IAI104P003 FIRST PROOF 13-11-03 20:51:54 **Acc***Computing*

Industry and Innovation, Volume 10, Number 4, 351–375, December 2003

Carfax Publishing
Taylor & Francis Group

SPONSERS, COMMUNITIES, AND STANDARDS: ETHERNET VS. TOKEN RING IN THE LOCAL AREA NETWORKING BUSINESS[1]

URS VON BURG AND MARTIN KENNY

Network-based industries cannot exist without standards. For firms competing in such industries the outcome of standards contests can determine success or failure. Entire industries can emerge to exploit a standard, e.g. the Internet. In standards contests business strategy can be of critical importance (Cusumano *et al.* 1992). This paper draws upon the work by von Burg (2001) to explain the outcome of the local area networking (LAN) adoption contest that began in the early 1980s and essentially ended in the early 1990s with the de facto ubiquity of the Ethernet standard.[2] Upon initial examination, traditional economic explanations, emphasizing increasing returns and strategic decisions made by individual firms or actors as critical in the process, would appear sufficient to predict the ultimate success of Ethernet. We challenge this explanation and argue that it is insufficient. Equally important to Ethernet's success was the ability of its sponsors to create a vibrant community of firms, which continually lowered prices and upgraded the technology.

Standard setting in the LAN industry is particularly interesting for four reasons. The first reason is that there was no government involvement in the process, the process occurred entirely in the private sector. The second reason is that there were a number of proprietary standards and two standards were even approved by the same standards-setting body, the Institute of Electrical and Electronic Engineers (IEEE). In other words, there were two *de jure* standards, of which one, Ethernet, would become the de facto standard. The third reason is that the standards had to evolve technologically to handle the increasing amount of data that firms wanted to communicate. This meant that those adhering to the standard had to agree on changing the standard. The fourth reason is that this process is a case study in the results of a situation in which a dominant vendor, IBM, backs an open standard against a community of smaller vendors backing an open standard. In this case the standard backed by the smaller vendors emerged victorious.

1 The authors gratefully acknowledge the industry participants who consented to be interviewed for this research and commented on previous versions of this paper. We also acknowledge valuable comments by Raghu Garud, Joel West, and two reviewers.

2 A local area network (LAN) is composed of a number of components. At its simplest a LAN consists of three components: the first component is the cabling or medium over which the data is transmitted. The second component is a transmitter and receiver, which place the data on the cable and retrieve the data from the cabling. The final component is the protocol, which defines the format of the data transmitted and received over the network. To these three most basic components many other devices and features can be added.

1366-2716 print/1469-8390 online/03/040351-25
DOI: 10.1080/1366271032000163621

IAI104P003 FIRST PROOF 13-11-03 20:51:54 **Acc***Computing*

This paper demonstrates that the success of Ethernet cannot be explained completely by traditional economic variables. Business strategies had an important impact upon the final outcome. Most important was how the strategic decisions affected the communities of firms that adopted particular standards. The openness of the standards' sponsor affected the vibrancy and competitiveness of the community. The more robust Ethernet community was able to generate technical improvements, not only on the cost side, but, most important, on the usability of the system. This allowed the community to stave off defeat by the initially technically superior IBM-backed Token Ring solution.

STANDARDIZATION THEORY, TECHNOLOGICAL COMMUNITIES, AND SPONSORS

Standards are vital to networks because they allow interoperability to occur.[3] This paper narrowly circumscribes our discussion to technical standards related to network technologies, though we recognize that the discussion can, with care, be more widely applied. A technical network is only possible because the network nodes agree to a set of parameters, which they will use in their interactions with the network. For example, in the USA, equipment directly connected to the electric network uses 110-volt alternating current. Similarly, devices transmitting into a LAN must operate according to agreed technical parameters. The discussions regarding standard adoption are technical, but it is people and firms that must agree to the standards. Not surprisingly, this means that there is a social component to this process.

Given the increased economic importance of technical standards, it is striking how few micro level historical studies there have been of the network-related, standards-setting process. Until recently, the bulk of the literature on standards adoption has been written by economists grappling with the obvious real world result that competition can result in winner-take-all outcomes, a situation which is at odds with economic theory that suggests some sort of market equilibrium between various competitors (e.g. Farrell and Saloner 1986; Katz and Shapiro 1986, 1994). Paul David (1986), in a path-breaking article, confounded this problem by arguing that, in the case of the typewriter, an inferior technology could actually become the standard and not even be dislodged by a superior technology.[4] In fact, he argued that past small events can have major repercussions on adoption.

To repair this problem, economists termed the increased value experienced when the number of nodes in a network increase as a "network externality", even though it is fundamentally an *internal* characteristic of a network. This is the reason networks become more valuable the larger they grow. In such situations, if one alternative gains a small advantage, then the network effects can amplify the small advantage to the point where the market "tips" irrevocably toward the leading technology (Arthur 1989). As the momentum of the leading technology increases, the lagging rivals fall

3 Technical standards are different from dominant designs in that specification deviance is dangerous because it can lead to either non-operation or fragmentation, a situation that holds when the different versions no longer operate together at all.

4 Liebowitz and Margolis (1990) challenged David's interpretation claiming that the QWERTY lock-in was explainable because the costs of switching were higher than the perceived benefit of switching.

even further behind and eventually become irrelevant or disappear, while the leader "locks-in" its dominance. A technology does not need to be superior to "lock-in", since the power of network effects tends to greatly exceed (minor) technological advantages (David 1986; Arthur 1989, 1994).

The difficulty with the network economics literature is that it has no methodology for predicting which standard will be victorious in the contest. The resort to arguments such as small events or good fortune, though they may be explanatory in certain cases, is academically unsatisfying and downplays the significance of strategic action (Sabel 1998). We show that, in fact, the sponsors' strategy can have a significant impact on the outcome of the standards contest.

Recognizing the economic benefits of increasing returns, there is ample scope for corporate strategic decisions. Obviously, the optimal strategy for a sponsor is to introduce the standard as early as possible to preempt alternatives and to encourage adoption. However, it is often the case that a rapidly commercialized standard could be inferior, which might delay or even prevent adoption (David and Greenstein 1990). Since LANs were an entirely new product, compatibility was not an issue. However, ownership and control of the standard was critical. Each firm proposing to sell LANs had to decide whether to adopt their own closed technology, create their own technology but license it to others, adopt a competitor's technology, or join other firms to develop a single technology.

The standards literature and the technological community literatures do not consider the roles and strategies of sponsors in the ultimate outcome of standards contests, even though sponsorship is a critical aspect of the standard process. The manner by which sponsorship is structured is a major factor affecting the size and richness of the community of users and suppliers. In the standards literature much of the attention has been directed to the role of the consumers,[5] however, for technical standards the suppliers of equipment (or software) based on the standard are of critical importance. Put differently, suppliers are perhaps the most important "users" of a standard. They discharge a critical role in the inter-standard competition, because they can lower costs, improve technology, and broaden the applications of the standard, to name just a few parameters of improvement. Their activity as a community however, can be constrained by the structure of the platform the sponsor has created.

For suppliers, in most circumstances, holding other variables constant, the most open standard is the most desirable. Openness can be a disadvantage if it leads to standard splintering, which makes the job of suppliers more difficult. This paper demonstrates the effects that the differing strategies of the various LAN sponsors had on concrete community-level outcomes. We hypothesize that, other things held equal, the more open standard has the highest probability of becoming dominant. One important differentiating characteristic is who is able to innovate on the standard; the more closed the platform the more limited the possibility of other firms innovating on that platform. In the case of the LAN industry, this would prove to be a critical differentiator. Thus the role of the sponsor, through the medium of the type and character of the community that is created, has an impact on the future evolution of the standard.

5 Bresnahan and Chopra (1990) emphasize the role of users in the demand for LAN standardization and the adoption of Ethernet.

Commitment to a particular technical standard is a fateful choice because market fortunes can leave those that selected wrongly irrevocably behind firms that have chosen what proves to be the correct path. Conversely, adopting a particular standard creates a vested interest in ensuring its success, everything else being equal. In effect, by agreeing to conform to a standard one's competitive future becomes attached to the standard. The result is that the adherents have a concrete stake in the standard's success and thus have a shared interest. This shared interest aspect of standards adoption is not well captured by economics. As Wade (1995: 113) puts it, the economics literature "yields little insight into the underlying processes by which competing designs garner support". In essence by adhering to the technical standard these firms are at least, in some measure, saying they will constrain their activities according to a certain specification. Wade (1995: 113) terms the organizations adhering to these designs as a community based on a design, which he finds to be different from a community based on a sponsor. This distinction is not dichotomous, however, as we shall see in the case of the LAN industry, the technological community is based on a design and there were sponsors.

While the standards and technology literature have not considered the broader role of sponsors and communities, there is a considerable sociological literature on communities of practice and networks that can be mobilized to understand different strategies or relations around collaboration (Brown and Duguid 1991; Lave and Wenger 1991). We argue that success in standards contests is dependent upon the community that a sponsor can create. Building upon earlier work by Fombrun (1986) and Astley and Fombrun (1987), Hunt and Aldrich (1998: 272) provide the following definition: "an organizational community is a set of coevolving organizational populations joined by ties of commensalism and symbiosis through their orientation to a common technology" (see, also Lynn *et al.* 1996). An excellent example of this is the community that coalesced around the VHS standard (Cusumano *et al.* 1992).

Drawing upon David and Greenstein (1990) and Tushman and Rosenkopf (1992), we define technological communities as including those firms and practitioners (mainly engineers) that are directly and indirectly involved in the development, manufacturing, and distribution of a particular technology. Depending on the specific technology, the set of participating organizations may vary significantly; it may entail manufacturers, suppliers, resellers, as well as standard bodies, universities, and professional associations (Rosenkopf and Tushman 1998). Note that the community as defined here includes only actors on the supply side.[6] Firms belonging to the same technological community may compete, but the important competitive dynamics take place between the communities. If one or several firms leave the community, it may have little effect on the community's overall success; also, if a particular community succeeds, then firms belonging to this community are apt to benefit. In this sense, the success of a community is far more important in a standard race than the success of individual firms.

At a minimum, the community is a cluster of autonomously acting firms agreeing to be bound by the constraints of a standard. But quite often its members, as the "community" term implies, do not just coexist independently of each other, but

(1) 6 This definition resembles the arguments by Seely Brown and Duguid (2000).

interact and communicate in some form, share the perception of some common goal, and develop and benefit from symbiotic relationships similar to those of a natural ecosystem (Porac 1994: 452). For instance, the communal members may directly collaborate with each other to create new knowledge and to advance their technology. They may also specialize and engage in some form of division of labor, even absent collusion. Since the community includes various members, the success of one communal member may strengthen the other ones, especially in their mutual competition with other standards or technological communities. Even if the community members do not directly interact and collaborate, they are at least linked together through their commonality of interest. In this sense, a community is more than a cluster of autonomously operating firms and practitioners involved with the same technology.

If Wade is correct that the level of organizational support matters in a standards race, then a critical question is how to garner such a community. One possible strategy is to license the use of the technology. If a firm opts for this strategy, the community may then encompass the proprietor as well as any licensees, resellers, and distributors of the technology. As the case of Microsoft demonstrates, such a community may become very large. However, such a regime has the disadvantage that it exposes the licensees to the risk of unilateral, discriminatory actions by the proprietor. This was a major issue in the Microsoft antitrust case and in Sun's Java
(2) technology (Garud *et al.* 1999).[7] Often, the proprietor is the greatest beneficiary of this strategy. If the sponsor does not possess a market-critical technology like the Windows operating system, the licensing strategy may fail to appeal to suppliers, with the result that no large, supportive supplier community emerges.

There are different community structures. A community formed around a licensed technology, which we call a sponsored community, is usually hierarchically structured. The sponsor clearly controls the technology and is responsible for its innovation, while the licensees often do not contribute to the creation and innovation of the technology. In contrast, the organizational structure of a technological community formed around an open standard, which we call an open community, is flatter, as no player controls the technology unilaterally. In fact, while in the sponsored community a single firm propagates technology and innovation to the licensees and resellers, the open community includes multiple independent manufacturers and innovators. Its structure can also gravitate toward a more concentrated structure, as a few firms may succeed in dominating the market, but in a sponsored community this is a given. The structure of the open community is unpredictable, and might depend on the maturity of the technology (Tushman and Anderson 1986; Utterback and Suarez 1993).

The theoretical distinction between different community structures raises the question of whether one community structure is more potent in a standards race. Because of the pivotal role of small events and the "tippiness" inherent in network technologies, standards battles are highly unpredictable (Arthur 1994; Grindley 1995). But if one controls for these factors and assumes equal conditions (that is, similar

7 This is a major concern in both the Microsoft and Java world. The market dominance of the Windows operating system allows clone makers such as Dell and Hewlett-Packard to build a thriving business; yet they suffer from the fact that Microsoft appropriates the largest benefits (Curry and Kenney 1999; Fields 2003).

IAI104P003 FIRST PROOF 13-11-03 20:51:54 **Acc***Computing*

market size, similar technological performance, market entry at approximately the same time, etc.), an open community indeed possesses a systematic competitive advantage over a sponsored community. The open community has greater innovation potential than the sponsored community, because innovation is spread through multiple independent manufacturers, thus allowing for simultaneous trial-and-error learning processes (Langlois and Robertson 1995).

Occasionally, a large firm such as Microsoft or IBM is able to pursue multiple paths simultaneously, but as David Teece *et al*. (1997) point out, corporations cannot select any path from an infinite range of future markets, technologies, and strategies; instead, they are bound by their present capabilities and positions. Thus, if a critical innovation happens to be too distant from the present path of the individual firm or sponsor, it must undertake what is often a costly and time-consuming adjustment process. Quite likely, by the time the sponsor has adjusted, the better-positioned firms of the open community have already conquered the new market. Note that for an individual firm, these (corporate) path dependencies are as strong as for the single innovator of the sponsored community. But as a *collective*, the open community may face weaker path dependencies than individual firms including the sponsor of the sponsored community.

Thus to secure a standard's adoption the most promising alternative may be the creation of an open standard, such as a *de jure* standard like Ethernet or an open source standard like Linux. This means that no vendor possesses private property rights, and that the standard is in the public domain, accessible to any vendor at any time and on a non-discriminatory basis (Borrus and Zysman 1997: 148). Hence, no vendor can appropriate the principal economic benefits solely on the basis of property rights, and modifications require a democratic process to be approved. As this levels the playing field among the various communal firms, openness is, everything else equal, the more attractive strategy for attracting suppliers than a licensing for-use strategy.

An open community's firms compete not only with firms of other communities but also with their communal peers. This ensures weaker firms are weeded out. The open community allows for greater economies from specialization. In contrast, quite often the sponsor of the sponsored community has to produce all components of the system on its own. The firms of the open community can specialize on a few parts, as the standard allows customers to rely on the other communal firms for the lacking complementary goods. In other words, they can benefit from the division of labor.

To conclude, we have argued that the character of sponsorship has a direct impact upon the technological community and that this can have a significant effect upon the outcome in a standards contest. We would predict that the sponsor of the most open candidate standard will, *ceteris paribus*, have the greatest possibility of having that standard adopted, because it will encourage the largest and, most importantly, most innovative community to grow around it, contingent upon establishing the standard in such a way as to not allow it to fragment. Conversely, a standard sponsor that self-deals or operates to weaken their community will on balance lose the standards battle. To maximize the probability of adoption, firms (or other organizations) sponsoring a standard should encourage diversity and multiple independent manufacturers and innovators.

Methodology

The data presented in this paper was gathered from two sources. The first sources were primary and secondary published materials, though some of the individuals that participated in the events provided us with unpublished materials. The second sources were interviews with 50 entrepreneurs, observers, and venture capitalists involved or familiar with the early history of the LAN industry. Each interview was approximately 1 hour in length, conducted by telephone, taped, and then transcribed. All respondents were offered anonymity, although only one exercised this option. The population of interviewees is quite comprehensive including at least one person from every major LAN startup or industry participant in the period from 1979 through 1985. Nearly every primary participant in the earliest stages of the industry's creation was interviewed.

THE EMERGENCE OF LOCAL AREA NETWORKS

In the 1950s and 1960s computers were very expensive, and there were only a few computers scattered at individual sites around the USA. Because of this and via massive federal support, the computer interconnection was done over wide area networks (or WANs). At the end of the 1960s this geography began to change as firms made more intensive use of computers requiring more than one computer at a site. Also, there was increasing adoption of the smaller minicomputers built by firms such as DEC and Data General. With the advent of the minicomputer, now much more frequently there was more than one computer at a site, but they could only share data electronically through slow phone line connections (a WAN connection) or by moving data encoded in a physical storage media from computer to computer. In the early 1970s research was initiated both in the private sector and at universities aimed at developing methods for interchanging data locally at higher speeds using dedicated cables, i.e. not through the phone system. Not surprisingly, researchers developed a wide variety of incompatible solutions, which varied on any number of parameters.

The Ethernet community forms

In the 1970s a number of different LAN systems were developed in universities and the private sector. At the Xerox Palo Alto Research Center, Robert Metcalfe and his collaborators developed a system that they would call "Ethernet". Contemporaneously, other researchers at MIT, the University of California, Irvine, and, slightly later, the IBM Zurich Laboratories, developed systems based on a token-passing methodology, which would be named "Token Ring".

The shaping of the Ethernet community began in early 1979, when DEC, the world's leading vendor of minicomputers, was in the midst of developing its VAX computer line (Bell 1988). The VAX computer line consisted of a wide range of compatible computers that DEC intended to connect into clusters, thereby forming a homogeneous, distributed computing environment (Bell 1988: 18f., 43f.). Since these clusters made the individual minicomputers more powerful, DEC expected to gain leverage in its competition with IBM mainframes, which were its principal competitors. With sales of $21.3 billion IBM was the giant in the computer industry (*Datamation* 1982: 102; Sirbu and Hughes 1986: 4).

To create such clusters, DEC needed a high-speed networking technology. Like the other computer vendors, DEC had traditionally developed proprietary, vertically integrated systems, but Gordon Bell, chief designer of DEC's VAX strategy, thought it was essential to have a standard in the networking realm (Bell 1988). As David Rodgers (1995) of DEC pointed out, DEC's customers strongly opposed a proprietary network. DEC therefore reasoned that an open LAN standard would increase customer acceptance, which in turn would spur its hardware sales. Having tested several existing networks, DEC decided Ethernet would best meet its needs (Sirbu and Hughes 1986: 5; Bell 1988). With its bus topology[8] and lack of central control, Ethernet appeared well suited for connecting engineering workstations along a corridor and for expanding a network incrementally. DEC was attracted to Ethernet because it operated at a relatively high speed (namely 2.94 Mbps) and it even seemed possible to upgrade Ethernet's speed. This was important to DEC, which needed high network speed for a future VAX super minicomputer, as well as for the synchronization of VAX clusters in real time and for fast access to remote hard disks (Sirbu and Hughes 1986: 5; Rodgers 1995).

DEC's decision was not driven by purely technological considerations. By 1978–79, Ethernet's inventor, Robert Metcalfe, had left Xerox PARC to become a visiting fellow at MIT (Saltzer 1997). As Metcalfe, who was very charismatic, had done at other places, he strongly championed Ethernet at nearby DEC, which had hired him as consultant to evaluate DEC's LAN development (Sirbu and Hughes 1986: 5; Bell 1995). Hence, Metcalfe was able to wield significant influence in convincing DEC to adopt Ethernet.

In early 1979, convinced of Ethernet's strengths, DEC sent a letter to David Liddle at Xerox, in which DEC inquired about the possibility of licensing Ethernet (Barney 1983; Sirbu and Hughes 1986). Like DEC, Xerox realized that opening Ethernet might be very beneficial. At the time, Xerox was trying to commercialize its Star workstation, a $15,000 personal computer intended for the office market (Smith and Alexander 1988). The Ethernet network was absolutely crucial for the success of the Star workstation, since it was designed to operate in a distributed computing system. If Ethernet was open, Xerox reasoned that this would spur Ethernet's adoption and thus the sales of its Star workstations and laser printers, its core products, all the while restraining the proliferation of the office computers of its competitors, especially Wang and Datapoint, which pursued proprietary networks.

But most importantly, Xerox agreed on an open standard because it needed suppliers. Although Ethernet played a vital role in Xerox's office line, Xerox had no core competency in manufacturing Ethernet components. Xerox not only lacked the necessary manufacturing capabilities, especially those for integrated circuits (ICs), but also expected that such components would command only low margins. If Xerox had to produce these parts, it would have to cross-subsidize the network, thereby diluting the profits from its workstation and laser printer business. Openness would

8 A bus topology is a network configuration that resembles a tree with no roots. It has branches, but never forms a closed loop.

free Xerox from wasting resources on a non-core business and make cross-subsidies unnecessary. To Liddle (1995), creating an open standard was a far better alternative than simply subcontracting the production of a proprietary Ethernet network, because an open standard was likely to attract *multiple* suppliers, thereby spurring price competition, while freeing Xerox from the risk that a single chip company might be able to withhold chips and demand higher prices, i.e. Williamson's (1985) classic market vs. hierarchy dilemma.

Although DEC did not depend on outside suppliers to the same extent as Xerox, since its capability set was better tuned to the production of Ethernet components, it shared Xerox's belief that outside suppliers would be useful (Rodgers 1995; Fuller 1996). Although DEC intended to produce some Ethernet components, by having additional Ethernet manufacturers DEC could focus on the development of its higher-level protocols (that is, DECnet), which allowed for more value-added features than the LAN technology. Besides, third-party Ethernet suppliers would be helpful for the provision of specialty products, such as bridges and routers, which DEC did not intend to manufacture (Rodgers 1995). Most importantly, DEC, like Xerox, depended on semiconductor firms for Ethernet chips. In fact, the two vendors realized that ICs would be vital to push Ethernet's initial price of approximately $3,000–4,000 per node down to $500, which they set as target (Rodgers 1995). In short, DEC and Xerox were interested in creating an open standard partly to increase the sales of their hardware and partly as a means to attract Ethernet suppliers, especially IC manufacturers.

The third firm to join the alliance was the IC maker, Intel. Brought into the alliance by Metcalfe in April 1979, Intel could benefit from an open standard, also. If Xerox or DEC had ordered a proprietary network IC from Intel, Intel would have had a smaller market and thus fewer sales over which to spread the IC's high fixed costs for manufacturing and opportunity costs of using scarce design engineers and fabrication facilities, while increasing risk by pursuit of what might be a low-volume LAN chip. In effect, a proprietary chip would have exposed Intel to higher asset-specific risks (Williamson 1985). Intel preferred an open standard because it increased the probability of adoption, thereby reducing the risk and increasing the upside potential. Conversely, the open standard freed Xerox and DEC from having to compensate Intel for the higher costs and risks of a proprietary LAN. They could also attract other IC vendors to compete with Intel (Sirbu and Hughes 1986). Intel could benefit by being the first firm to the market, and thus enjoying a temporary monopoly. For these reasons, the three firms complemented each other rather nicely. While Xerox provided the technology, DEC provided market clout and credibility, and Intel offered the ICs.

Initially, the three firms intended to create an industry-wide *de facto* standard (Crane 1995; Galin 1995). Their plan was to elaborate the Ethernet specification without outside interference and then to "announce it to the world as an open standard" (Sirbu and Hughes 1986: 5). But before the three firms (also called the DIX group) could finish their specifications, they were forced to show their hand. In February 1980 the IEEE had launched a standardization project called IEEE 802 with a similar goal, namely to create an open *de jure* LAN standard (Stallings 1984: 27). So, in May 1980 the DIX group joined the IEEE 802 project and offered Ethernet for adoption (Sirbu and Hughes 1986: 11).

IBM, which had also joined the IEEE standardization undertaking, championed what would become the other major standard, Token Ring, despite its longstanding tradition of offering completely proprietary systems. IBM joined because, as Werner Bux (1998) of IBM said, even loyal IBM customers were no longer willing to tolerate a proprietary standard in data communication, since this would preclude them from mixing computing devices from different vendors. Also, IBM was under great pressure from a longstanding antitrust investigation and knew it could not preannounce a proprietary LAN several years before it was actually available without raising scrutiny from the Justice Department (Love 1996). The IEEE provided a simple way of circumventing any antitrust attacks, especially since IBM's great technical expertise should allow it to control the IEEE anyway (Sirbu and Hughes 1986: 15f.). Finally, an open LAN standard did not jeopardize IBM's mainframe business as the firm continued to rely on many proprietary higher-level protocols and did not intend to use the LAN for linking its mainframes (Love 1996). In this sense, IBM's motivations were similar to DEC's, but IBM did not consider an open standard as a means to attract outside suppliers. In fact, IBM intended to build its own LAN business (Bux 1998).

The DIX group and IBM were not the only (computer) vendors to join the IEEE process. Numerous other computer manufacturers (including Hewlett-Packard (H-P), Honeywell, Burroughs, Prime, Apollo, and Wang), and even vendors of factory automation systems (such as Gould, Fisher-Porter, and Allen-Bradley) and several recently formed LAN startups (3Com and Ungermann-Bass) participated (Sirbu and Hughes 1986: 7; Loughry 1996). This broad interest, though a positive development for customers quickly led to severe disagreements over which technology should become the standard. When the DIX group released its Ethernet specifications, also called the Blue Book, in September 1980, some participants quickly identified various technical weaknesses in Ethernet (*Data Channels* 1980a: 2, 1980b: 2).

IBM opposed Ethernet mainly because it considered it as adequate only for small workgroup networks. IBM, which had always provided corporate-wide computing resources with its large mainframes, needed to provide its customers with a LAN capable of connecting a very large number of nodes. IBM especially disliked Ethernet because of its bus topology and random access method (properly termed, Carrier Sense Multiple Access with Collision Detection or CSMA-CD), which failed to provide the high levels of reliability, availability, and manageability (Love 1996) that it felt its
3 customers in the corporate MIS offices wanted. IBM also believed that Ethernet performed poorly under heavy network loads and regarded its method of connecting nodes to the wire as cumbersome and prone to failure (Bux 1981; Peden and Weaver 1988). In Table 1, we provide a schematic overview of the comparative strengths and weaknesses of the two technologies. As a result, IBM decided to adopt a token ring technology, whose deterministic transmission method inherently provided higher levels of predictability and reliability (Potter 1985: 321; Love 1996).

Unable to find a compromise and hopelessly divided, in December 1980 the participants decided to split the IEEE 802 group into several subgroups and to create a standards body for each of the main factions: (1) Ethernet for the DIX group, which was joined by most minicomputer firms including Data General, H-P, and several LAN startups; (2) Token Bus for the factory automation vendors; and (3) Token Ring. Though Token Ring was an open standard, it was mainly intended for IBM, which, in a clever

IAI104P003 FIRST PROOF 13-11-03 20:51:54 **Acc***Computing*

TABLE 1: TECHNICAL FEATURES OF ORIGINAL ETHERNET AND TOKEN RING (TR) AND COMPARATIVE ADVANTAGE

Feature	Ethernet	Token Ring	Advantage
Access methodology	Stochastic—CSMA-CD	Deterministic	At high usage levels TR was more reliable
Topology	Bus	Star-shaped ring	TR more reliable
Network management	None—trial-and-error diagnostics	In the hub, automatic bypass of down nodes	TR easier to manage
Wire	Coaxial cable	Telephone wire	TR easier to work with, cheaper, and easier to install
Speed	10 Mbps	4 Mbps	In real terms, equal speed, however, TR immediately announced a 16-Mbps system
Connection mechanism	Vampire tap	Plug-in connector	TR much easier to connect new node
Cost	Lower	Higher	Ethernet was 70% lower

strategy, first sided with the more numerous Token Bus supporters before it split away and received its "own" standard (*Data Channels* 1981b: 2; Graube 1995, 1997).[9]

With the separation of the antagonists into different subgroups, the participants began elaborating the specifications of their standards in earnest. Because the DIX had presented an almost complete specification in September 1980, Ethernet's standardization progressed relatively quickly. In December 1982, after some minor modifications, Ethernet received unofficial approval from the IEEE (Seifert 1991: 321; Graube 1995). Because IBM insisted on a much more capable technology, Token Ring's standardization progressed more slowly. Only in October 1984 was Token Ring's standardization completed (Bartik 1984; Love 1996). This delay was to play a significant role in the outcome of the later market battle, as it prevented Token Ring's swift commercialization and retarded the rise of a supplier community.

To conclude, in 1980 at the IEEE most incumbent computer manufacturers, including IBM, DEC, H-P, Data General, and Siemens, broke with their traditional business model based on closed standards and opted for openness in LAN technology. Despite this eagerness, they could not agree on a single standard and had to create two standards for the office market: Ethernet and Token Ring. While most minicomputer firms joined DEC in its support of Ethernet, Token Ring was primarily supported by IBM.

Creating businesses

The DIX group had a system that worked and created a platform upon which business could be done. The Ethernet standard quickly attracted suppliers because its openness and IEEE status provided them with a readily available technology for a nominal licensing fee.[10] The IEEE also guaranteed that no vendor could make arbitrary modifications.

9 Because we focus only on office LANs, the evolution of Token Bus is no longer considered.

10 Xerox set the license fee at $1,000 mainly to cover administrative costs.

Intel and other semiconductor firms began designing chips for what they thought would be an attractive business. As Judith Estrin (1995), founder of a startup supplier, explained, the semiconductor firms' support was critical because "the real key for anything to become the standard is having inexpensive semiconductors available". Its openness was likely to encourage users, while its adoption by most minicomputer firms immediately created a large market and validated its survival chances.

The first two Ethernet startup suppliers were established even before the Ethernet standard became officially available. While brokering the DIX alliance, Robert Metcalfe, Ethernet's inventor at Xerox PARC, attempted to persuade two friends of his—Michael Pliner and Ralph Ungermann, who in 1974 had co-founded a semiconductor firm called Zilog—to establish a networking company (Metcalfe 1991). This plan never materialized, but on 4 June 1979, Metcalfe established a firm, 3Com, in Menlo Park, California (*Data Channels* 1981a; 3Com 1984: 5; Charney 1995). Metcalfe intended to manufacture Ethernet components, and, ultimately, to establish his invention as the industry standard (Charney 1995; Crane 1995). Only 5 weeks later, his friend Ralph Ungermann and Charles Bass who was another friend of Metcalfe, established, Ungermann-Bass (U-B). Because in 1979 the DIX group had not yet released the Ethernet specifications, 3Com and U-B had to delay the development of Ethernet products. However, 3Com developed a network software package called Unet, and U-B shipped a network compatible with Xerox's original Ethernet technology (Bass *et al*. 1980; Charney 1995; Ungermann 1995). Pliner established Sytek, a LAN company that did not adhere to the Ethernet standard.

3Com and U-B had a head start, but shortly after Ethernet's standardization at the IEEE in December 1980 other startups were established. In May 1981, Paul Severino, together with David Potter and William Seifert, among others, established an Ethernet firm called Interlan in Chelmsford, Massachusetts. Interlan's Paul Severino had been involved with networking at Prime Computer, while his co-founders had worked on Ethernet's development at DEC. Four months later, in September 1981, William Carrico, Judith Estrin, and Eric Benhamou started another Silicon Valley Ethernet firm, Bridge Communications (Bridge) (Bridge Communications 1985). And in January 1982, Kanwal Rekhi, Inder Singh, and Navindra Jain started Excelan, also located in Silicon Valley (Excelan 1987: 20; Rekhi 1995). The founders of Bridge and Excelan had been involved with networking at Ralph Ungermann's first startup, Zilog. These five startups were not the only Ethernet startups, but they became the leading Ethernet firms in the mid-1980s.

Initially, the startups focused on the same market, namely minicomputers, and offered similar products, primarily Ethernet boards and terminal servers (*Data Channels* 1981c; Crane 1995). Very rapidly, the startups began specializing and differentiating their products. Addressing all the data communication problems of large corporations, U-B developed a system to interconnect the entire range of
(4) computing devices, including minicomputers, mainframes, minicomputers, terminals, front-end processors, and printers. In the process U-B created a category that became known as the general-purpose LAN market. As a result, U-B's product line became very broad (Ungermann-Bass 1984: 7). Even though it had an all-encompassing product line, it primarily specialized on the terminal–minicomputer market that was the preponderance of such systems in the early to mid-1980s (Ungermann 1995). As a

result of its head start and broad business focus, U-B became the largest firm among the five Ethernet startups with sales of $72.2 million in 1985.

Like U-B, Bridge focused on the general-purpose market, but instead of developing an extensive product line, it specialized more narrowly. Bridge's specialty was powerful communications, gateway, and network management servers (Bridge Communications 1985: 18f.). In some cases, Bridge and U-B servers overlapped in their functionality or were introduced at approximately the same time. But as a specialist Bridge focused more narrowly and thus expanded its product variety beyond the U-B offerings. With sales of $30.5 million Bridge ranked third among the five startups in 1985. This ever-expanding proliferation of products and options evolved into an important sales advantage for Ethernet.

While U-B and Bridge, as well as Interlan (see below), focused on the minicomputer–terminal market, 3Com decided to apply Ethernet to the microcomputer market. Initially, this seemed impossible because of Ethernet's high price. In 1979–80 an Ethernet connection cost approximately $3,000–4,000, while a microcomputer such as an Apple II cost between $1,000 and $2,000 (Davis 1981: 52). However, due to experience with personal workstations at Xerox PARC, Metcalfe felt minicomputers had a limited future. Thus, when IBM introduced its PC in August 1981, Metcalfe's 3Com decided to take a risk and develop a VLSI-based Ethernet board for IBM's microcomputer (Charney 1995; Metcalfe 1996). Neill Brownstein (1999), the lead venture capitalist in the U-B deal, said this was 3Com's only choice because they were losing so badly in the minicomputer segment. After much redesigning, in October 1982 3Com introduced its board, also called an adapter card, and quickly became the leading vendor of Ethernet PC adapters, selling 100,000 PC adapter cards by 1985 (3Com 1985: 1). As a result, 3Com quickly overtook U-B, and with sales of $46.3 million it ranked second among the five Ethernet startups.

Interlan and Excelan focused on boards and terminal servers, product categories that the other firms had already pioneered; yet both contributed to the growing product variety and competition in the Ethernet realm. Interlan, for example, introduced the first Ethernet boards for Data General's minicomputers, and Excelan was the first Ethernet vendor to use TCP/IP, the fledgling Internet protocol standard, on its Ethernet boards. In 1984, Interlan had sales of $18 million, and Excelan had sales of $9.9 million in 1985.

Startup suppliers clearly led the way in exploiting the Ethernet standard, but relatively quickly the incumbent computer and semiconductor manufacturers joined them. The first vendors to follow were those that had championed Ethernet's standardization at the IEEE 802, namely DEC, H-P, and Intel. DEC, in collaboration with the chip manufacturers AMD and Mostek, developed a fairly sophisticated Ethernet IC, but its entry was delayed. In 1983–84 DEC began shipping its initial Ethernet products (Davis 1982: 146; Rodgers 1995; Seifert 1995). Thanks to its extensive distribution channels and control over Ethernet's primary market (DEC computers), DEC quickly surpassed the startups and with sales of $173 million in 1985 it (temporarily) was the leader.

H-P, Ethernet's other major minicomputer proponent at the IEEE 802, initially relied on U-B as OEM supplier, but in the early 1980s it also introduced its own products (Thaler 1995; Loughry 1996). Like DEC, Intel experienced some delays, but in October

1982 it had its ICs on the market as well (Metcalfe 1992). In addition, several firms without as central a role in Ethernet's standardization at the IEEE introduced products. By the middle of 1983 at least six additional chip manufacturers were either developing or producing Ethernet chips, namely AMD, Mostek, Seeq, Fujitsu, Rockwell, and National Semiconductor (Hindin 1982: 89; Nelson 1983: 138). Since semiconductors were to play such an instrumental role in reducing network costs, the support provided a critical edge in the standard race. Though no comprehensive list of Ethernet vendors could be found, in 1983 the trade press named at least 21 firms either developing or manufacturing Ethernet products, the five startups (3Com, U-B, Interlan, Bridge Communications, and Excelan), eight computer manufacturers (DEC, H-P, Data General, Siemens, Tektronix, Xerox, ICL, and NCR), and seven chip manufacturers (Intel, AMD, Mostek, Seeq, Fujitsu, Rockwell, and National Semiconductors) (Nelson 1983: 138). Thus, only 2 years after the DIX group had made its first Ethernet announcement, Ethernet had already accumulated substantial support.

To conclude, in the early to mid-1980s the DIX group's goal of attracting suppliers by creating an economic space through an open standard was accomplished. Ethernet's adoption by most minicomputer firms encouraged startups, as well as computer and semiconductor manufacturers, to produce Ethernet components, thereby creating a dynamic, fast-growing supplier industry. This community was not cartel-like, nor did the firms have a neat division of labor. The initial licensing agreement was structured to encourage competition and it did just that. The firms acted autonomously; they developed their own products, maintained their own distribution channels, cultivated their own customer base, and competed fiercely with each other. The firms' adherence to the same standard also allowed for a communal "ecosystem" with complex forms of interactions and synergies. For example, most semiconductor firms developed an Ethernet chip for a specific vendor; Bridge resold 3Com's adapter cards; DEC and H-P initially used the startups as OEM suppliers; and DEC entered into a cooperative marketing/development/service agreement with Vitalink, a startup that joined the Ethernet community in 1984 after abandoning a failing satellite data transmission business (Bridge Communications 1985: 19; Vitalink 1989: 22).

As a result of such collaboration, division of labor, specialization, and intense competition, Ethernet was continually propelled into new markets, and prices declined rapidly. By 1985, Ethernet was no longer a minicomputer LAN, but also well entrenched in the PC and workstation market, and adapter card prices had declined from $3,000–4,000 in 1980 to approximately $600 in 1985. Simultaneously, Ethernet's adoption soared. By 1985, its principal suppliers had shipped products worth more than $500 million, and approximately 30,000 Ethernet networks had been installed, connecting at least 419,000 nodes and possibly significantly more (Goldstein 1985: 60). For all intents and purposes, in 1985 it would appear as though Ethernet had "tipped" the market, but IBM was now ready to introduce Token Ring.

The Ethernet community fixes Ethernet's technical shortcomings

Ethernet's dominance was far from assured, as it had serious design shortcomings. It was difficult to connect a node to the cable; the cable did not bend easily around corners; connections were often unreliable; an ill-connected node could take down the entire network; and finally, Ethernet's bus topology made it difficult to locate network failures. In the early 1980s, as the number of nodes connected to a LAN was small, and most LAN users were either engineers or in engineer-rich environments, these shortcomings were not fatal. However, in the mid- to late 1980s, LANs were entering office environments, and these shortcomings became serious bottlenecks. For instance, in environments in which new nodes were being added, network administrators often spent hours crawling through the ceilings adding new nodes and trying to locate problems.

This gave IBM's Token Ring a critical window of opportunity. Designed as a high-end, enterprise LAN, Token Ring was far better suited to accommodate the expanding networks. Its method of connecting nodes to the cable was much simpler. An individual node could not stall the entire network; and due to its hub topology it offered better network management and troubleshooting features. Thanks to the central point of connection, network administrators did not need to crawl through the ceilings but could identify and disable a malfunctioning node from a single location. All these advantages were reinforced when IBM decided to implement Token Ring on telephone wiring. Using the telephone wire was a tremendous advantage. It was inexpensive and easy to install, supported a hub-based topology, and most important, it was pre-installed in commercial buildings. Not surprisingly, Token Ring quickly gained considerable market share after its introduction in 1986. Because of its large installed base, Ethernet was not going to disappear overnight, but Token Ring, with its clear technical advantage, looked very powerful.

The primary response by Ethernet vendors was to improve their technology. Already in the early 1980s, shortly after Ethernet's standardization, Ethernet firms sought to improve the technology by implementing it on new cable types (such as fiber optic, thin coaxial wire, and broadband wire) and improving the method for connecting of nodes to the wire. These early improvements failed to seriously rival Token Ring as they did not address Ethernet's biggest problem, its problematic bus topology.

In 1986–87 several incumbent Ethernet firms including H-P were experimenting with methods for solving the bus topology problem, but this breakthrough was first achieved by a startup. While experimenting with a fiber optic Ethernet version at Xerox PARC, Ronald Schmidt (1995) realized that he could implement this Ethernet on the very wiring structure IBM was suggesting for its Token Ring, as both networks used a hub. Having built a prototype, Schmidt attempted to persuade Xerox to commercialize his Ethernet, but Xerox refused. In return for an equity stake, in 1985 Xerox let Schmidt, who was joined by Andrew Ludwick, spin out his own firm, SynOptics. Initially, SynOptics implemented Ethernet only on fiber optic and shielded telephone wire, which was more robust than the telephone wire but not as universally installed. But after much experimentation, Ronald Schmidt made an important innovation, and in mid-1987 SynOptics shipped the first 10-Mbps Ethernet version for telephone wire. Ethernet had finally overtaken Token Ring. Both ran at a similar effective speed on hub-based telephone wire.

SynOptics may have made the breakthrough, but it did not remain the only vendor for long. The other Ethernet vendors had been experimenting with a 10-Mbps Ethernet version for the telephone wire as well, and the hub, the main component of SynOptics' product line, was only a low-tech device. As a result, between early and late 1988, H-P, AT&T, U-B, David Systems, and Cabletron offered similar products (Mulqueen 1988: 72; Davis 1990: 71).

Ethernet's improvement and the large number of vendors offering (hub) products were a positive development for users. In 1987–88 only one handicap remained: the vendors' offerings were all proprietary, and unable to interoperate (Terrie 1991: 43). As they had done with the previous new Ethernet versions, in the middle of 1987 the vendors decided to create an IEEE Ethernet standard for the telephone wire (Thaler 1995). The elaboration of the standard specifications was not without struggle (Anderson and Woods 1990: 52). The market had already grown considerably, and none of the vendors wanted to leave its customers "stranded" by adopting an incompatible IEEE specification. In addition, 3Com and DEC, the two Ethernet sales leaders in 1987–88, were offering a structurally different approach than SynOptics and the other seven vendors that had submitted a proposal (Kolman 1988; Campbell 1990). However, after a painstaking process of reconciling technical differences and after 3Com and DEC withdrew their proposal, in September 1990 the IEEE Standards Board ratified a new standard, 10BaseT, as part of the IEEE 802.3 specification set (Anderson and Woods 1990; Metcalfe 1996).

The 10BaseT standard led to fierce competition, rapid price declines, commodification, and continued market growth. In 1991, over 100 vendors were offering 10BaseT adapter cards. Hub sales at SynOptics and Cabletron, the two leading hub vendors, shot up to $248.3 million and $180.5 million, respectively, up from $6.1 million and $9.5 million in 1987. To avoid the increasing commodification, SynOptics as well as some of the other Ethernet hub vendors began making their hubs more "intelligent" by adding sophisticated network management software features. Such "intelligent" hubs, for example, monitored the network, reported various network activities such as traffic and number of collisions, and provided statistical analysis (DiDio 1988).

Token Ring fails to keep pace with Ethernet

In the late 1980s, as Token Ring began losing its technological edge, it came under great pressure to close the price gap (Love 1996). Token Ring's prices indeed fell, but ultimately they failed to match those of Ethernet. Token Ring suffered from the fact that IBM added many sophisticated features to the token access method, a fact that made its chips inevitably more difficult to design and manufacture and thus more expensive (Lippis 1993; Bux 1998). But most important, Token Ring's market introduction in 1986 failed to attract suppliers, including semiconductor firms. Also, it did not trigger the establishment of specialized Token Ring startups in the way Ethernet's introduction had in the early 1980s. Thus, Token Ring never attracted a supplier community as large and diversified as Ethernet, with the result that there was less price competition, innovation, and product variety in the Token Ring realm.

Token Ring's weaker supplier community resulted partly from its delayed market introduction (Metcalfe 1993). But it also resulted from IBM's dominance over the standard and its various strategies that stymied, rather than nurtured, the community. Many of these strategies began even before Token Ring's market introduction. To refute criticism that Token Ring was mainly an IBM technology, in 1982 IBM began collaborating with the semiconductor firm Texas Instruments (TI) (Carlo and Hughes 1989; Bux 1998). Their collaboration aimed at having TI produce "guaranteed IBM-compatible" Token Ring chips for independent vendors, since adherence to the Token Ring specifications did not automatically guarantee chip compatibility (Mier 1986: 48). Though IBM's collaboration with TI was positive, IBM's role as kingmaker quickly backfired. When Token Ring's complexity delayed the introduction of TI's Token Ring chips in 1985–86, third-party vendors had no second source to turn to, and IBM refused to sell its own ICs (*Data Communications* 1985: 46f.). To make matters worse, TI's chips did not perform as well as those of IBM and were priced so high that third-party suppliers were not competitive with IBM (*Data Communications* 1985: 46f.; Salwen 1995; Ungermann 1995). Of course, the limited chip supply discouraged suppliers and in the process severely undermined Token Ring's competitiveness, which depended on ample ICs to allow price reductions.

IBM frustrated the rise of a community by casting doubt on the interoperability of Token Ring products (Metcalfe 1993). Though IBM collaborated with TI and adhered fully to the IEEE 802.5 Token Ring standard, it nevertheless implemented many more features in its products than those specified by the IEEE standard. A third-party supplier's Token Ring product therefore, even if it was fully compliant with the IEEE 802.5 specifications, was "unable to recognize all the network-management and control messages issued by an IBM adapter" (Mier 1986: 49). In addition, IBM's networking architecture required many proprietary, software-based interfaces and higher-level protocols to be implemented in its PCs (Mier 1986: 50f.). Since IBM did not make all these software features public, it created much confusion about the full interoperability of its products. Before IBM's Token Ring introduction, the independent suppliers did not know for certain whether their products would fully interoperate with those of IBM, and they could conduct compatibility tests only after IBM had released all its products. Worse, the independent vendors felt that IBM could easily render their (hardware) products incompatible by simply manipulating its software (Mier 1986). Because of IBM's market dominance, compatibility with IBM's Token Ring products was a serious concern to the independent suppliers.

These compatibility issues were eventually resolved, but in combination with the restricted chip supply they undermined the powerful supplier community. By singling TI out as a "guaranteed IBM-compatible" IC vendor and by casting doubts on the interoperability of its products, IBM eliminated exactly the type of competition that drove Ethernet's competitiveness. Frustrated with IBM's secretive behavior, many potential vendors adopted a wait-and-see attitude toward the development of Token Ring products. In 1986, for instance, U-B said that it was delaying the development of its own Token Ring chip until IBM's implementation had stabilized (Mier 1986: 49). Instead of developing Token Ring products and competing with IBM, many independent LAN vendors simply allocated most of their resources to Ethernet.

It is not that Token Ring garnered no supplier community; it indeed attracted some suppliers. In late 1985, when IBM announced its plans to ship Token Ring products, several LAN specialists, including the Ethernet vendors 3Com, U-B, and Excelan, among others, announced their intention to follow with Token Ring products as well (*Data Channels* 1986; Haber 1986: 42). Moreover, Token Ring's market introduction in 1986 led to the establishment of at least one new Token Ring startup specialist, Madge Networks in the UK, while Proteon, a previously established proprietary Token Ring specialist, added standardized products to its offerings (Salwen 1995). By late 1989 the Token Ring community had grown to at least 15 vendors (mainly selling Token Ring adapter cards for PCs), including 3Com, Madge Networks, Proteon, Tiara, U-B, and Western Digital (Greenfield 1989: 37).

Yet the rise of Token Ring suppliers could not conceal subtle but critical differences between the Token Ring and Ethernet community. As already mentioned, Token Ring did not attract an entire wave of startups as Ethernet had. The roughly two dozen Token Ring vendors that had been attracted by 1989 were dwarfed by the 200 Ethernet vendors counted in 1987 (Killorin 1987; Hurwicz 1991; Terrie 1991). IBM dominated the Token Ring community in a manner that was unparalleled in the Ethernet community. With a worldwide market share of 57.7 percent in the 4-Mbps Token Ring adapter market and 92.6 percent in the 16-Mbps Token Ring market in 1990 (weighted average 78 percent), IBM left little space for independent vendors (*Network World* 1991: 19). Proteon and Madge, the two leading independent Token Ring startups, each had only a 10 percent market share in the 4-Mbps Token Ring market and had lower revenues than the leading Ethernet suppliers such as 3Com and SynOptics (*Network World* 1991: 19). In other words, the Token Ring community had not only fewer but also, with the exception of IBM, smaller firms; it was more concentrated and less diversified than its Ethernet counterpart. IBM's effect on Token Ring was thus quite paradoxical. On the one hand, its adoption boosted Token Ring's market to a size it would have never reached without IBM's support. On the other hand, by dominating the market, Big Blue contracted the economic space for independent vendors, thereby impairing the rise of a large community.

Without a dynamic supplier community, Token Ring's competitiveness depended largely on IBM. IBM alone, however, could not keep pace with the many fast-growing Ethernet startups, all specializing in different products and market segments; consequently Token Ring's competitiveness began deteriorating. One indicator of its deteriorating competitiveness, Token Ring's prices, continued to exceed those of Ethernet. We have already mentioned the role of Token Ring's more complex chip design, the lack of vigorous competition, and the smaller market and consequently smaller economies of scale. But prices also remained higher because IBM was more interested in sustaining a profitable business than gaining market share through aggressive forward-pricing (Bux 1998). In addition, Madge Networks, which in the early 1990s emerged as the second-largest Token Ring vendor, adopted a strategy of beating IBM with superior technology. In other words, unlike many PC clone makers, IBM's main Token Ring competitor did not vie on the basis of lower prices but superior performance and quality. Of course, this tactic solidified premium prices in the Token Ring realm (*Network World* 1991; Reier 1995).

A second sign of Token Ring's deteriorating competitiveness was its increasing inability to keep pace with technological advances. This became first apparent in 1988–89, when IBM introduced the faster 16-Mbps Token Ring version but was unable to implement it on the crucial telephone wire until 1991 (Salamone 1990b; Hurwicz 1991; Greenfield 1992; Love 1996). What is more, by the time IBM succeeded in making its 16-Mbps Token Ring operable on the telephone wire, the Ethernet community had already taken Ethernet a step forward by offering switching technology and a 100-Mbps Ethernet version (Bhardwaj 1990; Verhalen 1995).[11] As in the case of hub technology, switching and 100-Mbps Ethernet were pioneered by startups (Kalpana and Grand Junction, respectively) and attracted a myriad of (imitating) firms (Verhalen 1995). The introduction of Token Ring switches, in contrast, lagged several years behind Ethernet; in fact, switching technology was only introduced in 1994 and never attracted as many startups as in the Ethernet realm (Klett 1994: 59; Saunders 1994: 87). This delay resulted partly from the higher throughput of the 16-Mbps Token Ring, making speed increases less urgent, and partly from its greater technical complexity, thereby complicating the implementation of switching (Klett 1994: 28). But most importantly, the smaller Token Ring market was simply not as attractive for startups as the Ethernet market. Thus, Ethernet, thanks to its broad community support, progressed much rapidly than did Token Ring. IBM's strategy toward the Token Ring community created the path that the technology took.

Token Ring's technological slowdown due to smaller community and startup support became particularly apparent in the next wave of networking technology, which was the internetworking market. In the mid- to late 1980s, IBM, as well as the Ethernet community, were trying to interconnect their customers with bridges. But because bridging caused technical difficulties in the Ethernet realm due to problems with bridging protocols, a few startups (such as Cisco and Wellfleet), began providing a more effective internetworking technology, namely routing, for the Ethernet realm. While Cisco and Wellfleet supported Token Ring in their routing products, IBM remained with bridging technology for several years, before it switched to routing as well. Once again it was the Ethernet startups that drove the transition to routing. The multifirm innovation process proved more powerful than initial technological advantages or sponsorship by a single large firm.

Eventually, the price gap and technological tardiness propelled Ethernet and Token Ring on two diverging, self-reinforcing processes. Despite further absolute market growth, Token Ring could not avoid a vicious circle of relatively fewer new customers, fewer innovations, and higher prices. In contrast, a virtuous circle of increased market share, more innovations, and lower prices continued to solidify Ethernet's technological lead and market dominance. Before 1990, these two self-reinforcing circles had diverged only modestly, but by 1995 the market had almost completely "tipped" toward Ethernet: only 3.8 million Token Ring adapters compared with 23.7 million Ethernet adapters were sold in this year, compared with 1.4 million and 2.2 million, respectively, in 1991 (*Electronic News* 1996: 20). The "tipping" resulted mostly from these two self-reinforcing processes, but note that in the late 1980s and early 1990s many corporations began interconnecting the LANs proliferating through their workgroups and department. Consequently, standardization now increasingly mattered because conversion was quite costly in terms of gateways and throughput deterioration (Salamone 1990a). The cost difference and performance similarity meant that the decisions to standardize the entire firm's computer data network resulted in the adoption of Ethernet. Now the network externalities appeared as overwhelming, however this was because of the prior strategic choices made by Ethernet's sponsors.

11 The increasing adoption of Ethernet technology encouraged venture capitalists to invest in its technological trajectory further accelerating that trajectory (Burg and Kenney 2000).

CONCLUDING REMARKS

This paper demonstrated the importance of communities and sponsor strategies for successfully establishing and improving a standard. Token Ring failed because of Ethernet's improvements, in terms of price and capability, but also scope, as the various members of the community searched for profitable opportunities and niches. These improvements occurred in a decentralized manner propelled by competition and entrepreneurship. This was due to the dynamic supplier community including chip vendors. Although some of the disparity originated from Token Ring's delayed commercialization and hence smaller market, it is still clear that IBM's role stymied the growth of the Token Ring community. By indulging its desire for market dominance IBM hamstrung the firms willing to support Token Ring. Then IBM, even with its enormous research resources, proved unable to maintain the pace of vigorous innovation, constant technical improvement, and market extension of the Ethernet community. Token Ring was never able to close the price gap and them fell behind technologically. Finally, the market tipped as new users adopted Ethernet, and then powerful network effects were unleashed in Ethernet's favor.

It is striking that the effects that provided Ethernet with its victory were not the technical network effects, but rather what one could term "community effects". The DIX group's sponsorship was so effective, because it provided a "safe" technology through the IEEE imprimatur, an obvious market by DEC's participation, and the promise of an openly available critical input, the semiconductor, on account of Intel's participation. This created a market space into which entrepreneurs could flow. These entrepreneurs continually extended the technology in different directions. In contrast, after sponsoring an open standard, IBM did everything possible to frustrate the growth of a community supporting Token Ring. As a result, Token Ring failed, and in the process IBM pursued a technological dead end. Oddly enough, this strategy meant that IBM never fully captured either the benefits of licensing or the benefits of an open system.

The economics literature on standards has, with the notable exception of Paul David's work, ignored the importance of communities of supplier firms in actually establishing the dominance of a standard. Business historians such as Cusumano *et al.* (1992) have provided more nuanced accounts, but the video recorder industry was not as driven by follow-on innovations by its technological community. The small events that might tip a standard's contest did not occur in the LAN industry, rather we found that dominance was achieved by a community of firms, nearly all of which were startups innovating new solutions and continually pushing Ethernet into new business fields. The openness of Ethernet and the strategic moves by the sponsoring DIX group created a space that offered small firms clear business opportunities. In contrast, IBM declared its commitment to an open standard, and then frustrated the creation of a community of standard supporters. IBM's strategy might have been viable in a more stable and slowly changing industry, but computer networking was a fast changing industry with continual improvements and new opportunities—a perfect environment to be exploited by venture capital-financed startups.[12]

In the corporate strategy and technology management literature there has been

12 For further discussion of venture capital and innovation, see Burg and Kenney (2000) and Kenney (2000).

increasing recognition of the significance of interfirm relationships. However, this literature has only begun to examine the relationship of standards to the creation of interfirm communities. This paper contributes a case study to that ongoing work, however, we extend previous analysis by specifically focusing on the role of standard's sponsorship. The strategic moves of a technological standard's sponsor can have a profound effect upon the acceptance of the standard and the ultimate success of communities supporting that standard.

There is an even deeper lesson implied in the Ethernet vs. Token Ring story. Namely, truly open systems, which attract and nurture communities, can be very powerful. An open standard, with its decentralized improvement dynamic, has strong advantages in a standards competition if standard coherence can be maintained. Currently, there are some fascinating "natural experiments" underway that could reinforce our conclusions. The most important of these is the current operating systems competition between the absolutely dominant Windows operating system and Linux, an entirely open operating system. If the Linux community can defeat Microsoft it would confirm this study's findings on the importance of technological communities for innovative activity.

REFERENCES

Anderson, R. and Woods, K. 1990: 10Base-T Ethernet: the second wave, *Data Communications*, (21 November): 49–64.

Arthur, W.B. 1989: Competing technologies, increasing returns, and lock-in by historical events, *The Economic Journal*, (March): 116–131.

Arthur, W.B. 1994: *Increasing Returns and Path Dependence in the Economy*. Ann Arbor: University of Michigan Press.

Astley, W. and Fombrun, C. 1987: Organizational communities: an ecological perspective, *Research in the Sociology of Organizations*, 5: 163–185.

Barney, C. 1983: 1983 Award for Achievement. Robert M. Metcalfe, *Electronics*, (6 October): 112–115.

Bartik, J. 1984: IBM's Token Ring: have the pieces finally come together?, *Data Communications*, (August): 125–139.

Bass, C., Kennedy, J. and Davidson, J. 1980: Local network gives new flexibility to distributed processing, *Electronics*, (25 September): 114–122.

6 Bell, G. 1988: Toward a history of (personal) workstations, in A.G. Goldber (ed.), *A History of Personal Workstations*, pp. 4–47. New York: ACM Press.

Bell, G. 1995: Personal e-mail communication with Urs von Burg (29 April).

Bhardwaj, V. 1990: Can fast packet switching give Ethernet new life?, *Data Communications*, (August): 81–88.

Borrus, M. and Zysman, J. 1997: Globalization with borders: the rise of Wintelism as the future of industrial competition, *Industry and Innovation*, 4(2) (December): 141–166.

Bresnahan, T. and Chopra, A. 1990: The development of the local area network market as determined by user needs, *Economics of Innovation and New Technology*, 1: 97–110.

Bridge Communications, Inc. 1985: *Securities and Exchange Commission S-1 File*. Mountain View, CA.

Brown, J.S. and Duguid, P. 1991: Organizational learning and communities of practice, *Organization Science*, 2(1): 40–57.

Brownstein, N. (co-founder and general partner, Bessemer Venture Partners) 1999: Personal communication (24 July).

Burg, U.V. 2001: *The Triumph of Ethernet: Technological Communities and the Battle for the LAN Standard*. Stanford: Stanford University Press.

Burg, U.V. and Kenney, M. 2000: There at the beginning: venture capital and the creation of (7) the local area networking industry, *Research Policy*, 29(9): 135–155.

Bux, W. 1981: Local-area subnetworks: a performance comparison, *IEEE Transactions on Communication*, COM-29 (October): 1465–1473.

Bux, W. (IBM, Zurich Laboratories designer of Token Ring) 1998: Personal communication (28 October).

Campbell, G. 1990: 10BaseT: the UTP standard arrives, *LAN Technology*, (June): 34–38.

Carlo, J. and Hughes, J. 1989: Token Ring compatibility: it's time to plug-and-play, *Data Communications*, (21 November): 26–34.

Charney, H. (ex-secretary and vice president of operation, 3Com; co-founder, Grand Junction, Inc.) 1995: Personal interview (14 July).

Crane, R. (designer of 3Com's PC adapter card) 1995: Personal interview (17 May).

Curry, J. and Kenney, M. 1999: Beating the clock: corporate responses to rapid change in the PC industry, *California Management Review*, (Fall): 8–36.

Cusumano, M.A., Mylonadis, Y. and Rosenbloom, R.S. 1992: Strategic maneuvering and mass-market dynamics: the triumph of VHS over Beta, *Business History Review*, 66(1) (Spring): 51–94.

Data Channels 1980a: Ethernet specifications announced as IEEE considers standard for local network, 7(11) (November): 2.

Data Channels 1980b: Different systems contend for endorsement of IEEE Local Network Committee, 7(13) (December): 2.

Data Channels 1981a: Brief bits, 8(6) (16 March): 7.

Data Channels 1981b: IEEE Local Net Committee endorses both Token and Ethernet type standards, 8(1) (5 January): 2.

Data Channels 1981c: Interlan markets Ethernet products for DEC computers, 8(25) (4 December): 3.

Data Channels 1986: 3Com enters Token-Ring market with new networking products, 13(30) (6 August): 1.

Data Communications 1985: Tip of Token Ring iceberg bared; IBM now embracing twisted-pairs, (November): 62–64.

Datamation 1982: Datamation 100, 28(6) (June): 114–226.

David, P. 1986: Clio and the economics of QWERTY, *American Economic Review Proceedings*, 75: 332–337.

David, P. and Greenstein, S. 1990: The economics of compatibility standards: an introduction to recent research, *Economics of Innovation and New Technology*, 1: 3–41.

Davis, D. 1981: 3Com unveils controllers, links future to Ethernet, *Mini-Micro Systems*, (December): 82–84.

Davis, D. 1982: Ethernet spec spawns diverse group of interface products, *Mini-Micro Systems*, (May): 143–151.

Davis, D. 1990: LAN vendors covet lowly telephone networks, *Electronic Business*, (30 April): 70–72.

DiDio, L. 1988: Token Ring LANs gaining momentum, *Network World*, 5(17) (25 April): 17, 42.

Electronic News 1996: Data net, *Electronic News*, 42 (29 January): 43.

Estrin, J. (ex-Zilog; ex-Ungermann-Bass; co-founder, Bridge Communications, Inc.; executive, Network Computing Devices, Inc.; founder, Precept Software, Inc.) 1995: Personal interview (24 April).

Excelan 1987: *Securities and Exchange Commission Form S-1*. San Jose, CA.

Farrell, J. and Saloner, G. 1986: Installed base and compatibility: innovation, product pre-announcements, and predation, *American Economic Review*, 76(5): 940–955.

Fields, G. 2003: *Territories of Profit: Communications, Capitalist Development, and the Innovative Enterprises of G. F. Swift and Dell Computer.* Stanford: Stanford University Press.

Fombrun, C. 1986: Structural dynamics within and between organizations, *Administrative Science Quarterly*, 31: 403–421.

Fuller, S. (Vice President, Chief Scientist DEC) 1996: Personal communication (23 February).

Galin, R. (Chairman of 1Base5; Vice President, Intel) 1995: Personal interview (5 June).

(8) Garud, R., Jain, S. and Kumaraswamy, A. 2002: Orchestrating institutional processes for technology sponsorship: the case of Sun Microsystems and Java, *Academy of Management Journal*, 45: 196–214.

Goldstein, M. 1985: IBM throws its hat into the ring, *Industry Week*, (28 October): 60–61.

Graube, M. (Chairman of IEEE 802.5 and Tektronix engineer) 1995: Personal communication (10 May).

Graube, M. (Chairman of IEEE 802.5 and Tektronix engineer) 1997: Personal communication (4 February).

Greenfield, D. 1989: Multivendor Token Ring networks come of age, *Data Communications*, (21 November): 37–43.

Greenfield, D. 1992: Token Ring closes in on Ethernet, *Data Communications*, (21 January): 15–18.

Grindley, P. 1995: *Standards Strategy and Policy.* Oxford: Oxford University Press.

Haber, L. 1986: IBM's Token Ring network signals start for LAN vendors, *Mini-Micro Systems*, (January): 38–42.

Hindin, H. 1982: Dual-chip sets forge vital link for Ethernet local-network scheme, *Electronics*, (6 October): 89–103.

Hunt, C. and Aldrich, H. 1998: The second ecology: creation and evolution of organizational communities, *Research in Organizational Behavior*, 20: 267–301.

Hurwicz, M. 1991: Beware of hidden factors in buying 16M Token Ring, *Network World*, (30 December/6 January): 1, 25, 29–32.

Katz, M. and Shapiro, C. 1986: Technology adoption in the presence of network externalities, *Journal of Political Economy*, 94 (August): 822–841.

Katz, M. and Shapiro, C. 1994: Systems competition and network effects, *Journal of Economic Perspectives*, 8(2): 93–115.

Kenney, M. (ed.) 2000: *Understanding Silicon Valley: Anatomy of an Entrepreneurial Region*. Stanford: Stanford University Press.

(9) Kenney, M. and Burg, U.V. 1999: Technology and path dependence: the divergence between Silicon Valley and Route 128, *Industrial and Corporate Change*, 8(1): 67–103.

Killorin, E. 1987: Will Token Ring or Ethernet dominate?, *Telecommunication Products and Technology*, (March): 34–39.

Klett, S. 1994: Token Ring switching gathers steam, *Computerworld*, (25 July): 59.

Kolman, J. 1988: A new twist for Ethernet, *PC Tech Journal*, (September): 87–98.

Langlois, R. and Robertson, P. 1995: *Firms, Markets and Economic Change*. London: Routledge.

Lave, J. and Wenger, E. 1991: *Situated Learning: Legitimate Peripheral Participation*. Cambridge: University of Cambridge Press.

Liddle, D. (Xerox PARC; founder, president and CEO of Metaphor, Inc.; president and CEO of Interval Research Corporation) 1995: Personal interview (21 June).

Liebowitz, S.J. and Margolis, S.E. 1990: The fable of the keys, *Journal of Law and Economics*, 33(N1): 1–25.

Lippis, N. 1993: Troubled times for Token Ring, *Data Communications*, (January): 27–28.

Loughry, D. (Chairman of IEEE 802.5 and Hewlett-Packard engineer) 1996: Personal interview (25 February).

Love, R. (IBM designer of Token Ring) 1996: Personal interview (2 February).

Lynn, L., Reddy, N. and Aram, J. 1996: Linking technology and institutions: the innovation community framework, *Research Policy*, 25: 91–106.

Metcalfe, R. 1991: Let the Ethernet chips fall where they may, *Network Computing*, (1 November).

Metcalfe, R. 1992: EtherLink: the hot product that made Ethernet, *Network Computing* (1 February).

Metcalfe, R. 1993: Looking out for No. 2; IBM LAN on upswing, *Infoworld*, 15 (25 January): 46.

Metcalfe, R. (inventor of Ethernet and founder of 3Com) 1996: Personal communication (10 May).

Mier, E. 1986: Question: how open is IBM's much-touted Token Ring?, *Data Communications*, (January): 47–52.

Mulqueen, J. 1988: SynOptics turns skeptics into believers in twisted-pair wiring, *Data Communications*, (December): 71–80.

Nelson, J. 1983: 802: a progress report, *Datamation*, (September): 136–152.

Network World 1991: IBM maintains Token-Ring dominance, 8 (1 April): 19.

Peden, J. and Weaver, A. 1988: Are priorities useful in an 802.5 Token Ring?, *IEEE Transactions on Industrial Electronics*, 35(3): 361–365.

Porac, J. 1994: On the concept of 'organizational community', in J. Baum and J. Singh (eds.), *Evolutionary Dynamics of Organizations*, pp. 403–424. New York: Oxford University Press.

Potter, D. 1985: IBM. Their leadership role in local networks, in *Localnet '85*, pp. 319–323. London: Online Pinner.

Reier, S. 1995: Bland ambition, *Financial World*, 164 (6 June): 56–59.

Rekhi, K. (co-founder of Excelan) 1995: Personal communication (15 June).

Rodgers, D. 1995: Personal communication (28 June).

Rosenkopf, L. and Tushman, M. 1998: The coevolution of community networks and technology: lessons from the flight simulation industry, *Industrial and Corporate Change*, 7(2): 311–346.

Sabel, C. 1998: Intelligible differences: on deliberate strategy and the exploration of possibility in economic life, http://www.columbia.edu/~cfs11/IntelDif.html, 10 February.

Salamone, S. 1990a: Getting from Ethernet to Token Ring by bridge, *Network World*, (31 December/7 January): 1, 39–44.

Salamone, S. 1990b: 16M vs. 4M Token-Ring: fourfold improvement?, *Network World*, 7 (12 February): 1, 36, 58–60.

Saltzer, J. 1997: Personal communication (30 January).

Salwen, H. (founder and CEO of Proteon) 1995: Personal communication (7 July).

Saunders, S. 1994: LAN switching comes to Token Ring, *Data Communications*, (January): 87–90.

Schmidt, R. (co-founder, SynOptics) 1995: Personal interview (5 June).

Seifert, R. 1991: Ethernet: ten years after, *BYTE*, (January): 315–321.

Seifert, W. (co-founder, Interlan; co-founder, WellFleet Communications; co-founder, Agile Networks) 1995: Personal interview (28 June).

Sirbu, M. and Hughes, K. 1986: Standardization of local area networks. Presented at the Fourteenth Annual Telecommunications Policy Research Conference, Airlie, VA (April).

Smith, D.K. and Alexander, R.C. 1988: *Fumbling the Future: How Xerox Invented, then Ignored, the First Personal Computer*. New York: W. Morrow.

Stallings, W. 1984: IEEE Project 802, *Computerworld*, (13 February): In Depth 27–41.

Teece, D.J., Pisano, G. and Shuen, A. 1997: Dynamic capabilities and strategic management, *Strategic Management Journal*, 18(7): 509–533.

Terrie, D. 1991: Competition driving 10Base-T card prices down, *Network World*, (October): 43–96.

Thaler, P. (Chair of 10Base-T Group and Hewlett-Packard engineer) 1995: Personal communication (20 June).

3Com 1984: *U.S. Securities and Exchange Commission Form S-1*. Mountain View, CA.

3Com 1985: *Annual Report*. Mountain View, CA.

Tushman, M. and Anderson, P. 1986: Technological discontinuities and organizational environments, *Administrative Science Quarterly*, 31: 439–465.

Tushman, M. and Rosenkopf, L. 1992: Organizational determinants of technological change, *Research in Organizational Behavior*, (14): 311–347.

Ungermann, R. (co-founder, Zilog, Inc.; co-founder, Ungermann-Bass; co-founder, First Virtual Corporation) 1995: Personal communication (8 November).

Ungermann-Bass 1984: *Annual Report*. Santa Clara, CA.

Utterback, J. and Suarez, F. 1993: Innovation, competition, and industry structure, *Research Policy*, 22: 1–21.

Verhalen, A. (former SynOptics employee) 1995: Personal interview (10 February).

Vitalink 1989: *Securities and Exchange Commission Form S-1*. Fremont, CA.

Wade, J. 1995: The dynamics of organizational communities and technological bandwagons: an empirical investigation of community evolution in the microprocessor market, *Strategic Management Journal*, 16: 111–133.

Williamson, O. 1985: *The Economic Institutions of Capitalism*. New York: The Free Press.