Atlanta
2. **Codenoll Technology, Sytek**	2. Bytex, Crosscom	2. Centillion Networks, Olicom USA
3. **IBM**, Network Equipment Technologies	3. **Excelan, Network System Corp.**, **Wellfleet Communications**	3. **3COM, Bay Networks**, First Virtual Corp.
4. **Microsoft, 3COM, UB Networks**	4. Tiara, **Sun**	4. **Ascend Communications, PictureTel Corp.**
5. **Excelan, Novell**, Oracle	5. Netrix, Pacific Communication Sciences	5. Dayna Communications, Xircom
6. SynOptics, Western Digital	6. Ericsson, Luxcom	6. Cabletron, Concord Communications
7. **AT&T**, Intel	7. **3COM, HP**	7. **NetEdge, NorTel**
	8. **Chipcom, IBM**	8. Ascom Timeplex, Netrix, Pacific Communication Sciences
	9. **National Semiconductor, Network Equipment Technologies**	9. Light Stream, **Tellabs**
	10. Fujitsu Network Systems, Tellabs	10. **Shiva**, Spider
	11. Codenoll Technology, Lanex	11. Ancor Communications, Sun Microsystems
	12. **Madge Networks, Cisco, SynOptics**	12. Aironet Wireless Communications, Digital Ocean
	13. Data Switch, Proteon	13. **AT&T, HP**
	14. Ascend Communications, **AT&T**	14. **Cascade Communications, Motorola**
	15. Banyan, **DEC**	15. DEC, **IBM**, **Proteon**
	16. **Retix, Novell**	16. Data General, Proxim
	17. Cheyenne Software, Networth	17. **ADC Kentrox, Ericsson**
	18. ACC Network Systems, UB Networks	18. Dynatech Communications, **General Datacomm**
	19. Stratacom, Vitalink Communicstions	19. **Interphase, Network Equipment Technologies**
		20. Data Switch, Lannet
		21. **Axon Networks, Chipcom**
		22. Gandalf Technologies, **Microcom**
		23. Artel Communications, Optical Data Systems
		24. **Alcatel Telecom, Newbridge Networks**
		25. Banyan Systems, NCR
		26. **Fore Systems, General Instrument**
		27. **BBN**, **Intel**
		28. Lanoptics, **Cisco**
		29. Network Communications, **Novell**
		30. Newport Systems, **Networth**
		31. Network Peripherals, **SynOptics**
		32. Alantec, **Wellfleet Communications**
		33. Applied Network Technologies, **Crosscom**
		34. Aim Technology, **Network General**

Note: Firms highlighted in bold have centrality above the means and those underlined have centrality one standard deviation above the means. The subgroups in each period were identified directly from Figures 5, 6, and 7.

There are 40 and 21 alliance agreements in the core and the periphery structures respectively but the two experts were not aware of this dichotomy. Each of the two

[32] A summary of other alliance agreements is included in Tables E-1, E-2, and E-3 of Appendix E.

expert coders spent approximately three hours in coding the agreements, separated in time and place. Among 61 alliance agreements, one was discarded from the sample since both coders identified that it was unrelated to any form of technological development. E1 (the engineer) was unable to determine the nature of 21 agreements but he attempted to code 8 of them anyway. However, E2 (the research scientist) coded all 60 agreements. Among 47 dual coded agreements, 17 (36%) were coded as modular by one coder and incremental by the other. E1 also identified four architectural innovations which E2 coded as either incremental or modular innovations. Columns A and B of Tables D-1, D-2 and D-3 show the coding by E2 and E1 respectively.

In fact, after coding both experts raised some concerns about their judgments, which might explain the variation in coding. They were not sure whether to assess the technical outcomes of joint development activities or the original technologies brought by individual partners. Joint development activities were critical to the original innovations when the concepts of these innovations were still relatively new. However, the same activities were later considered trivial after such innovations had been widely spread. Based on his in-depth knowledge of the industry history, E2 concluded that the timing of joint development activities relative to the development of the original technologies is an important criterion. He made his decisions using the following guideline: if the time interval between the original and the joint development is within a couple of years, the characteristics of both activities would be considered together in coding the agreement; otherwise, the joint development activities alone would be coded within the taxonomy of innovation in Figure 3.

Another concern raised was whether to consider either or both the technical and market implications of innovations. However, such criteria were not obvious in the taxonomy of innovations. Both experts therefore coded the agreements strictly based on the technical changes implied by the relevant activities.

To reduce the errors in coding, E2 offered to reassess all 21 agreements found disparate in both sets of answers. Prior to the second exercise, we also identified 10 additional agreements which created inconsistency in E2's coding. E2 finally went through 31 agreements the second time and found that he needed to change 5 (16%) of his original answers. Two of these changes are now consistent with the results by E1 but three others are not. Unfortunately, E1 was not available to do the same exercise and so further comparison is not possible. Given that the results by E1 are incomplete, Table 8 shows the statistical summary of the results by E2 only.

Table 8. The Nature of Innovations Associated with the Core-Periphery Structure

	Table D-1 (1985-1989)			**Table D-2 (1990-1993)**			**Table D-3 (1991-1996)**			
	Arch.	**Mod.**	**Incr.**	**Arch.**	**Mod.**	**Incr.**	**Arch.**	**Mod.**	**Incr.**	**Total**
Core	0	4	2	0	5	6	1	12	9	39
Periphery	0	0	2	0	2	8	0	4	5	21
Total	0	4	4	0	7	14	1	16	14	60

Note: Arch. = Architectural innovations, Mod. = Modular innovation, Incr. = Incremental innovation. These results are coded by E2.

Only one architectural innovation is identified in all agreements, achieved within the core structure of firms. The core structure also consists of 21 (54%) modular innovations and 17 (44%) incremental innovations. The distinction between the two numbers appears to be marginal but the number of modular innovations has increased by more than 100% from the second to the third period. On the other hand, 6 (29%) modular innovations and 15 (71%) incremental innovations are identified in the periphery structure. The analysis of variance (ANOVA) shows that the core-periphery structure of the industry can indeed be differentiated by modular and incremental innovations at the 5% statistical level. In technology alliances, core firms were more likely to develop modular innovations whereas periphery firms develop incremental innovations.

The above results raise several questions about the relationship between core-periphery structure and modular-incremental innovation. Do firms that persist in alliance formation also tend to develop modular innovations internally? Likewise, do firms that seldom form alliances also tend to focus on incremental innovations? In the two experts' opinion, an attempt to classify "modular firms" versus "incremental firms" may prove to be futile since many technical details internal to the firms are not obvious nor available for systematic analysis. Perhaps a more relevant question is whether modular innovations are better achieved through partnerships for certain firms and incremental innovations for others?

A modular innovation replaces the core concept of a component layer with completely new functionality but leaves other layers unaffected. Modular innovations thus have considerable implications on cost-performance and interoperability (or compatibility) across heterogeneous network environments, subsequently affecting many competitors, suppliers as well as customers (Christensen 1992a). As such, forming alliances to develop modular innovations with competitors, suppliers or customers can gain greater support for interoperability that is demanded in the entire market. Cooperation with potentially "powerful" partners may even enhance the visibility and status of the focal firm in the industry (Baum & Oliver 1991).

The alliances formed between 3Com and Microsoft to develop OS/2 LAN Manager in the late 1980s probably best illustrate the above proposition. Their modular innovations, as shown in column A of Table D-1, were networking software compatible with the IBM networking environment. Robert Potter, former president and CEO of Datapoint Corp., which commercialized the first LAN technology ARCnet, observed, "[The biggest story of 1988 was] the rapid movement of PC network software vendors away from proprietary protocols and software and toward the IBM and Microsoft standards."[33]

In contrast, incremental innovations add new functionality to a component layer and enhance interfaces with adjacent layers. Little disruption to the basic network architecture will be incurred. For example, the first four agreements under the periphery structure indicated by Column A of Table D-2 illustrate the implementation of new functionality in established technologies such as bridges and routers (which are Layer 2 and Layer 3 technologies respectively) to support FDDI or Frame Relay (which are both Layer 2 protocols.)

Besides the nature of the innovation, are there other factors that possibly explain the correlation between core-periphery structure and modular-incremental innovation?

Assuming that specific position of the firm in the network can influence the technological options pursued by the firm, different insights will accrue to individual firms in the same network (Burt 1992b). Individual firms have made investments in their relations with others and developed knowledge about their parts of the network (Hakansson and Johanson 1988). Increasing networking experience and information benefits bring better opportunity to implement competing and/or complementary technologies. In contrast, the lack of such opportunity limits the extent to which internally developed technologies can affect the market. Thus, firms in the core of the network are better positioned to jointly develop innovations with greater technical implications than those firms in the periphery of the network.

If, however, the relationship between core-periphery structure and modular-incremental innovation is a spurious one, factors that may cause the two events independently are the costs and complexity of existing technologies. When such costs and complexity are high, firms tend to share risks and costs with their partners (Contractor & Lorange 1988). Under similar conditions, more modular innovations are undertaken to replace mainstream technologies within a component layer. Even when a firm's innovations replace its old technologies, the firm can gain a first-mover advantage in entering new markets (Christensen 1992a). The continuing growth of Sun Microsystems in rapidly changing environment can in fact be explained by the firm's ability to introduce "economies of substitution", whereby technological development involves replacing only certain components while retaining others (Garud &

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[33] NetworkWorld, December 26, 1988.

Kumaraswamy 1993). Under these circumstances, neither network position nor the nature of the innovation has causal implications for one another.

Given that core-periphery structure and the nature of the innovation may covary because one variable causes the other or because a third variable causes both, the study does not have sufficient data to prove one or the other of these three possibilities. However, the stability and the significance of core-periphery structure have raised many important implications for future studies of alliances and innovations. The instability of some firms in alliance formation may not be just a case of random noise but instead reflects a distinction between a core set of relationships that are important in the industry and a periphery set of relationships that are important only on some occasions.

7. Discussion and Conclusions

With 12 years of alliances among the 150 sample firms in the data communications industry, the longitudinal data in the study have presented strong evidence for some regularity and stability of the industry network. The network structure is best described in terms of core-periphery, whereby a small number of firms are seen repeatedly in the core of the network and many others are in the periphery forming sporadic relationships. The core-periphery structure appears to be fluid in that some firms enter and exit at the periphery of the network whereas others move from the periphery and then remain in the core of the network. Instead of being the targets for acquisition, members of the network have become more likely to acquire non-members.

Moreover, core firms are more likely than periphery firms to make acquisitions.

Several interesting questions have been raised about the motives for alliances and acquisitions underlying the core-periphery structure. In social network theory, the emergence of networks is a result of resource mobilization in the organizational field (Granovetter 1992). As discussed in section 5, sources of network stability are related to one or more factors, namely, transaction costs, information benefits and degree of resource dependency. In addition, the acquisition activity in the industry does not appear to have an impact on network stability. The sociological argument further informs us that the sources of network variability are contingent upon the specific position of the firm in the social network. More important, the innovative behavior of the firm can be influenced and constrained by its own set of past relationships.

Further analysis in Section 6 based on limited data shows that the set of core ties is associated especially with modular innovations whereas the set of periphery ties is associated more frequently with incremental innovations. Neither core nor periphery alliance relationships have generated radically new innovations and few architectural innovations are found. What about the nature of technologies possessed by the 57 non-members and 13 members of the industry network that were acquired by both core and periphery firms? In addition to some incumbent firms in the industry, the set of non-member firms also includes new entrants.[34] Existing studies of technological innovation assert that new entrants are more likely to have radical and competence-destroying innovations (Tushman & Anderson 1986; Utterback & Suarez 1993). Although such innovations have not been detected in this research, it is conceivable that acquisitions have been made in order to invest in such potentialities. Since the search for more qualified and willing experts takes time, the attempt to code the acquired technologies will be explored in future research.

The above concern in fact points out a major limitation of the study in its original intent to exclude analyses of firms not participating in the network driven by technology alliances. The difficulty of conducting research built upon social network theory is to define the boundary for a system of organizations and to link the structure of social relations to the behavior of the firm (Marsden 1990). "Is the population the right unit of analysis?" was raised by DiMaggio (1994), a question remaining most problematic and yet challenging to researchers who are interested in the sociology of organizations. What defines the boundary of the network in the study is an arbitrary artifact which could be eliminated if all 496 industry firms are included in the sample. Those firms that have been identified as non-members can be viewed instead as potential members of the industry network. Moreover, about 53% (85 out of 160) of the acquisitions from 1985-1996 were made among the non-members. Analyses based on the population data would no doubt enlighten us on all the questions uncovered in this study. In spite of the limitation, the findings presented so far remain valid for the core-periphery structure of interorganizational networks.

Existing studies of technological innovation have identified other patterns of network structure. Barley, Freeman and Hybels (1992) found in the biotechnology

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[34] The term new entrants refers to start-up firms and established firms from other related industries.

community that their clustering results are consistent with the generalist-specialist structure in population ecology. Moreover, variation in alliance activity is associated with firms whose attributes differ in a coherent fashion. In contrast, Kogut, Shan and Walker (1992) showed that network structure rather than firm attributes affects the decision to cooperate in the biotechnology industry. In their follow-up study, they found that the structural position of the firm, as a proxy for the amount of social capital, is a strong predictor of network formation (Walker et al. 1997). Finally, based on the similarity of firm capabilities, Nohria and Garcia-Pont (1991) identified complementary blocks and pooling blocks as significant structural patterns of the automobile industry network. The above studies have alluded to network positions and firm attributes as potentially important factors in interorganizational dynamics.

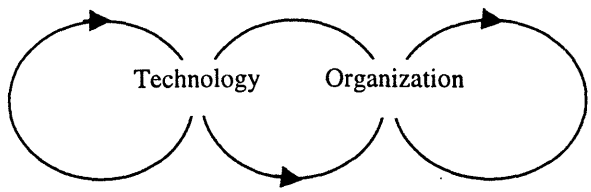
Besides network positions and firm attributes, the highly interdependent, complex and yet standardized properties of the data communications technologies appear to be additional conditions for alliances and innovations. Successive innovations in this market are defined by both how well they interoperate with and how much they differentiate from competing products. In many instances, alliances bring not only complementary technologies but also competitive information about competitors' products. The description of technological innovation here is akin to the concepts of "new technological systems", "large technological systems" and "open systems" explained by Freeman (1994), Hughes (1987) and Tushman and Rosenkopf (1992) respectively. Tushman and Rosenkopf (1992:312) argue that "the more complex and/or open the product, the greater the technical uncertainty and the greater the intrusion of organizational dynamics in technological evolution." They further posit that interorganizational dynamics are heightened only when core technologies are threatened (Rosenkopf & Tushman 1994). The findings in this study have implied that firms in the core of the network seek new technological opportunities through horizontal cooperation. These findings are also in accord with the observations made in the development of complex flight simulators (Miller, Hobday, Leroux-Demers & Olleros 1995). Therefore, the core-periphery structure of the industry network may not be unique to the data communications industry.

8. Directions for Future Research

The concept of interorganizational networks is not yet fully defined and understood in the study. A good definition of interorganizational networks is one that refers to its significant structural patterns, the governance mechanisms, as well as the conditions underlying network formation, stability and decline. Jones, Hesterly and Borgatti (1997) broadly define networks of firms in the following: "network governance [that] involves a select, persistent, and structured set of autonomous firms (as well as nonprofit agencies) engaged in creating products or services based on implicit and open-ended contracts to adapt to environmental contingencies and to coordinate and safeguard exchanges. These contracts are socially and not legally binding." As demonstrated in the study, short-term formal agreements involving technological development also have potential impact on emerging relations in the industry. Therefore, two general research questions are: 1) What are the differences between formal and informal networks of firms? 2) Under what conditions is one form of networks more salient than the other? Jones and her colleagues argue that better understanding of these conditions have implications on adaptation, coordination and safeguarding in network governance.

A more specific research question arising from this study is what factors determine the role between core and periphery firms (or high-centrality versus low-centrality) and how these factors shape the emergence of new technologies. If technological attributes are fundamental to the dynamics of core-periphery network, the interaction and replication processes among organizations add a new dimension to the evolution of new technologies (see Figure 8). Central to the co-evolutionary concept of organization and technology are the interactions between organization and technology and the feedback of their interactions to firm behavior and technological attributes (Baum & Singh 1994; Rosenkopf & Tushman 1994; Van de Ven & Garud 1994). From a system dynamics viewpoint, both positive and negative feedbacks are possible in the relationship between organization and technology. Understanding both technological and organizational attributes will shed light on the conditions under which positive feedback loops are more likely than negative feedback loops. Therefore, the co-evolutionary setting for an open, complex technological system may extend the linear models of "dominant designs" and stage-evolution explained in Abernathy and Utterback (1978) and Tushman and Anderson (1986).

Figure 8. Dynamic Feedback Loops of Organization and Technology



However, an attempt to draw any theoretical implications of the co-evolutionary process is both difficult and frustrating since our understanding of the potential impact of interorganizational relationships on technological performance is still limited. More empirical research using rigorous statistical methodology is required to examine the roles of core and periphery firms in affecting their technological outcomes. In fact, the dynamics of core-periphery structure is consistent with the sociological explanation of embedded relations as the social capital of the firm (Burt 1992a; Granovetter 1992). The social capital of the firm is the amount of resources that have accrued to the firm by virtue of maintaining direct and indirect relationships with other firms in the same organizational field. The behavior of the firm, and hence its technological performance, is constrained and influenced by its ability to gain access to the social capital in the environment.

On the contrary, alternative theories suggest that firm attributes might be a more important determinant of firm behavior. The resource-based view of the firm infers that a firm's internal resources are distinctive capability sustaining the competitive advantage of the firm (Barney 1991; Wernerfelt 1984). Similarly, Teece (1986) argues that a firm must have control over the necessary complementary assets in order to implement its innovation successfully. Yet in another viewpoint, Rosenbloom and Cusumano (1987) posit that learning and consistency of management strategies are key to successful innovation. While attributes of firms such as internal capabilities and resources are important sources of innovations, the differential access to information and resources through interorganizational relationships is also a potential source of firm heterogeneity that cannot be ignored. Therefore, an empirical contribution to the field of economic sociology and technology management would be to assess the relative importance of firm attributes versus structural position in affecting technological performance of the firm.

Appendix A. Synopsis of Local Area Network Standards and Technologies

Local area networks or LANs are used to connect computers located within a single building or a localized group of buildings.[1] PC-based LANs generally include a network file server, network operating system, cabling and connectors, adapter cards, shared peripherals such as printers and facsimile machines, and applications software. Adapter cards that support the type of standard protocol configured in a network, like 3Com EtherLink PC card for Ethernet network, provide the basic connection from PCs to the network cables. Internetworking devices such as bridges, routers, gateways, hubs, and switches are installed when data exchange between networks is necessary. Figure A-1 below shows three LANs being connected to a backbone LAN by two bridges and a router. The backbone in turn is connected to a wide area network called PSDN by a switch.

The early application of LANs was to enable distributed workstations to access an electronic mail server or a laser printer. Today, sophisticated applications involving the transmission of documents incorporating images and other media are becoming common, increasing the demands on the capacity of LANs. Devices known as switches are used to interconnect LAN segments in order to meet the demand for higher bandwidth. For greater physical separations of LAN segments, high speed LANs will be used as backbone. Another type of network is wide area networks or WANs, which are composed of multiple establishment-wide LANs. WANs can be classified into two categories: public data networks (PDNs) and private networks. PDNs are installed and managed by the public carriers while private networks are by large national and multinational corporations. Private networks are also known as enterprise-wide networks.

The two LAN standards that have been widely adopted are Ethernet-based (such as 10Base-T) and Token-ring networks. As for internetworking between LANs and WANs, one of the important considerations is the standard for providing end-to-end network services to local users. End-to-end network services are delivered such that the possible presence of multiple networks is made transparent to the users. At present, two competing internetworking standards provide these network services, namely, ISO Internet Protocol,[2] and

[1] A useful academic reference text is by Larry Peterson and Bruce Davie, "Computer Networks," 1996, San Francisco, California: Morgan Kaufmann Publishers, Inc.

[2] Founded in 1946, ISO is an international standards organization composed of national standards

Internet Protocol (IP) that is used by the Internet (formerly known as ARPANET). Issues that are related to how network services should be provided are called network management, which includes network maintenance, addressing, routing, error and flow control.

Owing to the complexity of data communications, a reference model for the structure of a communication system has been formulated so that the standards associated with different levels of the system can be simplified. Figure A-2 below presents the International Standard Organization (ISO) Reference Model for data communications between two computers. Figure A-3 illustrates the network environment of the ISO Reference Model and the technologies which are included for this study.

The ultimate goal of interconnectivity is to achieve an open system interconnection environment. That is, a set of application programs, running on different computers connected by proprietary networks, are enabled to perform distributed applications. This high level of connectivity is further supported by two different standards, i.e., Open Systems Interconnection (OSI) suite and Transport Control Protocol/Internet Protocol (TCP/IP). Both standards support specific application protocols such as remote access and mail service. The most popular applications currently supported by TCP/IP, for example, are electronic mail system and Netscape.

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bodies from over 75 countries. For example, ANSI (American National Standards Institute) is a member of ISO. ISO has defined a number of important computer standards, the most significant of which is perhaps OSI (Open Systems Interconnection), a standardized architecture for designing networks. See http://www.sandybay.com/pc-web/ISO.htm.

Figure A-1. LAN-based Data Communications Networks*

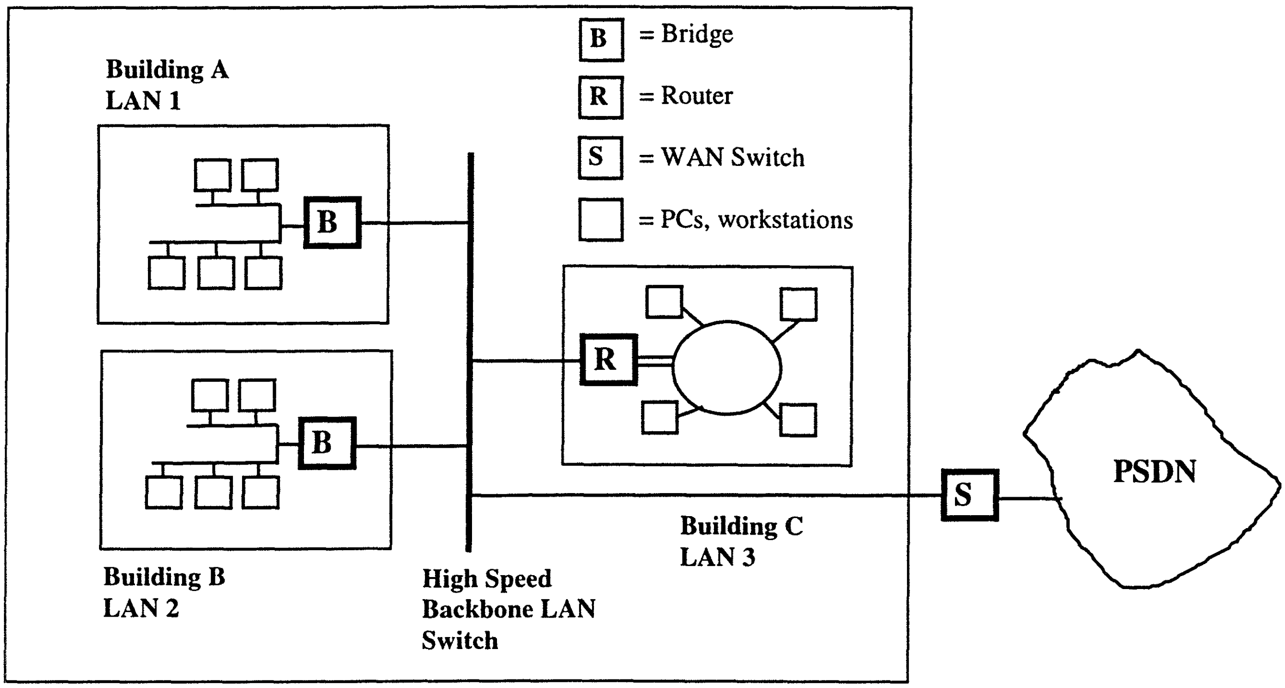


Figure A-2. International Standards Organization (ISO) Reference Model*

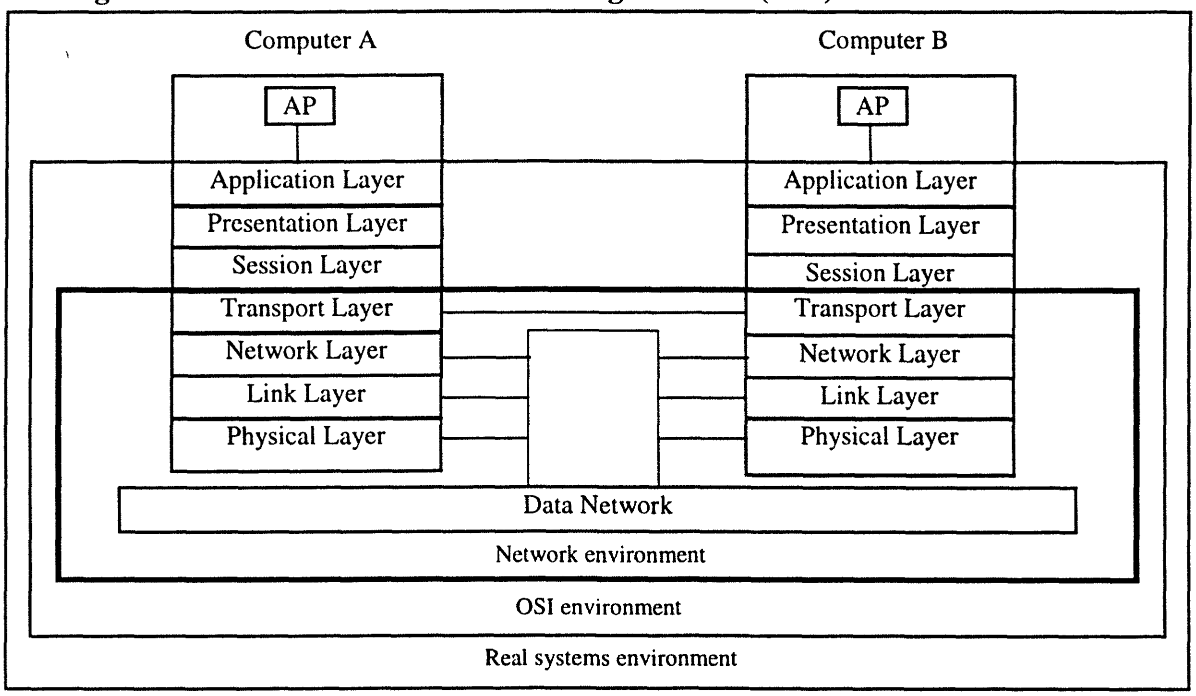


Figure A-3. Network Environment - Standards and Technologies*

4 Transport Layer	Transmission Control Protocol (TCP)* or User Datagram Protocol (UDP)			Gateways works at Network Layer and above
3 Network Layer	Internet Protocol (IP)			Bridges, Switches function with dissimilar LANs
2 Data Link Layer Logical Link Control	IEEE 802.2			Bridges, Switches function with similar LANs; Routers work in both Network and Data Link Layers
Medium Access Control	IEEE 802.3 Ethernet	IEEE 802.4 Token Bus	IEEE 802.5 Token Ring	
1 Physical Layer				Repeaters and network interface cards operate at the physical layer; Coaxial cable is by far the most popular medium implemented for LANs
	Transmission Medium			

- All three figures are adapted from Fred Halsall, "Data Communications, Computer Networks and Open Systems," 1996, (Fourth Edition), Addison-Wesley.

Appendix B. Social Network Analysis using UCINET IV[3]

Table B-1. Output of Geodesic Distances among Pairs of Firms, 1985-1988

DISTANCE
Type of data: ADJACENCY
Nearness transform: NONE
Input dataset: C:\UCINET\NETWORK1\D85-8LSC

For each pair of nodes, the algorithm finds the # of edges in the shortest path between them.

Length of optimal paths between all pairs of nodes:

	1 3CO	2 ATT	3 CHP	4 COD	5 CPQ	6 CDS	7 DCA	8 DEC	9 DSC	10 EXC	11 HP	12 IBM	13 INT	14 MDG	15 MCT	16 MS	17 NET	18 NVL	19 ORC	20 RAB	21 RTX	22 SCO	23 STR	24 SNP	25 SYT	26 UBN	27 WSD	28 SMC
1 3CO	0	3	4	1	4	4	1	3	4	3	1	3	4	3	4	2	4	5	4	5	3	3	4	6	2	4	7	5
2 ATT	3	0	7	4	7	7	4	6	7	2	2	2	1	2	1	1	3	4	3	4	2	2	7	5	5	3	6	2
3 CHP	4	7	0	3	2	2	5	1	2	7	5	7	8	7	8	6	8	9	8	9	7	7	2	10	2	8	11	9
4 COD	1	4	3	0	3	3	2	2	3	4	2	4	5	4	5	3	5	6	5	6	4	4	3	7	1	5	8	6
5 CPQ	4	7	2	3	0	2	5	1	2	7	5	7	8	7	8	6	8	9	8	9	7	7	2	10	2	8	11	9
6 CDS	4	7	2	3	2	0	5	1	2	7	5	7	8	7	8	6	8	9	8	9	7	7	2	10	2	8	11	9
7 DCA	1	4	5	2	5	5	0	4	5	4	2	4	5	4	5	3	5	6	5	6	4	4	5	7	3	5	8	6
8 DEC	3	6	1	2	1	1	4	0	1	6	4	6	7	6	7	5	7	8	7	8	6	6	1	9	1	7	10	8
9 DSC	4	7	2	3	2	2	5	1	0	7	5	7	8	7	8	6	8	9	8	9	7	7	2	10	2	8	11	9
10 EXC	3	2	7	4	7	7	4	6	7	0	2	2	3	2	3	1	3	2	1	4	2	2	7	3	5	3	4	4
11 HP	1	2	5	2	5	5	2	4	5	2	0	2	3	2	3	1	3	4	3	4	2	2	5	5	3	3	6	4
12 IBM	3	2	7	4	7	7	4	6	7	2	2	0	3	2	3	1	1	4	3	4	2	2	7	5	5	3	6	4
13 INT	4	1	8	5	8	8	5	7	8	3	3	3	0	3	2	2	4	5	4	5	3	3	8	6	6	4	7	1
14 MDG	3	2	7	4	7	7	4	6	7	2	2	2	3	0	3	1	3	4	3	4	2	2	7	5	5	3	6	4
15 MCT	4	1	8	5	8	8	5	7	8	3	3	3	2	3	0	2	4	5	4	5	3	3	8	6	6	4	7	3
16 MS	2	1	6	3	6	6	3	5	6	1	1	1	2	1	2	0	2	3	2	3	1	1	6	4	4	2	5	3
17 NET	4	3	8	5	8	8	5	7	8	3	3	1	4	3	4	2	0	5	4	5	3	3	8	6	6	4	7	5
18 NVL	5	4	9	6	9	9	6	8	9	2	4	4	5	4	5	3	5	0	2	2	4	4	9	1	7	1	2	6
19 ORC	4	3	8	5	8	8	5	7	8	1	3	3	4	3	4	2	4	2	0	4	3	3	8	3	6	3	4	5
20 RAB	5	4	9	6	9	9	6	8	9	4	4	4	5	4	5	3	5	2	4	0	4	4	9	3	7	1	4	6
21 RTX	3	2	7	4	7	7	4	6	7	2	2	2	3	2	3	1	3	4	3	4	0	2	7	5	5	3	6	4
22 SCO	3	2	7	4	7	7	4	6	7	2	2	2	3	2	3	1	3	4	3	4	2	0	7	5	5	3	6	4
23 STR	4	7	2	3	2	2	5	1	2	7	5	7	8	7	8	6	8	9	8	9	7	7	0	10	2	8	11	9
24 SNP	6	5	10	7	10	10	7	9	10	3	5	5	6	5	6	4	6	1	3	3	5	5	10	0	8	2	1	7
25 SYT	2	5	2	1	2	2	3	1	2	5	3	5	6	5	6	4	6	7	6	7	5	5	2	8	0	6	9	7
26 UBN	4	3	8	5	8	8	5	7	8	3	3	3	4	3	4	2	4	1	3	1	3	3	8	2	6	0	3	5
27 WSD	7	6	11	8	11	11	8	10	11	4	6	6	7	6	7	5	7	2	4	4	6	6	11	1	9	3	0	8
28 SMC	5	2	9	6	9	9	6	8	9	4	4	4	1	4	3	3	5	6	5	6	4	4	9	7	7	5	8	0

Distance matrix saved as dataset C:\UCINET\NETWORK9\D85-8D

Elapsed time: 1 second. 1/29/1998 9:37 AM.

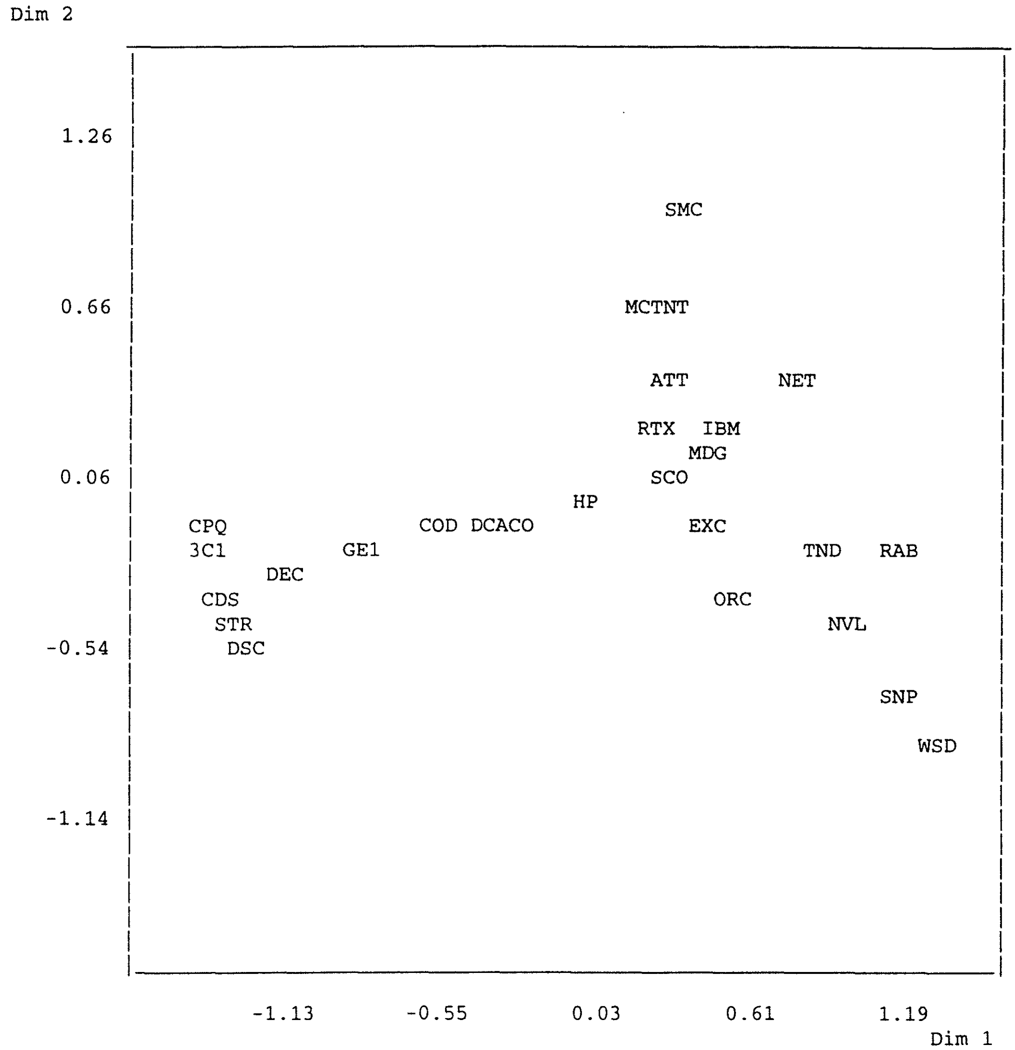
[3] Borgatti, Everett and Freeman, 1992, *UCINET IV*, Columbia: Analytic Technologies. UCINET IV is a software program for social network analysis. For more information see http://www.heinz.cmu.edu/project/INSNA/soft_inf.html

Table B-2. Output of Multidimensional Scaling (MDS) Coordinates among Pairs of Firms based on Geodesic Distance, 1985-1988

```
NON-METRIC MULTIDIMENSIONAL SCALING
Input dataset:             C:\UCINET\NETWORK9\D85-8D

Starting config:           TORSCA
Type of Data:              Dissimilarities


               1     2
           ----- -----
  1 3CO    -0.30 -0.02
  2 ATT     0.32  0.51
  3 3C1    -1.47 -0.21
  4 COD    -0.60 -0.07
  5 CPQ    -1.49 -0.09
  6 CDS    -1.45 -0.31
  7 DCA    -0.40 -0.09
  8 DEC    -1.18 -0.24
  9 DSC    -1.36 -0.54
 10 EXC     0.48 -0.05
 11  HP     0.00  0.06
 12 IBM     0.50  0.35
 13 INT     0.30  0.84
 14 MDG     0.46  0.18
 15 MCT     0.21  0.78
 16  MS     0.30  0.17
 17 NET     0.79  0.56
 18 NVL     1.00 -0.46
 19 ORC     0.56 -0.34
 20 RAB     1.20 -0.20
 21 RTX     0.27  0.29
 22 SCO     0.31  0.10
 23 STR    -1.41 -0.42
 24 SNP     1.21 -0.70
 25 GE1    -0.89 -0.16
 26 TND     0.90 -0.18
 27 WSD     1.37 -0.94
 28 SMC     0.36  1.18

Coordinates saved as dataset C:\UCINET\NETWORK9\D8COORD
```

Note: Several starting configuration methods to locate the firms are available under non-metric MDS technique in UCINET: Metric –Gower's metric coordination procedure; Torsca – principal components of rank-order data; Random – locates points randomly in space. Torsca was applied to the dataset in this study. See Table B-3 for MDS output.

Table B-3. Output of MDS Map based on Coordinates in Two-dimensional Space



Stress in 2 dimensions is 0.041

Elapsed time: 1 second. 1/29/1998 8:49 AM.
UCINET IV 1.66/X Copyright 1991-1996 by Analytic Technologies.

Appendix C. Centrality

In social network analysis one of the commonly used measure is centrality, which can identify the most "important" or "prominent" actors in a social network. According to a review of social network analysis (Freeman 1978), the idea of centrality as applied to human communications was introduced by Bavelas at the Group Networks Laboratory at M.I.T. in the late 1940s. The studies conducted by the research group under the direction of Bavelas found that centrality was related to group efficiency in problem solving, perception of leadership and the personal satisfaction of participants (Bavelas 1948; Bavelas & Barrett 1951).

Three types of centrality measures have been used to quantify the prominence of an individual actor embedded in a network: degree, betweenness and closeness (Freeman 1978; Wasserman & Faust 1994). Degree centrality of an actor is the simplest measure of the number of ties (degree) to all other actors (nodes) in a graph. The most central firm is considered to be the most active actor in the network. Betweenness centrality measures the number of intermediaries between two nonadjacent actors. These "other intermediate actors" potentially might have some control over the interactions between the two nonadjacent actors. If an actor lies between many of the actors via their shortest paths, it is said to have high centrality in the network.

Closeness centrality measures how central or close an actor is to all other actors. This is the same as finding minimum distances to all other actors and the idea is that the more central the firm the lower the cost or time for communicating information to and from all other actors. Assuming that the shortest (geodesic) distance between two actors is $d(n_i, n_j)$, the sum of the geodesic distances from actor n_i to all other actors n_j is given by

$$\sum_{j=1}^{g} d(n_i, n_j) \qquad \text{where } j \neq i.$$

For example, in a star network with 5 actors connected to a single actor in the center, the sum of the geodesic distances for the central actor is 5 (1+1+1+1+1) whereas the sum for each of the 5 other actors is 9 (1+2+2+2+2). The closeness centrality index for actor n_i based on Sabidussi's method (Freeman 1978) is given by

$$C(n_i) = \left[\sum_{j=1}^{g} d(n_i, n_j) \right]^{-1} .$$

The closeness centrality index generated in UCINET IV is normalized by dividing the actor's index by the maximum possible closeness centrality index, i.e. $(g-1)^{-1}$, in the network. The standardized index ranges between 0 and 1. When the index equals unity, it means the actor is maximally close to all other actors. When the index equals zero, one or more actors are not reachable from the actor in question. However, the closeness centrality measure is only meaningful for a connected graph, i.e. every node is reachable from all other nodes. Otherwise, if one node is not reachable, then the distance from all other nodes to this specific node is infinitely long and the distance sum for every actor is ∞. The input to closeness centrality is a symmetric binary matrix, i.e. when the number of alliances is 1 or greater between two actors, the value will be 1, otherwise 0.

Appendix D. Cohesive Subgroups and Technological Developments, 1985-1988, 1989-1992, 1993-1996

Table D-1. Cohesive Subgroups and Technological Developments, 1985-1988

Cohesive Subgroup	Technological Development	Coder Ratings A	Coder Ratings B
CORE 1985, 1988 Microsoft and UB Networks	In 1985, Intel, Microsoft and UB Networks announced a strategic development and marketing agreement for Intel's Open Net system, one of the key features of which is compatibility with PC Network by IBM. In 1988, UB Networks signed an OEM licensing agreement for Microsoft's LAN Manager and intended to extend its current product capabilities to an OS/2 base.	M	I
1985, 1987 Microsoft and 3Com	In 1985, Novel and 3Com formed agreements with Microsoft to obtain MS-DOS 3.1 and MS Network software, designed to be closely compatible with IBM's PC-DOS 3.1 and PC Network software. In 1987, 3Com jointly developed the OS/2 LAN Manager with Microsoft; in addition, both companies jointly made sales calls to large corporate users. 3Com also developed 3 open, network system software based on the LAN Manager.	M	I
1988, IBM and Network Equipment Technologies	NET has benefited from its 2-year-old joint development and marketing relationship with IBM in the T-1 market.	I	?
1986, Codenoll Technology and Sytek	In separate cooperation with Sytek and 3Com, Codenoll has come up with fiber optic versions of the two companies' network adapter cards.	M	M
1986, AT&T and Intel	AT&T and Intel jointly developed their integrated services digital network (ISDN) microchips compatible in a move that would give ISDN terminal makers more choices in designing products.	M	M
1987, Oracle, Novell, Excelan	Novell's agreement with Oracle used Excelan's TCP/IP Workstation software and Novell's TCP/IP Gateway software to provide transaction processing through links between LANServer and PC workstations. Oracle customers will be able to use Netware to connect with a variety of network schemes, including Ethernet, token-ring networks and Arcnet.	I	M
PERIPHERY 1988, SynOptics and Western Digital	SynOptics' LattisNet 10-Mbps Ethernet transceiver will be incorporated into a version of Western Digital's EtherCard Plus network interface card for the IBM PC XT and AT, PS/2 Model 30 and compatibles.	I	M
1988, Chipcom and DEC	The Ethermodem III Bridge is the result of a joint development agreement between Chipcom and DEC. Based on DEC's LAN Bridge 100 architecture and Chipcom's broadband transceiver technology, the bridge links Ethernet subnetworks to a broadband Ethernet backbone.	I	M

Source: Lexis/Nexis, 1996/7.

Note: A is E2 (Research Scientist) and B is E1 (engineer). M - Modular Innovations, I - Incremental Innovations, A - Architectural Innovations

Table D-2. Cohesive Subgroups and Technological Developments, 1989-1992

Cohesive Subgroup	Technological Development	Coder Ratings A	Coder Ratings B
CORE			
1989, Excelan, Network System Corp. and Wellfleet Communications.	The three companies put together LAN II, consisting of multiple protocols and multiple networks. It's a workstation solution internetworked with a mainframe solution. NSC provided the HyperChannel series of high-speed networks used to connect supercomputers and mainframes. Excelan is focused on networking workstations, minicomputers and PCs. Wellfleet developed Ethernet bridges and routers for linking LANs and WANs.	M	M
1989, 3COM and HP	HP and 3Com developed products together and cooperated in worldwide joint service. In promoting single interface, HP embraced 3Com's networking scheme to tie its minicomputers to other vendors' hardware. The firms announced six areas of product development focused heavily on standards such as TCP/IP, CCITT's X.400 and the Open Systems Interconnect model.	M	M
1989, Banyan and DEC	DEC offered a licensing program for its Local Area Transport (LAT) protocol, saving third-party vendors the trouble of having to reverse-engineer the popular terminal-to-VAX networking specification. Banyan integrated networking products with LAT.	M	M
1990, Cisco and Madge Networks	Cisco licensed Madge's Fastmac data buffering and transfer software for use in Cisco's Token-Ring routers.	I	I
1990, 1991, Cisco and SynOptics	In 1990, they jointly developed a router module for Synoptics' LattisNet wiring concentrator. In 1991, SynOptics, Cisco and SunConnect jointly developed the next-generation, integrated routing hub for Ethernet, Token Ring, and FDDI, dubbed the RubSystem. In another joint development agreement, Cisco and Synoptics integrated routers with the wiring hub.	I	M
1991, Madge Networks and SynOptics	Madge announced a licensing agreement with SynOptics for Madge's FastMAC Token-Ring software. FastMAC Token-Ring and Bridge Management software package would be incorporated into SynOptics' LattisNet Token-Ring product line.	I	I
1992, Chipcom and IBM	IBM and Chipcom jointly developed intelligent hubs to link heterogeneous computers and networks into enterprise networks. The partnership helped IBM fill a gap in its internetworking product line.	I	M
1992, National Semiconductor and NET	NS agreed to license ATM interface designs from Adaptive Corp., a unit of NET, and used the technology to develop multimedia computer and high-speed networking equipment.	M	M
1990, 1992 Retix and Novell	In 1990, Novell and Retix in joint development to provide X.400 pathway in MHS LAN. In 1992, Retix joined with Novell to deliver the first X.400 capability to the NetWare Global Messaging environment.	M	M
1991, Tiara and Sun (Sitka)	Sitka Corp is formerly the TOPS Division of Sun Microsystems. Sitka and Tiara improved the interoperability of two popular network operating systems and provided each system with connections to a wider variety of network environments.	I	I
1992, Ascend Comms. and AT&T Paradyne	AT&T Paradyne and Ascend cooperated in the development and distribution of products for wide-ranging networking applications in the global bandwidth-on-demand marketplace.	I	?

Table D-2. Cohesive Subgroups and Technological Developments, 1989-1992, Continued

Cohesive Subgroup	Technological Development	Coder Ratings	
		A	B
PERIPHERY			
1990, ACC Networks and UB Networks	UB Networks to integrate Advanced Computer Communications (ACC) multiprotocol bridge/router with UB Access/One intelligent hub. The agreement with ACC was sparked in part by the need to bring branch offices into the corporate network.	I	M
1990, Data Switch and Proteon	Data Switch integrated Proteon's LAN products into its data processing and communications switching and control systems.	I	M
1990, Stratacom and Vitalink Comms.	Vitalink Communications and Stratacom had a joint-development effort through which Vitalink bridges and routers will support Stratacom's Frame Relay Interface.	I	M
1990 Codenoll Technology and Lanex	Lanex and Codenoll Technology entered into a strategic alliance to develop additional technology and products for Fiber Distributed Data Interface (FDDI) networks.	I	I
1991, Cabletron and Cayman Systems	They jointly developed GatorMIM CS media interface module. The device is an Apple Talk-to-Ethernet media interface module, based on Cayman's gateway technology, that plugs in to a Cabletron Multi Media Access Center Ethernet hub.	M	M
1991, Crosscom and Bytex	Bytex incorporated CrossCom's next generation token-ring bridging technology in its Maestro Intelligent Switching Hub. Maestro is a matrix-switching hub that lets users remotely configure and manage the physical links of their token-ring LANs.	I	M
1991, Networth and Cheyenne Software	The two companies jointly developed network management software for NetWorth's 10Base-T concentrators.	I	I
1991, Netrix and Pacific Communication Sciences	Netrix and Pacific Communication Sciences had a joint-development agreement that let each company rely on the other's expertise for integrated circuit-packet switches and voice-compression techniques.	I	A
1992, Ericsson and Luxcom	Ericsson expanded its relationship with Luxcom to jointly develop a collapsed backbone that supports multimedia applications.	I	A
1992, Tellabs and Fujitsu Network Systems	Fujitsu Network Systems and Tellabs used WAVE to make history, providing the first mid-span meet of synchronous optical network (SONET) equipment that included a link of data communications channels.	M	M

Source: Lexis/Nexis, 1996/7

Table D-3. Cohesive Subgroups and Technological Developments, 1993-1996

Cohesive Subgroup	Technological Development	Coder Ratings A	Coder Ratings B
CORE			
1993, Interphase and NET	NET and Interphase developed ATM adapter cards to link workstations to ATM networks.	M	M
1993, SynOptics and Network Peripherals	Network Peripherals and SynOptics jointly developed ATM adapter cards. Network Peripherals built the adapters for EISA, Micro Channel and S-bus architectures using ATM technology from SynOptics.	M	M
1993, Networth and Newport Systems Solutions (NSS)	NetWorth licensed NSS' LAN/MPR bridge software for NetWorth's Series 4000 Local Ethernet Bridge. Also, NSS certified the NetWorth NetWare Application Engine (NAE) as a platform for its routers.	I	M
1993, Network Communications Corp. (NCC) and Novell	Novell had a licensing and technology agreement with NCC whereby NCC will acquire exclusive rights to develop, market and support the hardware- based version of Novell's LANalyzer network analyzer. The agreement includes the hardware-based LANalyzer only; Novell continued to develop and market its software-only LANalyzer for Windows product.	I	?
1994, Chipcom and Axon Networks	Joint development of two network monitoring applications for Chipcom's line of intelligent switching hubs that complies with the Simple Network Management Protocol's Remote Network Monitoring Management Information Base (RMON).	I	?
1994, Ascend Communications and PictureTel	They have been supplying complementary solutions to their worldwide customers for several years. The Ascend Multiband MAX Bandwidth-on-Demand product provided public network connections for the PictureTel M-8000(2) Multipoint Conferencing family.	M	?
1994, Alantec and Wellfleet Communications	They had a co-operative marketing and technical support alliance, covering their Backbone Concentrator Node routers and PowerHub products respectively. It covered four key initiatives: interoperability testing, technical training, co-ordinated technical support, and joint sales and marketing.	I	?
1994, Network General Corp and AIM Technology	They integrated their product lines to create end-to-end client/server network management. Network General also bought a 10% stake in AIM Technology, a Unix systems management software provider. AIM used the equity investment to accelerate development of its SharpShooter product, a fault and performance management application for Unix systems.	I	?
1994, Crosscom and Applied Network Technology (ANT)	CrossComm signed a technology license agreement with Applied Network Technology for the development of new Ethernet switching technology for CrossComm's XL product line.	M	M
1994, Lanoptics and Cisco	They jointly developed integrated hub/router products. The Cisco AccessPro router card will be available with StackNet, LanOptics' multi-protocol stackable hub, and packaged with BranchCard, LanOptics' PC based hub card.	I	M
1994, LightStream (LITES) and Tellabs	They jointly developed and distributed ATM switching systems. The two companies negotiated an OEM agreement whereby Tellabs would market LightStream 2010 ATM products. In addition, Tellabs and LightStream planed a technology licensing agreement that would allow Tellabs to develop new features and functions for the LightStream 2010 ATM products.	M	A
1994, 1995, Proteon, IBM and Dec	In 1994, Proteon had licensed DEC and IBM to use its internetworking software and had extended a previous joint development agreement with IBM to develop remote site router family products. In September 1995, IBM and Proteon reaffirmed their continuing joint development of remote site internetworking products including implementation of the DLSw specification.	M	M
1995, 3Com and Bay Networks	3Com and Bay Networks jointly announced a cooperative mutual patent license agreement. The agreement covers all patents presently held by both companies and extends to all patents that will be issued to both organizations during the next five years.	?	?
1995, AT&T and HP	AT&T and HP agreed to develop public and private networks using wired and wireless technology to improve delivery of multimedia information and interactive services.	M	I
1995, 1996, Cascade Communications and Motorola	In 1995, Motorola teamed up with frame relay switch maker Cascade to develop a terminal adapter that lets remote users run frame relay traffic over ISDN lines. In 1996, Motorola's Multimedia and Information Systems Groups and Cascade agreed to cooperate to provide high-speed Internet access via cable to end-users. The combination of Motorola's CableComm system and Cascade's multiservice switching products will allow increased capacity for high-volume, easily expandable Internet access.	M	M

Table D-3. Cohesive Subgroups and Technological Developments, 1993-1996, Continued

Cohesive Subgroup	Technological Development	Coder Ratings A	Coder Ratings B
1996, ADC Kentrox and Ericsson	Ericsson and ADC Kentrox signed a systems integration agreement to deliver ATM solutions to network operators and service providers. Ericsson will market and sell ADC Kentfox ATM access products for data communications and WANs. The agreement also includes the framework for cooperative development of new ATM products and services.	M	M
1996, NetEdge and Nortel	Nortel's LAN Module allows network providers to offer LAN interconnect service on an ATM-over-SONET backbone to multiple customers via the same network connection that also supports voice and narrowband data. The LAN Module incorporates the NetEdge's award-winning ATM edge routing technology.	M	M
1996, General Datacom and Dynatech Comms.	They successfully demonstrated the interoperability between Dynatech's DynaStar 100 and the GDC APEX®. The combination of these products provides ATM all the way to the access point without multiple network conversions.	I	?
1996, Fore Systems and General Instrument	They jointly developed a high-speed, ATM-based telecommunications network system. The system is designed to enable broadband telecommunications operators to provide high-speed, two-way communication services to computers over hybrid fiber coax (HFC) cable TV plants.	A	A
1996, BBN and Intel	BBN has built a trial network to demonstrate that the Resource Reservation Protocol (RSVP) can give the guarantees necessary to ensure that real-time data, as well video, audio and other multimedia elements, get through. The network was designed in conjunction with Cisco, content provider Worldwide Broadcasting Network (WBN) and Intel.	M	I
1996, Alcatel and Newbridge Networks	They had an agreement that would enable carriers and corporate customers to deliver SONET (Synchronous Optical Network) services from the public backbone network directly to customer premises.	M	M
1996, Microcom and Gandalf Technologies	Microcom formed technology partnership with Gandalf Technologies that allows Gandalf to incorporate Microcom's modem technology into its Xpressway ™ central site concentrators.	I	M
1996, AM Comms. And Scientific Atlanta	AM Communications and Scientific-Atlanta jointly developed new transponder technology.	I	?
PERIPHERY			
1993, Banyan and NCR	They co-developed a WaveLAN driver for Banyan's VINES network operating system. NCR also initiated a joint –marketing program with Banyan through which Banyan VARs can market NCR's WaveLAN wireless LAN product with VINES.	M	I
1993, ODS and Artel Communications	Optical Data Systems and Artel integrated Artel's StarBridge Turbo Ethernet Switch technology into the ODS Infinity Hub.	M	M
1993, Data General and Proxim	Proxim licensed its RangeLan2 kit to Data General. Data General integrated Proxim's RangeLAN2 wireless LAN technology into a future family of mobile computing systems	M	M
1993, Ascom Timplex, Netrix and Pacific Communication Sciences	Since 1991, Netrix and Pacific Communication Sciences have signed a joint-development agreement that lets each company rely on the other's expertise for integrated circuit-packet switches and voice-compression techniques. PCSI is working with Ascom Timeplex to develop a daughterboard that supports the CELP algorithm as well as facsimile transmissions.	I	I
1994, Dayna Comms. and Xircom	Xircom and Dayna Communications launched a joint-development and cross-licensing deal for Apple connectivity products	I	?
1994, Data Switch and Lannet	They established a joint sales, marketing, and technology-sharing agreement to develop and market systems to simplify and reduce the cost of integrating mainframe data centers with PC-based networks.	I	?
1995, Ancor and Sun	Ancor Communications and Sun Microsystems jointly developed switched Fibre Channel support for server storage.	M	M
1995, Centillion Networks and Olicom	They developed token-ring and ATM switching solutions incorporating Centillion's Speed Switch 100 and Olicom adaptors.	I	A
1996, Cabletron and Concord Comms.	They integrated Concord's Network Health performance analysis and reporting applications into Cabletron's Spectrum, the No. 3 enterprise management platform after Hewlett-Packard's OpenView and Sun Microsystems' SunNet Manager.	I	?

Source: Lexis/Nexis, 1996/7.

Appendix E. Other Cohesive Subgroups

Table E-1. Cohesive Subgroups and Technological Developments, 1985-1988

Cohesive Subgroup	Technological Development
1986 DEC and CDS	Concord Data Systems, Inc. has announced a multiyear agreement with DEC to develop General Motors Corp.'s Manufacturing Automation Protocol interfaces for DEC's Microvax computers.
1988 DEC and CPQ	Compaq and DEC are developing VAX-to-MS-DOS linkages.
1988 DEC and DSC	DEC and DSC to develop network systems; agreement designed to foster CCS, ISDN, other telecom advancements.
1988 DEC and STR	DEC's EMA is OSI-based, and according to the company, will accommodate both voice and data requirements and manage SNA and Transmission control Protocol/Internet Protocol environments. Stratacom will develop interfaces to EMA with its own network management products.
1987 3CO and DCA	3Com formed alliances with Digital Communications Associates Inc. (DCA). DCA manufactures add-on boards to link microcomputers to mainframes.
1988 TND and RAB	UB Networks licensed from Rabbit Software SNA technology.
1986 MS and SCO	Xenix-Net, developed jointly by Microsoft and The Santa Cruz Operation. Xenix-Net provides networking, distributed file system capabilities and transparent file sharing in mixed environments consisting of Xenix System V.2-and DOS-based systems.
1988 MS and HP	HP and Microsoft announced their joint strategy for moving the OS/2 Presentation Manager to the Unix environment.
1988 MS and MDG	Madge Networks licensed Microsoft's OS/2 LAN Manager.
1988 MS and RTX	Retix licensed Microsoft's OS/2 LAN Manager.
1988 INT and SMC	Intel and Standard Microsystems Corp. jointly developed LAN Ethernet VLSI.
1988 ATT and MCT	AT&T continued to buttress its support of dominant communications protocols for its 3B processor series through a recent alliance with Micom-Interlan, Inc. that extends Transmission Control Protocol/Internet Protocol, or TCP/IP, functionality to the entire line.

Source: Lexis/Nexis, 1996/7.

Table E-2. Cohesive Subgroups and Technological Developments, 1989-1992

Cohesive Subgroup	Technological Development
1989 CBT and LSI	Cabletron and LSI to develop a transceiver chip that complies with the proposed IEEE 10BaseT standard for 10M bit/sec Ethernet over unshielded twisted-pair wiring.
1991 CBT and SIL	Cabletron and Silicon Graphics developed network management system.
1992 CBT and FOR	Cabletron and Fore Systems jointly developed products for ATM technology.
1992 CBT and WDT	Cabletron and Windata developed a wireless LAN module for Cabletron's hub line that will forge wireless links to workstations and other devices.
1992 BYT and GDL	Bytex and Gandalf Data Systems jointly developed token ring solutions.
1989 XCO and TRW	Crosscom and TRW formed alliance in Ethernet, broadband and wan internetworking solutions.
1991 XCO and GEN	General Datacomm, Crosscom jointly developed multimedia internetworking solutions.
1992 NSC and STO	Network Systems Corp and Storage Technology Corp developed storage devices for network.
1992 NSC and NT	Northern Telecom and Network Systems Corp. in Lan/Wan joint product development.
1991 3CO and SYN	3Com will incorporate Synernetics Lanplex 5000 architecture into its new Linkbuilder 3GH third-generation structured wiring hub.
1992 SUN and EO	EO licensed Sitka's (un Sun) mobile net solutions.
1992 NTR and SIE	Netrix and Siemens Private Communications Systems jointly developed packet switching products.
1989 HP and AMD	HP and AMD in 10Base-T Ethernet Lan product development.
1989 COD and WSD	Codenoll Technology licensed from Western Digital Lan card design and software
1990 SNP and FAR	SynOptics & Farallon Computing integrated F's phoneNet into S's network platform
1991 SNP and RMD	SynOptics licensed network management software from Remedy Corp
1989 CSO and ULT	Cisco integrated its router with Ultra Network Technology's network
1992 CSO and CSC	To develop CSCO's router to manage Cascade's frame relay network
1992 PTE and NLK	Proteon and Netlink to develop IBM connectivity products
1989 ATT and INT	AT&T and Intel have signed an agreement to develop personal computers designed to support AT&T's networked computing offerings.
1991 DEC and DVS	DEC and David Systems joint develop SNMP (simple network management protocol) to manage networking products
1992 DEC and MS	DEC and Microsoft integrated their networking strategies by linking application programming interfaces (APIs) for DEC's Network Application Support (NAS) and Microsoft's Windows Open System Architecture (WOSA).
1991 NVL and NCC	Novell and Network Communications Corp developed internet test and diagnostic instruments
1992 NVL and MDY	Novell and Microdyne jointly developed interface cards
1991 TND and NEP	Network Peripherals & UB Networks in FDDI concentrator products
1992 TND and BBN	UB Networks and BBN has been working for UB's ATM and multimedia solutions.
1990 VLK and XPL	Vitalink and Xyplex will work together to develop and market what they claim will be the first interoperable remote bridges from different vendors.

Source: Lexis/Nexis, 1996/7.

Table E-3 Cohesive Subgroups and Technological Developments, 1993-1996

Cohesive Subgroup	Technological Development
1995 BAY and MS	Bay and Microsoft formed an alliance that will integrate Bay Networks' Routing Services (BayRS) into Microsoft's Windows NT Server.
1995 BAY and FUJ	Bay and Fujitsu Network Switching in joint development of ATM technologies.
1995 XIR and NEC	Xircom licensed to NEC wireless technology.
1993 TLA and TRW	Tellabs and TRW would work together to develop SONET and ATM technology and products.
1995 TLA and PRO	Tellabs and Promptus Communications in joint development of enhanced inverse multiplexing technology that will benefit the customers of both companies.
1994 SUN and CNT	Sun licensed SNA network software from Computer Network Technology's Brixton Systems Inc. Sun's Sparc/Solaris enterprise.
1993 ATT and PRE	AT&T Paradyne developed with Premisys in network access technology.
1993 ATT and PNR	AT&T Paradyne licensed remote access technology from Penril Datability.
1995 ATT and MUL	AT&T Microelectronics licensed from Multi-Tech Systems the digital simultaneous voice and data TM chip sets.
1993 CSO and XER	Cisco and Xerox signed a marketing agreement to resell bridges and routers. (This agreement should have been omitted in the study.)
1995 CSO and NOK	Cisco and Nokia to develop ATM technologies.
1995 CSO and TBI	Cisco acquired TBIT's MICA technology and formed an alliance with TBIT.
1995 CSO and CPQ	Cisco and Compaq formed licensing and joint development agreement.
1995 CSO and USR	Cisco and US Robotics to integrated USR's modem and C's routing technology into 1 box.
1996 CSO and MDG	Cisco and Madge Networks to develop hi-density ISDN switch.
1996 CSO and XPO	Cisco licensed its VLAN Technology to Xpoint.
1993 SHI and APP	Shiva and Apple developed point-to-point protocol technology.
1995 HP and NEV	HP and Netvantage integrated 100VG-AnyLAN into both companies' switches.
1995 HP and NSC	HP and Network Systems manufactuered server channel solutions.
1996 HP and CEL	HP and Cellnet data system to develop wireless communications technologies and client/server computing solutions.
1993 IBM and KAP	IBM and Kaplana in Token Ring ATM integration.
1996 IBM and XYL	IBM and Xylan in Lan switching product development.
1994 PRX and ZEN	Proxim and Zenith Data Sys in wireless computing product development.
1994 PRX and LXE	Proxim and LXE Inc in wireless LAN product development.
1996 ADK and PAR	ADC Kentrox acquired 20% stake in Paragon Networks (wan) to integrate access products.
1993 NET and NS	Network Equipment Technology licensed to National Semiconductor ATM software.
1995 DAS and DCM	Data Switch's T-Bar integrated with Datacom Systems' technology to develop new Lan switch products.
1994 AXO and RAY	Axon and Xyplex jointly developed network management systems.
1994 AXO and PHO	Axon and Phoenix Microsystems to develop products for the emerging field of LAN/WAN monitoring system.
1994 CHP and SYN	Chipcom and Sync Research integrated S's SNA technology.
1993 ODS and SMC	Optical Data Sys and Standard Microsystem Corp. integrated its bridge and routing technologies into O;s hub technology.
1993 NEW and XYP	Newbridge and Xyplex in ATM development.
1996 NEW and SIE	Newbridge and Siemens in ATM development.
1993 NCR and NAT	Network Application Technology & NCR to integrate network management programs with NCR StarSentry SNMP management platform.
1993 NWT and TND	UB Networks has 50.4% stake in Networth.
1994 NWT and GRJ	Networth licensed Grand Junction's router tech, 10Base-T and Fast Ethernet adapter technologies.
1994 SNP and STR	SynOptics and Stratacom in ATM technology.
1994 SNP and BA2	SynOptics and Xylogics integrated X's servers into S's hubs.
1993 WFL and MAK	Wellfleet and Make Systems announced a technology sharing agreement aimed at producing a network design tool for router-based networks.
1994 XCO and MLT	Crosscom and Multimedia Communications Inc. signed a technology licensing agreement.
1996 NEG and NSY	Network General acquired interests in Netsys network systems.

Source: Lexis/Nexis, 1996/7.

Appendix F. Interoperability Forums and Standards-setting Alliances, 1989-1996

Table F-1. Interoperability Forums and Standards-setting Alliances

Name of Alliance and Date of Formation*	Objective of Alliance
1. FDDI Forum 1989	Established by Synernetics in 1989 to accelerate the Fiber Distributed Data Interface (FDDI) Station Management (STM) standard to completion. 13 vendors also jointly developed a design specification for an interoperable STM implementation that ensures full FDDI standard compatibility.
2. 10BaseT Consortium February 1990	10 vendors formed a consortium to ensure interoperability of 10BaseT products and to exchange technical information.
3. Frame Relay Trial January 1993	13 companies participated in frame relay trial. The objective is to demonstrate the interoperability of frame relay technology in the Open System Interconnection (OSI) environment. Frame relay is an emerging technology which provides interconnection, both directly and indirectly, among subnetworks in OSI environment.
4. Fast Ethernet Alliance August 1993	About 80 vendors came together to form the Fast Ethernet Alliance (FEA). The goal of the FEA was to speed Fast Ethernet through the Institute of Electrical and Electronic Engineers (IEEE) 802.3 body, the committee that controls the standards for Ethernet. The FEA succeeded in June 1995, and the technology passed a full review and was formally assigned the name 802.3u. The IEEE's name for Fast Ethernet is 100BaseT. 100BaseTis an extension of the 10BaseT standard, designed to raise the data transmission capacity of 10BaseT from 10Mbps to 100Mbps.
5. 100 VG-AnyLAN September 1993	100 VG-AnyLAN is a new IEEE 802.12 technology for transmitting Ethernet (802.3) and token-ring (802.5) frame information at 100M bits per second. The actual standard was jointly developed by IBM Corp, AT&T Corp and Hewlett - Packard Co. A group of 13 computer networking companies have agreed on the way forward for high- speed data networking and announced products based on a new technology standard known as 100 VG-AnyLAN. This coalition is competing with the FEA in designing a standard that allows existing networks to be upgraded to move data at a rate of 100Mbit/s
6. 20Mbps Full duplex Ethernet October 1993	About 12 firms formed a consortium to develop interoperable products incorporating the Full Duplex Switched Ethernet access method. Full-duplex Ethernet boosts speeds by allowing data to be transferred in both directions at once on a dedicated Ethernet segment, something that's usually prevented by CSMA/CD.
7. ATM25 Alliance September 1994	25 vendors formed the ATM25 Alliance to accelerate the acceptance of Asynchronous Transfer Mode (ATM) at the desktop. The group's charter is to make 25Mbps ATM products open, accessible and interoperable with other leading ATM products.
8. Token Ring Alliance (Astral) November 1994	16 vendors of Token-Ring networking products formed an alliance to promote their ties with customers, assuring them that new products are designed to be interoperable.
9. Versit: Convergence of Communications and Computing November 1994	Apple Computer, AT&T, IBM and Siemens formed Versit, a global initiative to enable interoperability between existing and emerging communication and information products. The cooperation covers products including telephones, PBXs, computers, networks, servers and personal digital assistants.
10. ISDN Forum January 1996	Four companies formed the ISDN Forum to simplify interoperability between ISDN customer premise equipment (CPE) and the public switched network. 3Com, Ascend Communications, AT&T Network Systems, and U.S. Robotics are the forum's founders.

Table F-1. Interoperability Forums and Standards-setting Alliances, Continued

Name of Alliance and Date of Formation*	Objective of Alliance
11. ATM RMON February 1996	Seven firms collaborate to develop specification for ATM remote monitoring and analysis tool solutions to advance the management of ATM networks.
12. Wireless LAN April 1996	13 vendors of wireless LAN formed alliance to promote awareness of wireless LAN. It does not plan to get involved in standards making or interoperability; instead it creates an advisory committee for the industry, composed of customers, independent software vendors and systems integrators.
13. Gigabit Ethernet Alliance May 1996	More than 50 firms have joined the Gigabit Ethernet Alliance to develop Gigabit Ethernet Standard that allows half and full duplex operations at 1,000 megabits per second. In addition, it also addresses backward compatibility with 10BaseT and 100BaseT technologies. The Gigabit task force will actively pursue specification development of protocol, media access controller, repeater and physical layer technologies.
14. Vendor's ISDN Association June 1996	13 ISDN customer premise equipment (CPE) manufacturers have formed a new organization -- called Vendors' ISDN Association (VIA), previously was known as the ISDN Forum. The group has unified CPE vendors on key market and technical issues that will help the entire ISDN industry grow.

*Date of formation is approximate only.
Source: Lexis/Nexis: CMPCOM database, 1996.

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