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With Whom Do Technology Sponsors Partner During Technology Battles? Social Networking Strategies for Unproven (and Proven) Technologies

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The academic literature on technology battles has grown rapidly since the 1970s, tracking the ever-expanding role of information and communication technologies in our daily lives. An intriguing thread in this literature pertains to the influence of social networks on standards setting processes. While scholars acknowledge networks' importance, their relevance to sponsors' efforts to diffuse their technologies and establish them as de facto standards have been neglected. We theorize that sponsors choose alliance partners according to their location in the networks that connect potential adopters and that the network position that enhances a partner's attractiveness depends on a technology's stage of development. We hypothesize that sponsors of technologies that are early in their development and unproven commercially choose partners to create multiple points of contact between previous and potential adopters, called wide bridges. These redundant ties can foster the broad acceptance of a new technology that is essential to drive its diffusion. Sponsors of technologies in later stages of their development, with a commercial track record, can rely on a sparser network of ties to activate peer-to-peer diffusion. In line with our predictions, we found that during the battle to establish a 2G wireless standard in the U.S. market, Qualcomm, sponsor of the unproven CDMA (code division multiple access) technology, formed alliances that conformed to a wide-bridge pattern, while Ericsson, sponsor of the proven TDMA (time division multiple access) technology, formed alliances consistent with a peer-to-peer pattern of diffusion.

Keywords: technology battles; standards competition; diffusion; alliance formation; social networks; wireless; dominant design
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Introduction

An expansive body of research has examined how the sponsors of new technologies compete for market dominance (Murmann and Frenken 2006, McIntyre and Subramaniam 2009, Narayanan and Chen 2012). Of particular interest are battles involving discontinuous technologies, which can trigger an era of ferment during which industry entrants and incumbents compete to establish their variant of the discontinuous technology as a de facto standard or dominant design (Abernathy and Utterback 1978, Tushman and Anderson 1986, Besen and Farrell 1994, Agarwal et al. 2002). Technological discontinuity, such as the transition from analog to digital cellular phone signals, exposes incumbents and entrants alike to the vagaries of unclear and evolving demand for the new performance attributes it enables (Adner 2002).

To address this uncertainty, sponsors seek the support of allies, who can tilt a battle in their favor by certifying claims of technological superiority (Dokko et al. 2012, Delcamp and Leiponen 2014). Sponsors seek support for their technology in standard-setting organizations (Rosenkopf and Tushman 1998, Simcoe 2012) and through alliance partnerships (Cusumano et al. 1992, Garud et al. 2002), and a potential adopter's position in both networks can affect its allegiance (Ranganathan and Rosenkopf 2014). Partners can help sponsors to garner the support of important actors, such as regulators, and can influence potential adopters' appraisal of a sponsor's technology (Das and Van de Ven 2000, Suarez 2005). As it accumulates support, a sponsor can influence institutional logics[1] that underlie important selection forces in the competition between designs (Garud and Rappa 1994, Vasudeva et al. 2015).

Partnership choices, such as whether to commercialize a new technology collaboratively, are critical to a new technology's success (Marx et al. 2014, Marx and Hsu 2015) since alliance partners provide access to essential complementary assets (Teece 1986, Gans and Stern 2003), attract complement developers (Boudreau 2010, Eisenmann et al. 2010), and accelerate performance improvement (Soh 2010). Despite these important roles, we know relatively little about why sponsors of new technologies choose particular alliance partners during technology battles. Scholarly study has primarily investigated *when* sponsors seek partnerships (e.g., when do sponsors choose to commercialize their technologies collaboratively), rather than *which* (or, what type of) partners they choose. We suggest that in addition to the anticipated benefits of an economic exchange (e.g., from access to complementary assets or developmental resources), sponsors will also consider potential partners' capacity to help diffuse their technologies. The high stakes in technology battles makes this an economically relevant partnership consideration (Iyengar et al. 2011).

A critical difference between competing technologies is their stage of development, and we theorize that this is reflected in sponsors' partnership choices. For instance, sponsors of early-stage technologies typically have generated minimal evidence to support their performance claims, and this produces friction in the diffusion process and hinders sponsors' efforts to gain support for these technologies (Rogers 1995, Geroski 2000, Ghosh and Rosenkopf 2015). When potential adopters are uncertain about a technology's advantages, a decision to adopt it is risky, and we refer to the technology as "unproven" (Centola 2015). By contrast, a technology has been "proven" if its sponsor's performance claims have been publicly vetted, for instance through commercial deployment. When adopters see evidence of a technology's performance, an adoption decision requires less inducement from the technology sponsor or from its prior adopters (Watts 2002).

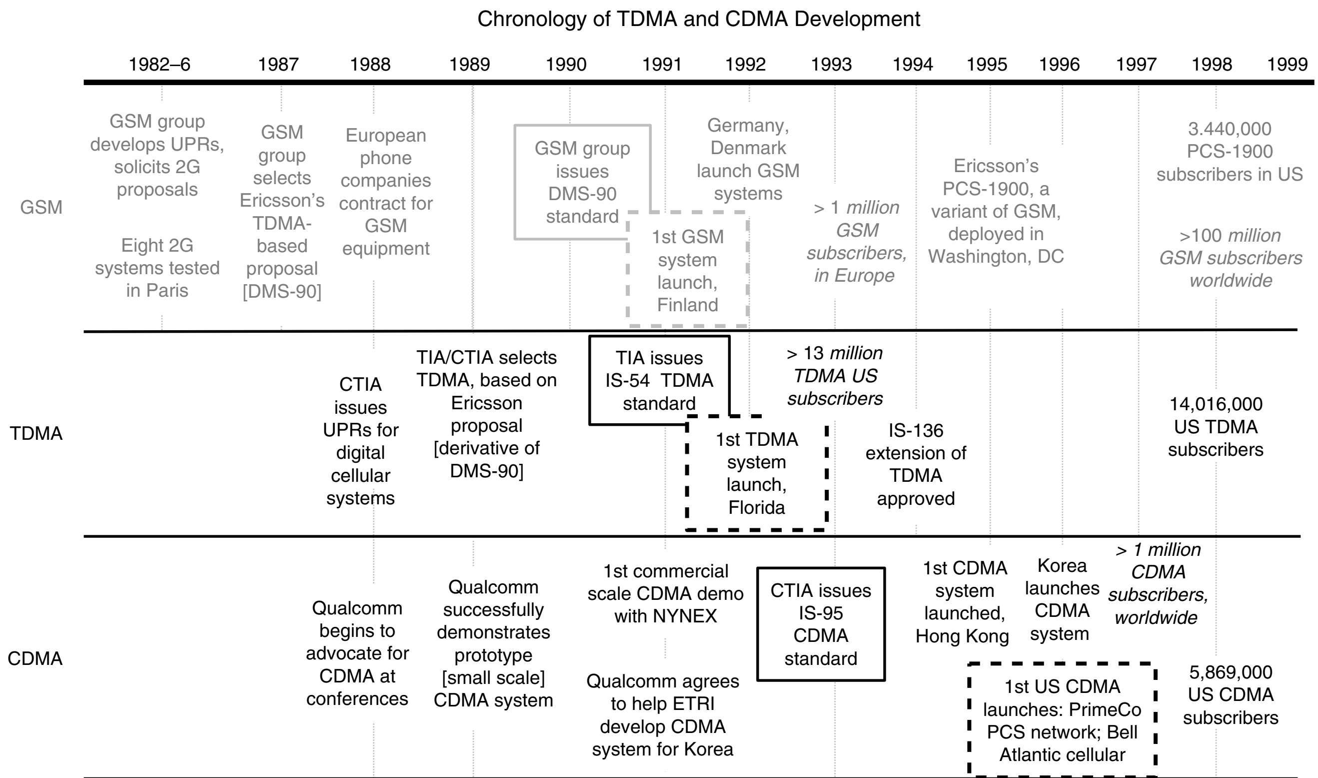
We build on social networks and contagion theory, which posits that well-understood and low-risk technologies diffuse through a simple contagion process, whereas poorly understood or otherwise risky technologies diffuse through complex contagion (Watts and Strogatz 1998, Gibbons 2004, Watts and Dodds 2007, Centola and Macy 2007, Centola 2015). We theorize that a sponsor of an unproven technology can allay concerns about its technology's performance by creating multiple points of contact between prior and potential adopters, and, through its alliance ties, will form the wide bridges that activate complex contagion. A sponsor of a proven technology does not need to reassure potential adopters, and hence will form alliance ties that foster peer-to-peer contagion, such as sparse ties to cliques.

We investigate whether these hypotheses are borne out in the second generation (2G) wireless standards battle in the U.S. market. We focus on the design competition between two discontinuous digital technologies, time division multiple access (TDMA) and code division multiple access (CDMA), which precipitated a transition from the 1G analog voice transmission standard in the United States, the Advanced Mobile Phone System (AMPS; Calhoun 1988, Marx et al. 2014). Ericsson's TDMA was endorsed as a viable digital standard by the U.S. Telecommunications Industry Association (TIA) in 1989 and formally issued in 1991. Its development began in the early 1980s, and it had been selected by the Groupe Spécial Mobile (GSM) as part of the European 2G standard in 1987, where it was commercially validated in 1991–1992. Qualcomm began developing CDMA for use in wireless voice communications in 1989 and obtained the TIA's endorsement in 1993. CDMA was first commercially launched in the United States in 1996, whereas TDMA achieved this milestone in 1992. In the 2G battle for the U.S. market, TDMA was proven prior to CDMA (Armstrong 1995). Figure 1 represents the chronological development of TDMA and CDMA, as well as GSM in Europe.

In line with our expectations, Qualcomm, sponsor of the unproven CDMA technology, formed wide-bridge alliance ties consistent with a complex contagion pattern, while Ericsson, sponsor of the proven TDMA technology, formed alliance ties that follow a peer-to-peer contagion pattern. In supplemental analyses, we observed that potential adopters were more likely to partner with Qualcomm if they had multiple indirect ties to this sponsor; indirect ties were irrelevant to a decision to partner with Ericsson. Also, as uncertainty about CDMA dissipated (reflected in Qualcomm's accumulation of licensing agreements with phone companies), indirect ties became less important to the decision to ally with Qualcomm. Network diagrams suggest that these patterns were reversed for the 3G battle, in which Qualcomm offered an extension of its 2G CDMA technology, while Ericsson promoted a controversial, relatively unproven CDMA-based alternative (see Appendix C).

Understanding how sponsors navigate technology battles is important, since the outcomes can profoundly affect industrial and societal infrastructures and condition competition for years to come (Sarkar et al. 2006). Our study makes two contributions to this literature. First, we extend the literature on technology battles by identifying two distinct strategies that sponsors can use to influence adopters and drive diffusion through social networks and by theorizing that sponsors will emphasize the strategy that is consistent with their technology's stage of development. The importance of alliance partners in technology battles has been noted (Garud et al. 2002, McIntyre and Subramaniam 2009), but few studies have examined whether sponsors choose partners in a discriminating way.[2] Conceptual frameworks take the battle or technology life cycle as the unit of analysis and hence downplay differences between the competing technologies (Bekkers 2001, Suarez 2004). A vast body of research investigates how social networks and uncertainty affect diffusion, but this work tends to relate network structure and technology characteristics to diffusion patterns, rather than to sponsors' strategies in standards battles (Rogers 1995, Watts and Strogatz 1998, Geroski 2000, Gibbons 2004, Greve 2009). Additionally, prior research indicates that the sponsors of new technologies seek alliance partners to access complementary assets,

Figure 1 Chronology of TDMA and CDMA Development



Notes. UPRs = universal performance requirements; DMS = digital multiplex system; PCS = personal communication service; NYNEX = New York/New England Exchange (telephone company); ETRI = Electronics and Telecome Research Institute (government-funded South Korean research institute).

promote the production of complementary technologies, and influence institutional logics. We identify the ability to influence social contagion as a fourth reason to prefer particular alliance partners.

To the social networks and innovation literature, we contribute by explaining how a technology's stage of development might influence potential adopters' susceptibility to peer influence, and thus the efficacy of alternative strategies for diffusing new technologies. Building on the concept of contagion, social network research frequently assumes that simple contact is sufficient for information to diffuse throughout a network, yet not only is there friction in this process (Ghosh and Rosenkopf 2015), a singular contact might not be enough to induce a change in behavior or trigger a choice when there is uncertainty (Morris 2000, Centola 2015). We theorize how the stage of a technology's development relates to adopters' susceptibility to peer influence and thereby the type of contagion likely to propel its diffusion.

We now turn to the research. We present a brief summary of relevant theory and then we develop our hypotheses. Next, we review the context for our study and explain our sample, the data we used, and the empirical tests of our hypotheses. Finally, we discuss the results and their implications for theory.

Technology Battles and Social Networks

Design Competition

Novel technologies emerge as new solutions to particular problems and progress through fairly predictable stages of development as their commercial viability is tested (Suarez 2004). Once there is proof that a technology operates the way it was conceptualized to do, its sponsor must then demonstrate that it can be economically developed and produced on a large scale and that it will attract a sufficient number of adopters (Utterback and Abernathy 1975, Bekkers 2001, Calhoun 1988). However, the battle for adopters often begins before sponsors have garnered conclusive evidence that their technologies will work as promised in the field (Arthur 1989, Van de Ven and Garud 1989, Manceau et al. 2014). Hence, during design competition,[3] sponsors must persuade adopters that their technology is superior at the same time they accumulate evidence to support their claims (Tushman and Anderson 1986, Murmann and Frenken 2006).

In Tushman and Anderson's (1986) model, competing designs are variants of a discontinuous technology[4] and as such are often represented as competing on equal footing during this stage of a technology battle. However, design competition can occur between technologies that differ in important ways, such as in their novelty (Das and Van de Ven 2000), the degree to which they are backward compatible with prior technologies (Shapiro and Varian 1999), and in their stage of development—our focus. When technologies at different stages of development meet in battle, a sponsor that has generated less evidence of how its technology performs in the field will likely have a tougher time persuading potential adopters that it offers the better solution. There may be debate regarding what performance trade-offs the market will gravitate toward and on what dimensions of performance an unproven technology will excel (Garud and Rappa 1994, Adner 2002).

A key challenge for sponsors during design competition is to persuade adopters that their technology offers a better solution than designs that offer different performance trade-offs (Van de Ven and Garud 1989, Church and Gandal 2005). For example, in the battle between VHS and Beta video recording formats, one offered better image quality and the other offered longer recording (Rosenbloom and Cusumano 1987). Video recording was a new function, and it was unclear how this function would be used and what performance attributes those uses would prioritize. The battle between TDMA[5] and CDMA to become the de facto 2G standard for the U.S. wireless communications market was typical in this regard: the technologies offered different sets of performance trade-offs between attributes such as ease of installation, potential for interference, and cost per call, and there was substantial uncertainty about which technology would appeal to the majority of adopters (Wallace et al. 1996, Elstrom 1997, Bekkers 2001).

The market for wireless communications was first established in the early 1980s with the advent of analog 1G wireless voice transmission technologies, and it was still a new market at the time of the 2G battle. Of almost 100 million U.S. phone lines in 1985, only 340,000 were cellular[6] (The World Bank 2016a, b). As demand for wireless grew, it was clear that wireless phone companies needed technologies that could make more efficient use of the available radio frequency spectrum. Debates about the relative merits of TDMA and CDMA focused on their relative abilities to expand call capacity, lower cost per call, and offer acceptable voice quality (Bekkers 2001, Schiesel 1996). From 1985 on, many papers comparing the merits of CDMA versus TDMA were published, and these illustrate the challenge of clearly discerning which technology was superior (e.g., see Jung 1993, Armstrong 1995, Falconer et al. 1995, Hemphill 2009). Although researchers reported a number of benefits of CDMA, including superior capacity, flexibility, and immunity to multipath fading, the main enemy of radio mobile communication, others concluded that CDMA's potential advantages over TDMA and AMPS came at the cost of implementation complexity (Gilder 2000). As Bekkers (2001, pp. 351–352) observed,

> Qualcomm and other proponents of CDMA claimed large capacity advantage over analog AMPS. In addition, the CDMA camp claimed lower operating costs because of fewer needed base stations for a given capacity, a higher service quality, and simplified planning. These claims, however, were strongly disputed by TDMA advocates. They did not believe that real-life systems could achieve the claimed capacity gain and thought that the complexity of the technology would not allow it to be cost-effective. They also pointed out that CDMA required complex mechanisms such as a very fast power control to work properly.

Cost (total infrastructure investment as well as cost per call) was a particularly salient issue for phone companies, most of whom had lost money on their 1G services[7] (Calhoun 1988). Debates over the expected costs to install and operate a CDMA system were vigorous, as were forecasts for its capacity advantages. Many variables could cause its performance to degrade as the number of subscribers to a cellular network rose, making it difficult to anticipate how CDMA would perform in practice (e.g., Kohno et al. 1995). Qualcomm's early forecast of a 40× capacity gain over AMPS was subsequently reduced to a less than 10× gain (Wallace et al. 1996). CDMA's detractors claimed that it would "violate the laws of physics" and accused Qualcomm of faking its demonstration (Brodsky 2008, p. 199). Marx et al. (2014, p. 3103) characterized CDMA as having been "controversial" at the time, noting that handling multiple calls on the same frequency simultaneously and managing the interference, as opposed to sequentially stacking calls, went against the "prevailing protocol, TDMA." Substantial skepticism was voiced in the popular press as well.[8]

To win a design competition, sponsors must quickly diffuse their technologies regardless of the uncertainty that adopters face. Prior work describes how social network ties act as conduits of information and influence, shaping choices like technology adoption even in the face of uncertainty.

Social Networks and Technology Adoption

Firms rely on social networks to acquire and validate information, reduce uncertainty, and to make sense of unfamiliar situations, including choosing which technology to adopt (Coleman et al. 1966, Granovetter 1973, Rosenkopf and Padula 2008). For example, Burt (1987, p. 1290) argued,

> When confronted with an empirically ambiguous question, a question that cannot be resolved by concrete facts, people turn to the other people with whom such questions are discussed and, in their reciprocally socializing debate, create a consensual, normative understanding of the question, resolving the question's uncertainty in their own minds, if not in fact. As a result of this understanding, [one's] adoption quickly follows [the others] because they have come to share the same evaluation of the adoption's costs and benefits.

Social networks affect new technology adoption decisions and diffusion patterns (Suarez 2005, Lee et al. 2006, Tucker 2008, Birke 2009), and studies suggest that social influence is most powerful when potential adopters are uncertain of a technology' benefits (Kraut et al. 1998, Bandiera and Rasul 2006, Centola 2010, Karsai et al. 2014). Hence, network ties should be instrumental to sponsors during design competition, when adopters have trouble appraising their technology choices. While each adoption lends credibility to a sponsor's performance claims, the degree to which individual adopters affect a technology's diffusion depends on the type of social contagion adopters are susceptible to.

Social Contagion and Diffusion Strategies

Social contagion refers to the spread of information, beliefs, technologies, and behaviors through social contact (Burt and Talmud 1993). While the mechanisms underlying transmission can vary,[9] contagion originates when an "activated" node in a social network comes into contact with a susceptible node (Centola and Macy 2007). In the context of disease transmission, activated nodes are actors that have been infected. With respect to technology diffusion, activation occurs through collaboration or extensive communication with a sponsor, including commitments to further the development of a sponsor's technology or its complements (Soh 2010). Social contagion has been modeled using activation thresholds to represent the susceptibility of actors to the influence of their peers (Granovetter 1978, Schelling 1978), where a threshold is the number of activated contacts that are needed for a focal actor to become activated (i.e., better informed or more committed to a technology).

Studies suggest both direct and indirect contact can lead to activation and spread information and behaviors throughout a social network, but that the range of potential activation thresholds is large (Strang and Tuma 1993). A simple contagion is passed on through singular contact between activated and unactivated nodes in a network (Burt and Talmud 1993). Collectively, such peer-to-peer influence can create a domino effect and quickly diffuse a new idea or technology through a social network (Watts 2002, Watts and Dodds 2007). By contrast, complex contagions only diffuse through wide bridges, i.e., as each unactivated node is exposed to several different activated nodes (Centola and Macy 2007, Centola 2015).

This distinction has a pivotal effect on the rate at which diffusion occurs through social networks and on the kinds of ties that can accelerate or derail diffusion (Centola and Macy 2007). We expect the distinction to be especially salient during design competition when sponsors of proven technologies might need to appeal to adopters differently than do sponsors of unproven technologies. Scholars have emphasized the importance of alliance partnerships during design competition (Soh 2010, Eisenmann et al. 2010), and the social contagion literature implies that an important consideration in forming alliance ties is a partner's capacity to influence other adopters and thereby the diffusion of a sponsor's technology.

Simple Contagion and Peer-to-Peer Diffusion. Simple contagions can diffuse from peer to peer, because a singular contact with an activated node is sufficient to pass on the information needed to affect the unactivated node's decisions or behaviors (Angst et al. 2010). The more fully developed a technology, the greater the evidence regarding whether and how it works and what benefits it is capable of delivering to its users. Certainty reduces the need for collective sense making to evaluate a technology. Potential adopters are also likely to be more aware of better developed technologies, which would have had longer presence in both the industry and the media. Prolonged exposure to a technology can create the perception that it is a viable solution, reducing adopters' need for affirmation from their peers (Utterback and Abernathy 1975, Kraut et al. 1998) and validation of the information they receive about it. It is easier for actors to communicate about a proven technology and to derive meaningful insights from simple contact, and potential adopters thus grow more susceptible to peer influence as a technology becomes familiar to them.

Watts and Dodds (2007) have argued that when adopters are ready to be influenced, contact with any prior adopter is sufficient for a technology to diffuse. Their work challenges the long-held notion that diffusion tends to occur faster through influentials—actors that exert an extraordinary influence on the decisions of others (Katz and Lazarsfeld 1955, Merton 1968). Watts and Dodds (2007) simulated a large variety of network structures to assess when those actors with disproportionate influence on others are responsible for triggering massive cascades of adoption. They found that influentials accelerated diffusion in some situations, but when activation thresholds were low, diffusion occurred as or more quickly through peer-to-peer contact. Furthermore, they showed that when this contact comes through weak ties—which bridge a long distance between different clusters[10] in a network, very few ties are needed to accelerate diffusion (Watts and Strogatz 1998). Abrahamson and Rosenkopf (1997) refer to a similar concept, a boundary weakness, which occurs when potential adopters who are predisposed to adopt an innovation have a single tie to another potential adopter.

Empirical evidence supports the power of peer-to-peer diffusion. In experimental work, Salganik et al. (2006) found that social influence, exerted through anonymous contact with peers, determined which songs became hits. Trusov et al. (2010) found that in an Internet community, most people were influenced by a few others and that a small number of people have a disproportionate influence—but these were not necessarily the hubs of the network. This research suggests that if a technology can diffuse via simple contagion, a sponsor can accelerate its diffusion by forming alliances sparsely throughout the network of potential adopters. Each alliance activates a node in the network of potential adopters by signaling to others that it has made some degree of commitment to the sponsor's technology and by affording its firsthand access to information about the technology. Since the sponsor's alliance partners (i.e., the activated nodes) can influence their direct and indirect ties through simple contagion, a sponsor does not need to form redundant ties with those actors. Based on this, we hypothesize the following:

Hypothesis 1 (H1). *A sponsor of a proven technology will form alliances consistent with a peer-to-peer diffusion strategy.*

Complex Contagion and Wide-Bridge Diffusion. Centola and Macy (2007) argue that not all contagions are simple. Rather, when actors are exposed to risk or uncertainty, or substantial cost is involved, potential adopters may require multiple independent exposures to activated peers before they are ready to make a choice. Technologies that are earlier in their development cycle and hence unproven are more likely to diffuse through complex contagion (Coleman et al. 1966, Centola and Macy 2007). Adopting an unproven technology is risky as it might ultimately fail to work as promised. Moreover, evaluating the risks associated with adoption is difficult. If a technology has not been publicly validated, then potential adopters must piece together information from multiple sources to assess these risks and compare them against a technology's potential (Centola and Macy 2007). However, since shared knowledge about new and unproven technology is limited, its adopters cannot easily transfer what they learn to potential adopters (Cohen and Levinthal 1990, Lane and Lubtakin 1998).

Given these challenges, Centola and Macy (2007) argue that complex contagions require wide bridges for diffusion. Wide bridges are comprised of multiple local connections between activated and unactivated nodes in an adopter network, and they can play a number of roles that aid in the diffusion process. Wide bridges provide independent affirmation of the potential benefits, increasing the credibility of a sponsor's claims about the advantages of an unproven technology. Credibility is likely to be a particular issue if the unproven technology is up against one that has been publicly validated or endorsed and has more test cases in the field. An unproven technology is unlikely to be viewed as a credible option until several of an actor's direct ties have adopted it (Coleman et al. 1966, Angst et al. 2010). Social affirmation of a sponsor's claims is particularly important when factors that could impinge upon a technology's performance—such as the availability of complementary technologies or enabling infrastructure—lay outside a sponsor's control. Multiple exposures are also critical when few successful adoptions have been publicized and the value adopters can derive from a technology depends upon how it is implemented or the timeframe in which it can be deployed. Social affirmation can create a perception that novel choices are nonetheless legitimate, as hearing the same story repeatedly can reduce the tendency to view surprising information as far-fetched (Centola and Macy 2007). As Arthur (1987, p. 591) writes, "often a technology that is more adopted enjoys the advantage of being better known and better understood. For the risk-averse, adopting it becomes more attractive if it is more widespread."

A sponsor that expects to encounter resistance from potential adopters will recognize the need to offer additional assurances that its claims regarding the technology's advantages are valid (Garbler and Grübler 2013), and we expect sponsors will form alliances with this in mind. The most credible assurances come from prior adopters (Coleman et al. 1966, Conley and Udry 2010), and a sponsor could choose alliance partners that make these connections. Specifically, a sponsor can create the wide bridges required to activate complex contagions by building multiple indirect ties to potential adopters. Essentially, the sponsor chooses to emphasize structurally redundant alliance ties over efficient ones.

Wide bridges operate through dense local ties that connect activated to unactivated nodes in an adopter network. A sponsor activates nodes by forming alliances with them. Where multiple indirect ties connect a sponsor to potential adopters (unactivated nodes), the unproven technology can diffuse. Since a sponsor does not know how many activated nodes will trigger unactivated nodes to adopt it has an incentive to activate as many nodes in a locality as possible (i.e., that is, to concentrate its alliances on its partners' partners). The greater the concentration of indirect ties to unactivated nodes in the adopter network, the higher the likelihood that the sponsor's unproven technology will diffuse through its partners to other actors they are connected to. Furthermore, once the contagion begins to spread, the odds that any given activated tie will form part of a wide bridge increases. Based on this, we expect that a sponsor of an unproven technology will choose to ally with firms in the adopter network that are tied to firms the sponsor already has alliances with. Choosing alliance partners in this way increases a sponsor's opportunities to create wide bridges.

Hypothesis 2 (H2). *A sponsor of an unproven technology will form alliances consistent with a wide-bridge diffusion strategy.*

Sponsors might further accelerate the diffusion of new technologies by gaining the endorsement of influential actors, such as firms that are well connected in a focal adopter network (Coleman et al. 1966, Van den Bulte and Lilien 2001). Influentials tend to be in touch with leading edge practices and are perceived by their peers as credible sources of information (Iyengar et al. 2011). This makes them especially relevant to sponsors of unproven technologies. These sponsors can accelerate diffusion by first gaining the support of influential adopters and relying on them to allay the concerns that other adopters might have (Weimann 1994, Iyengar et al. 2011). In the same vein, Rosenkopf and Padula (2008) maintain that a firm offering novel technology will seek prominent actors in an adopter network as sources of credible endorsements, and that prominent actors are more willing to partner with them. Sponsors of well understood technologies could also choose to partner with influentials. However, Watts and Dodds (2007) demonstrate that when thresholds for influence are low (i.e., susceptibility to peer influence is high), influentials do not accelerate diffusion any more than do peer contacts, suggesting that sponsors of proven technologies have little reason to prefer influentials as alliance partners. An actor's degree centrality in a social network is only one metric of influence, but it is particularly relevant to sponsors of new technologies (Katz and Lazarsfeld 1955, Merton 1968, Podolny 2001). Central actors can synthesize emerging understanding about an unproven technology and pass on new evidence of its merits to their contacts. Therefore we expect the following:

Hypothesis 3 (H3). *A sponsor of an unproven technology will form alliances with central actors in the adopter network.*

Research Method

Empirical Setting

To test our hypotheses, we focused on the battle to establish a standard for the second generation of mobile communications technology in the U.S. market, which took place from the mid-1980s through the 1990s. A technical standard based on TDMA[11] was endorsed by the TIA in 1989 and formally published in 1991. It was challenged by a second technology, CDMA, for which the TIA published a formal standard in 1993[12] (Hemphill 2009, Bekkers 2001). Whereas the first generation (1G) technology[13] transmitted analog voice signals, the 2G technologies encoded and transmitted digital signals. Mobile phone use had grown tremendously, and analog systems were unable to support the volume of calls in densely populated urban areas such as New York and Los Angeles. Digital transmission solved the capacity problems since it made more efficient use of the radio frequency spectrum.

When compared to 1G technology, the 2G technology was a competence-destroying technological discontinuity for both equipment manufacturers and phone companies (Tushman and Anderson 1986, Dahlin and Behrens 2005): the digital transmission signal required the development of new infrastructure equipment and handsets. The TDMA and CDMA standards were, however, competence-enhancing extensions of expertise and technology that Ericsson and Qualcomm, respectively, possessed prior to 2G.

By the time the TIA issued the formal standards specification, IS-54, for TDMA in 1991, equipment manufacturers had developed TDMA-based equipment and it had been deployed by European phone companies (TDMA was an important component of the European de jure GSM standard, which was approved by 17 European countries in 1987; Bekkers 2001). TIA issued the formal standard, IS-95, based on CDMA in 1993, and its first installation by a phone company occurred in Hong Kong in 1995. Despite these differences in starting conditions, the existence of more than one technical option allowed for an intense design competition stage that lasted until the next discontinuity in signal technology, 3G, was introduced (see the timeline in Figure 1).

Design Competition. The 2G design competition phase is characterized by competition between the old 1G standard versus the new 2G standard, as well as competition between the two 2G versions. To facilitate moving from 1G to 2G, the earliest version of TDMA could be integrated with the FDMA (frequency division multiple access) analog technology. This partial backward compatibility was of limited importance, however, since the gain in switching to the 2G standard was far greater and few phone companies wanted the combined systems (Hemphill 2009, Bekkers 2001). The competition was heavily focused on which of the two technologies would ultimately perform better and what performance characteristics (call capacity, cost per unit of capacity, total investment cost per cell, call quality) would sway most adopters. Most of the 2G battle existed in a state of technological ferment, since both TDMA and CDMA were continuously improved upon.

For phone companies, one of the 2G standards' most attractive features was their modular structure (Calhoun 1988, Bekkers 2001). This meant that the operators could freely choose different equipment firms for different parts of the system rather than, as was the case for 1G, being tied to a single supplier that delivered a turn-key system guaranteeing that any follow-up orders would go to the same vendor (Färjh and Wahlberg 2014). Although sponsors conducted simulations and ran experiments, a technology's performance advantages could only be fully proved when manufacturers incorporated the technology into infrastructure and subscriber equipment and phone companies launched their digital services. While the standard served as a platform attracting equipment manufactures on the one hand and phone companies on the other, network effects were surprisingly limited in the United States in contrast to the European market, since few users expected roaming (moving between service areas with different phone companies[14]; Bekkers 2001). Customers mainly made calls within a service area, meaning that compatibility between areas was of limited importance, reducing network effects (Suarez 2005).

Dominant Design. At the end of the 2G technology cycle in 2001[15] the worldwide market share for the TDMA standard was 86% (this includes different versions in the United States, the European GSM standard, and the Japanese Personal Digital Cellular (PDC) standard), and the market share for CDMA was 13% (International Telecommunications Union ITU). However, when we break the numbers down per geographical market, we find that the lucrative U.S. market had a duopoly situation with respect to the dominant design, with subscribers split between TDMA and CDMA at 55% and 45%, respectively.

Data Sources

We used four databases to generate the sample and main variables: the SDC Platinum database on alliances (Thompson-Reuters), Standard & Poor's Compustat for firm characteristics, the U.S. Patent and Trademark Office database for patent information, and the Federal Communications Commission database for phone company adoption data. We used the first two databases to establish the sample and risk set, as described below and in Appendix A. To better understand sponsor strategies, we also interviewed industry participants (Färjh and Wahlberg 2014, Joubard 2014), read the sponsors' 10-K and annual reports, and studied various documents from relevant standard development organizations (primarily the TIA and Cellular Telephone Industries Association (CTIA)) as well as technical reports, interviews with Qualcomm's founders, news articles, and scientific and trade journal publications describing industry activity during the 1980s and 1990s.

Establishing the Sample and the Risk Set

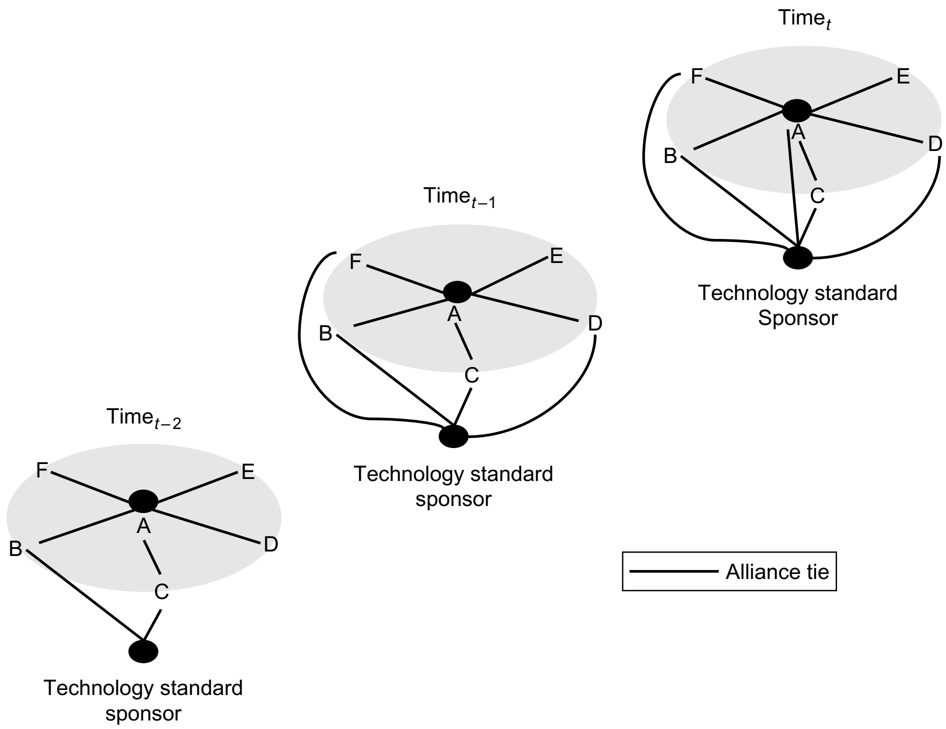
To test our hypotheses, we needed to create an appropriate risk set, i.e., population of candidate partners, with whom the sponsors might seek to form alliances to affect the outcome of the 2G battle. We also needed to establish appropriate network boundaries to capture potential partners' positions in the network of potential adopters. We utilized a sequential process for this, which is summarized in Appendix A.

First, we included the population of wireless equipment manufacturers, Standard Industrial Classification (SIC) code 3663. Unless a sponsor intends to supply the market for their technology, equipment manufacturers must incorporate its technology before phone companies can use it to support their networks. However, sponsors face a bit of a chicken and egg dilemma, in that demand from the phone companies as well as from firms in adjacent industries could encourage equipment manufacturers to support a technology. Therefore, we included firms outside of the wireless equipment industry (SIC 3663) in the risk set and in the network of potential adopters, provided that we had evidence of their probable interest in wireless communication technologies. We included all alliances in which at least one member was from the wireless equipment industry (SIC 3663) and then examined whether any non–SIC 3663 partners were likely to have interests in 2G technologies and the capability to incorporate these technologies in their product and service offerings. Partners in the following industries were deemed to meet this criterion: wireline equipment (SICs 3661 and 3669), wireline phone companies (SIC 4812), wireless (cellular) phone companies (SIC 4813), and industries in which wireless protocols were used in complementary technologies (consumer electronics, computers, software, and automobiles). Rosenkopf and Padula (2008) follow a similar process.[16] The risk set was comprised of firms that were both potential partners to the sponsors and adopters of its technology. These firms could originate from one of 28 SIC classes, but about 46% were in the wireless equipment manufacturing industry (3663, 3661, 3669), about 13% were wireless and landline phone companies (4812, 4813), and 10.5% were complement makers (7372, 3651, 7375, 4899, 7373, 7376, and more). Hence, firms in the risk set were overwhelmingly participants in the wireless telecommunications industry value chain.

We included wireless communication firms that were publicly traded on the U.S. stock exchange during our observation period, even if they had formed no alliances, and we included alliances with at least one U.S.-based firm. If an alliance did not include a U.S.-based firm, we examined whether the alliance contained partners with a geographical focus on the U.S. market. We investigated the content of every alliance deal reported in the SDC database to examine these criteria and relied on other secondary sources to investigate firms and alliances where the requisite information in the SDC database was unclear. The filtering process left us with 736 firms in the risk set. The number varied over time; there were, for instance, 54 firms in 1990, 242 in 1995, and 87 firms in 1999. Within the alliance risk set, Qualcomm had 117 alliance ties and Ericsson had 33 alliance ties during the 2G timeframe. We found that joint ventures comprised about 30% of Ericsson's alliance ties (10 out of 33) and 14% of Qualcomm's alliance ties (15 of 104). Alliance deal texts mentioned 12 different activities, with the average alliance comprising 1.55 activities. The most common activity combinations were manufacturing and sales/marketing, and geographical expansion and phone services. The firms' deal content differed somewhat: Qualcomm's alliances are slightly more likely to involve some manufacturing (28% versus 16%, $\chi^2(1) = 3.7$, $p < 0.10$) and phone services (11% versus 0%, $\chi^2(1) = 7.4$, $p < 0.01$); Ericsson's alliances are more likely to involve some licensing (45% versus 21%, $\chi^2(1) = 12.8$, $p < 0.01$) and slightly more likely to involve some research and development (R&D; 36% versus 24%, $\chi^2 = 2.9$, $p < 0.10$).

Given that alliance termination data are unavailable, and as our empirical setting was changing rapidly and product

Figure 2 An Exemplar Case of Wide-Bridge Strategy Influencing Potential Adopters



life cycles were short, we used a three-year alliance window (Soh and Roberts 2003, Lavie and Rosenkopf 2006). We included alliances formed since 1987, five years before the first 2G networks were in operation, to reduce left censoring. To construct the social network variables, we created 11 yearly matrices (from 1990 to 2000) using UCINET 6 (Borgatti et al. 2002); each annual matrix includes alliances formed in t, $t-1$, and $t-2$.

Dependent and Explanatory Variables

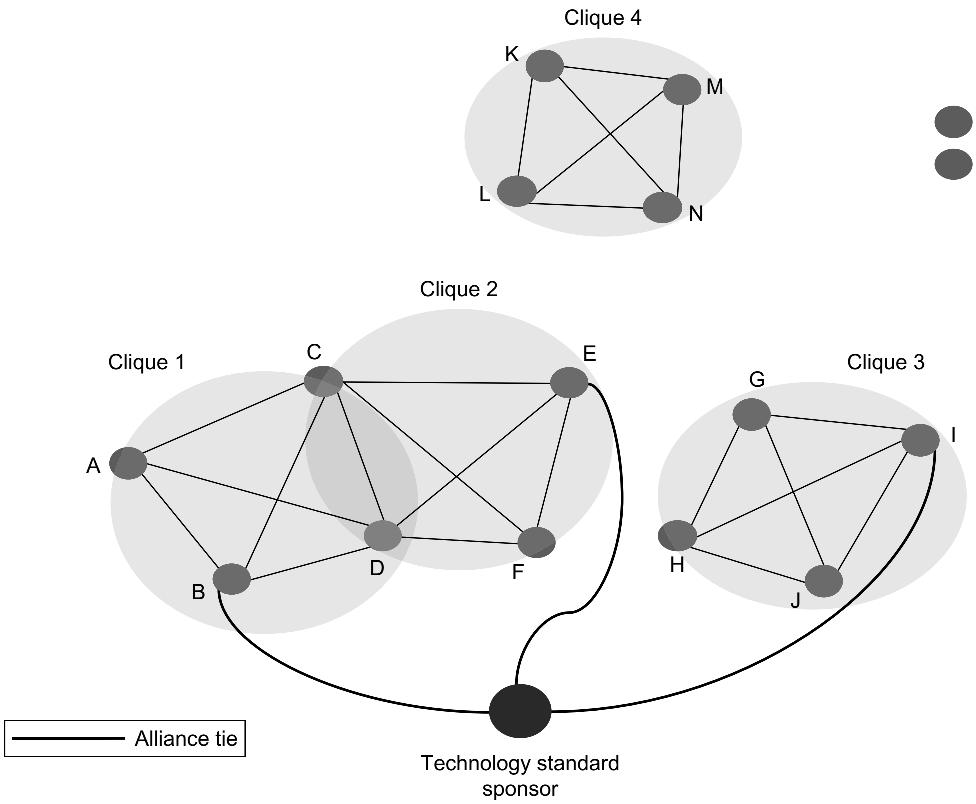
Dependent Variables. We estimated separate models for Qualcomm and Ericsson and created two dependent variables, one for each candidate partner. The first variable, *Qualcomm ally*, equals 1 if Qualcomm entered an alliance with the potential partner firm i, during year t. *Ericsson ally* captures the same information for all potential partners, but is set according to whether Ericsson formed an alliance with the firm i, during year t.

Independent Variables. The variable *Wide-bridge* is a partner attribute that captures whether a potential partner helps the sponsor build a wide bridge. *Wide-bridge* is the fraction of a potential partner's alliance partners that the sponsor also has alliances with. A higher wide-bridge ratio means that more of a potential partner's allies have already been activated in some way, by forming an alliance with the sponsor. For example, consider a technology sponsor initiating an alliance with firm A at time t (Figure 2). Since the sponsor already has alliances with four of firm A's partners (firms B, C, D, E), the wide-bridge ratio is $4/5 = 0.8$, describing a wide bridge where much exchange about the sponsor's technology can occur. Qualcomm and Ericsson have separate networks captured by *Wide-bridge_Q* and *Wide-bridge_E*, respectively.

The variable *Peer-to-peer* denotes whether a potential partner's network position is in a clique where no one else is in an alliance with the sponsor. If a potential partner is in a previously unconnected clique, this variable is set to 1; otherwise, it is set to 0. Ericsson forming alliances with a potential partner in an unconnected clique is consistent with our H2 prediction. A clique is a group where all firms have ties (alliance relationships) to each other (Kilduff and Tsai 2003). Cliques are groups of four or more actors, and neither dyads nor triads are considered to be cliques (Wasserman and Faust 1994, Provan and Sebastian 1998). We used UCINET to generate firm-clique matrices and from those created dichotomous indicators for the two peer-to-peer variables, *Peer-to-peer_Q* and *Peer-to-peer_E*, indicating if a potential partner is the only sponsor-connected clique member.[17]

Assume that there are 16 candidate firms and one technology sponsor in an alliance network, and that there are four cliques (cliques 1, 2, 3, and 4) in the network (Figure 3). In a clique, all firms have alliances with each other. Since the sponsor already has an alliance with firms B, E, and I in cliques 1, 2, and 3, a sponsor seeking peer-to-peer connections is uninterested in allying with other member of these cliques (firms A, C, D, F, G, H, and J) as the sponsor already has established a connection with each clique. However, any of the firms K, L, M, and N would be good targets for the sponsor

Figure 3 An Exemplar Case of Peer-to-Peer Strategy Influencing Potential Adopters



to establish a peer-to-peer connection, since clique 4 is unconnected to the sponsor. On the basis of this logic, firms A∼J are coded as 0, whereas firms K∼N are coded as 1. Although isolate firms (such as firm O and P) are also coded as 0, we use an additional variable, *Isolate*, to control for this effect.

Centrality measures the number of connections each candidate partner has with other actors in the overall 2G-relevant network divided by the total number of possible connections in the network, i.e., normalized degree centrality (Freeman 1979). The more central a candidate partner's network position, the more visible and influential the candidate is with respect to technology diffusion.

Control Variables—Alternative Explanations

Our models include controls for partner characteristics that might provide an alternative reason for sponsors to prefer them. If these were correlated with the network variables in our hypotheses but excluded from our models, we could inadvertently attribute empirical relationships to the wrong underlying mechanisms. We also control for network variables that could affect the importance of partner network position, and for technology characteristics that could affect perceptions of their value.

Partner Attribute Controls. Sponsors might be attracted to more visible partners that could help bring credibility to their technology or to partners with larger resource stocks to invest in further technology and business development. These firms might be centrally located in adopter networks, which we hypothesize about and measure separately. In addition, firm size is typically used to control for these effects. Most of the firms in our sample are based outside the United States, and Compustat has financial data for only the 36% U.S. firms in our sample, so we proxy for size with the variable *Public*, to indicate that a firm is publicly traded. Publicly traded firms tend to be more visible and larger than private firms.

Sponsors of unproven technologies might seek to partner with firms that innovate, as they are accustomed to working through technological uncertainty and might assist Qualcomm's efforts to further develop its technology. Innovative firms are better equipped to appraise unproven technologies, more easily persuaded to accept the associated risks, and could provide credible endorsements of the sponsor's technology. *Firm patent stock* sums the patents a firm has been granted in the four years, $t-5$ to $t-1$, prior to the end of the observation year t. We used the natural logarithm of firm patent stock since the distribution is highly skewed. We counted technology-specific patents separately and include them as *Firm patents–TDMA* and *Firm patents–CDMA*.[18]

Firms in three kinds of businesses would have been particularly important for commercializing the 2G wireless technologies: equipment manufacturers, complementary product makers, and phone companies. Sponsors might have an affinity to certain kinds of partners, according to differences in their business models or degree of vertical integration. Dummy variables control for industry fixed effects: (1) *Equipment manufacturer* (SICs 3661, 3663, 3669, 3672, 3674, 3679, 3571, 3575, and 3577), (2) *Phone company* (SICs 4812 and 4113), (3) *Complement maker for end users* (consumers) (consumer electronics, SIC 3651; prepackaged software, SIC 7372; and information retrieval services, SIC 7375), and (4) *Complement maker for phone companies* (computer integrated systems design, SIC 7373; computer facilities management services, SIC 7376; or telecom product services, SIC 4899).

We controlled for *Common geographic region* using a dummy variable. Both homophily theory and agglomeration economics suggest that two colocated organizations are more likely to form a tie. We coded this variable 1 if the candidate firm's headquarters was located in the same geographical region as the sponsor (Qualcomm, North American; Ericsson, European) and otherwise 0.

We controlled for whether a firm previously had an alliance with the sponsor. Familiarity can attenuate perceived risk, and prior partners would have some information about a sponsor's capacity to further develop its technology and the credibility of the sponsor's claims about its advantages. Hence, familiarity can foster trust and reduce uncertainty about the benefits of partnership and technology adoption (Gulati 1995, Li and Rowley 2002). *Prior tie* was set to 1 if a candidate had already partnered with the sponsor, 0 otherwise.

Partner's Ego Network and Industry Network Controls. *Network cohesion* was calculated as the number of alliance ties in a potential partner's ego network divided by the maximum number of possible alliance ties. The ego network includes not only the potential partner's direct alliance ties, but also alliance ties among the firm's alliance partners. The denser a potential partner's ego network, the more likely the firm will form an alliance with others inside the ego network (Koka and Prescott 2002).

The variable *Common third party* indicates whether a given sponsor-potential partner dyad shared common partners from previous alliances within the previous three years ($t-3$ to $t-1$). Firms tied to a common partner are assumed to have access to reliable information about one another through the common partner, enhancing trust, and can also experience relational pressures to form a tie due to common interests or for competitive reasons (Gulati and Gargiulo 1999).

Isolate indicates whether a candidate partner stood entirely outside the adopter network (1, yes; 0, no). Isolates could enable a sponsor's networking strategy. For example, an isolate could help a wide-bridge strategy by forming a tie with a potential adopter that a sponsor had targeted, or it could help the peer-to-peer strategy by connecting to a clique where a sponsor had no prior tie. Isolates might also be attractive for non-networking reasons that we do not account for elsewhere.

We control for two industry-level network variables. *Network centralization* measures heterogeneity in firm (i.e., potential partner) network centrality. A higher score indicates that an industry's alliance network was centralized around fewer firms in a given year. The variable is a ratio varying between 0 (all firms have equal centrality scores) and 1 (one firm dominates the network) and is operationalized as the average difference between the centrality of the most central firm and that of all other firms (Freeman 1979), or

$$Centralization = \frac{\sum_{i=1}^{n}[C_{\max} - C_i]}{n-1},$$

where $C_{\max}$ is the centrality measure of the most central firm, and n is the number of firms in the network.

Network density is the number of alliances formed divided by the number of possible alliances in the adopter network. A denser network can alter alliance-seeking behaviors: rapid alliance formation is more likely in a sparse network, whereas a denser network is more inert (Watts and Dodds 2007) as sponsors need fewer alliances to channel information when many parties already are connected. This variable also controls for alternative factors that might affect the propensity to form peer-to-peer alliances, since it captures varying levels of opportunity to form peer-to-peer ties and need for redundant ties (wide bridge).

Technology-Level Controls. Installed base is seen as a key determinant of a technology's ability to attract new adherents (Birke 2009), suggesting that as install base grows, sponsors will form more alliances. Even with minimal communication or complement-driven network effects, installed base reflects adopters' appraisals of a technology's value. As phone companies are the ultimate adopters in this context, we used the cumulative number of U.S. phone companies that adopted each standard to capture the installed base of the standard, labeling these variables *TDMA_adoption* and *CDMA_adoption.*

Uncertainty about a technology's feasibility might affect partnership choices. Technology-specific patent count signals both technological competence in and credible commitment to the standard, which could promote alliance formation. We use the count of patents in TDMA- and CDMA-related patent classes, *TDMA_patents* and *CDMA_patents*. A higher patent count indicates lower technological uncertainty because it signals R&D investment in the standard (Singh 2008). Finally, no product could be sold until a formal standard was approved and issued by the standards association, TIA. We included the time since a technology-specific standard was approved, expecting regulatory uncertainty to decrease over time. Whereas a larger installed base attracts partners, we expect a decrease in regulatory uncertainty to make alliances less important. Formal approval, rather than the support of alliance partners, can signal that a standard is viable. To capture regulatory uncertainty, we created two clocks, *TIAclock_TDMA* and *TIAclock_CDMA*, which capture the difference between the current year and the year in which the TIA endorsed a standard.

Results

Tables 1 and 2 report descriptive statistics and correlations for the Qualcomm and Ericsson models.

Estimation Strategy

To test our hypotheses, we analyze each sponsor's alliance network separately using piecewise exponential hazard models to avoid bias created by right censoring. Other advantages are that we need no a priori assumptions regarding the duration dependence since the model's flexibility allows different diffusion rates, which fits with the empirical context. TDMA (Ericsson) was developed earlier than CDMA (Qualcomm), and we expect adoption likelihoods for the two standards to vary over time (Blossfeld and Rohwer 1995).

We specify two periods signifying before and after market entry for the two technologies. In the Qualcomm models, the two periods are (1990–1996) and (1997–2000), the break coinciding with the start of South Korean commercialization in 1996 and Bell Atlantics launch of the first U.S. CDMA service (Bekkers 2001). For the Ericsson models, two other periods were specified (1990–1992) and (1993–2000), with the break in hazard rates indicating that the first TDMA system began U.S. operations in 1992 (Singh 2008).

We kept firm observations in the data set until an event occurred (an alliance formed between a sponsor and a candidate partner), after which we dropped the candidate partner from the risk set. This approach reduces the risk of endogeneity (e.g., the conditions for a second alliance tie are impacted by formation of the first) and provides a more conservative test of our theory. We updated the time lagged and time-varying independent variables each year, estimating the coefficients using maximum likelihood methods. Since we have repeated observations for most candidate partners, we used the "cluster" option in Stata to calculate robust standard errors.

When we compare the network coefficients (H1–H3) across the two models, we find systematic differences in sponsor strategies (see Tables 3 and 4).

Qualcomm Model

Table 3 presents the hazard model results for Qualcomm's alliance partner network. Hypothesis 2 predicts that a technology sponsor offering an unproven technology, Qualcomm, would form alliances consistent with a wide-bridge diffusion strategy. The hypothesis is supported, as the *Wide-bridge* coefficient is significant and positive (Models 2–6, $p < 0.05$). Qualcomm activates several firms in the potential adopter network that are connected by locally dense ties, where wide bridges can form. The positive effect of *centrality* ($p < 0.001$) suggests that Qualcomm sought to partner with firms that occupied a central position in the adopter network, supporting H3.

Controls for CDMA patent stock, industry affiliation, isolate status, national differences, network centrality, and network density are consistently significant across the models (p-value ranges from < 0.05 to < 0.001). We entered the uncertainty variables separately into the models since they are highly collinear. Two indicators for industry affiliations (if a firm manufactures equipment or provides users with complementary products) have positive and significant effects, suggesting that firms in these categories were key allies for Qualcomm during the observation period. This does not make firms in other categories unattractive as partners, but the results indicate that Qualcomm first tried to partner with complementary manufacturers to signal to others that their standard had backers. A positive and significant coefficient for the firm CDMA patent stock variable is consistent with the idea that Qualcomm was more likely to partner with firms that could contribute to its technology development. The negative and significant effect of *TIAclock_CDMA* and the positive and significant effect of CDMA adoption suggest that Qualcomm relies on partners less as regulatory uncertainty is reduced (i.e., after it was formally endorsed by TIA) and forms more partnerships as market uncertainty declines (i.e., as more phone companies deployed CDMA), respectvely.

Ericsson Model

Table 4 presents the hazard model results for the Ericsson alliance network. Hypothesis 1 states that a sponsor with a proven technology would form alliance ties consistent with a peer-to-peer diffusion strategy. This is supported in Models 2–6, where the effect of *Peer-to-peer* is positive and significant ($p < 0.05$).

Ericsson entered fewer alliances than Qualcomm, which is also consistent with the peer-to-peer strategy where only a few key connections are needed to accelerate diffusion (Watts and Dodds 2007). Industry history and interviews lend additional support to our finding: Ericsson clearly questions the value of alliances. An executive active in Ericsson during the 2G standard-setting period in the 1980s, now head of standardization strategy in information and communications technology (ICT) stated that the firm views collaboration as useful prior to and during standard setting. Once a standard is established, former standard partners are competitors and the fight is on (Färjh and Wahlberg 2014). Qualcomm's view of alliances was the opposite, as indicated in its 1999 annual report:

> The Company has an ongoing commitment to the evolution and expansion of its technologies and products through strategic partnerships and alliances. These partnerships and alliances are designed to ensure product leadership and competitive advantage in the marketplace.
>
> (Qualcomm 1999, p. 8)

Table 1 Correlation Table: Qualcomm Model

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1 *Public*	1.00																		
2 *Firm patent stock*	0.05	1.00																	
3 *Firm patents–CDMA*	−0.02	0.23	1.00																
4 *Equipment manufacturer*	0.26	−0.07	−0.02	1.00															
5 *Phone company*	−0.07	−0.03	0.00	−0.52	1.00														
6 *Complement maker for end users*	−0.07	0.02	0.01	−0.33	−0.06	1.00													
7 *Common geographic region*	0.04	−0.17	−0.09	0.21	−0.09	−0.07	1.00												
8 *Prior tie_Q*	−0.32	0.00	0.00	−0.38	0.15	0.16	−0.19	1.00											
9 *Isolate_Q*	0.00	0.08	0.02	−0.20	0.13	0.08	−0.13	0.16	1.00										
10 *Network cohesion*	−0.39	0.00	0.02	−0.56	0.29	0.18	−0.25	0.58	0.10	1.00									
11 *Common third party*	−0.01	0.19	0.27	−0.24	0.21	0.11	−0.19	0.11	0.17	0.18	1.00								
12 *Network centralization*	−0.02	−0.01	−0.06	−0.05	0.04	0.01	−0.01	−0.06	−0.01	0.07	0.05	1.00							
13 *Network density*	0.05	0.00	−0.07	0.09	−0.07	−0.04	0.01	0.37	−0.04	−0.14	−0.06	−0.16	1.00						
14 *CDMA_adoption*	−0.03	0.01	0.10	−0.03	0.04	0.03	0.00	−0.31	0.05	0.06	0.05	−0.33	−0.78	1.00					
15 *TIAclock_CDMA*	−0.02	0.02	0.11	0.00	0.02	0.02	0.01	−0.26	0.03	0.02	0.02	−0.53	−0.61	0.92	1.00				
16 *CDMA_patents*	−0.01	0.03	0.10	0.02	0.00	0.01	0.03	−0.19	0.01	0.00	−0.01	−0.46	−0.40	0.67	0.88	1.00			
17 *Wide-bridge_Q*	−0.07	0.07	0.05	−0.26	0.16	0.14	−0.17	0.21	0.09	0.34	0.51	0.01	−0.02	0.03	0.04	0.05	1.00		
18 *Peer-to-peer_Q*	−0.10	0.02	−0.01	−0.22	0.11	0.02	−0.14	0.13	−0.03	0.23	−0.06	0.03	−0.04	−0.02	−0.04	−0.06	−0.07	1.00	
19 *Centrality*	−0.14	0.30	0.35	−0.27	0.17	0.04	−0.12	0.14	0.04	0.15	0.61	0.04	0.03	−0.05	−0.06	−0.05	0.14	0.16	1
Mean	0.87	0.52	2.98	0.75	0.08	0.04	0.80	0.56	0.04	0.40	0.27	0.34	0.02	427.1	2.00	2,240	0.07	0.05	0.01
S.D.	0.34	1.42	23.87	0.43	0.28	0.19	0.40	0.50	0.21	0.48	0.94	0.04	0.01	219.7	2.11	3,451	0.22	0.22	0.02

Notes. $N = 3{,}293$. Correlations above 0.005 are significant at $p < 0.05$.

Table 2 Correlation Table: Ericsson Model

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1 *Public*	1.00																		
2 *Firm patent stock*	0.05	1.00																	
3 *Firm patents–TDMA*	−0.02	0.22	1.00																
4 *Equipment manufacturer*	0.26	−0.07	0.01	1.00															
5 *Phone company*	−0.07	−0.03	−0.02	−0.52	1.00														
6 *Complement maker for end users*	−0.07	0.02	−0.02	−0.33	−0.06	1.00													
7 *Common geographic region*	0.01	0.17	0.17	−0.19	0.09	0.09	1.00												
8 *Prior tie_E*	−0.34	−0.02	−0.01	−0.38	0.15	0.14	0.12	1.00											
9 *Isolate_E*	−0.08	0.09	0.17	−0.13	0.08	0.03	0.10	0.06	1.00										
10 *Network cohesion*	−0.39	0.00	−0.02	−0.56	0.29	0.18	0.24	0.55	0.04	1.00									
11 *Common third party*	−0.09	0.16	0.29	−0.31	0.25	0.09	0.23	0.22	0.22	0.30	1.00								
12 *Network centralization*	−0.02	−0.01	−0.03	−0.05	0.04	0.01	0.03	−0.05	0.00	0.07	0.04	1.00							
13 *Network density*	0.05	0.00	−0.04	0.09	−0.07	−0.04	0.01	0.39	0.00	−0.14	−0.06	−0.16	1.00						
14 *TDMA_adoption*	−0.04	0.01	0.06	−0.05	0.05	0.03	−0.03	−0.36	0.00	0.08	0.04	−0.35	−0.82	1.00					
15 *TIAclock_TDMA*	−0.04	0.01	0.06	−0.04	0.04	0.03	−0.04	−0.35	0.00	0.07	0.05	−0.36	−0.80	0.98	1.00				
16 *TDMA patents*	−0.03	0.02	0.06	−0.02	0.03	0.03	−0.04	−0.32	0.00	0.05	0.05	−0.43	−0.73	0.95	0.99	1.00			
17 *Wide-bridge_E*	−0.17	0.01	0.02	−0.33	0.15	0.15	0.15	0.29	0.02	0.42	0.64	0.06	−0.06	0.02	0.01	0.00	1.00		
18 *Peer-to-peer_E*	−0.06	0.03	0.00	−0.24	0.16	0.04	0.07	0.14	−0.02	0.24	−0.08	0.03	−0.05	0.02	0.00	−0.02	−0.10	1.00	
19 *Centrality*	−0.14	0.30	0.36	−0.27	0.17	0.04	0.15	0.15	0.42	0.15	0.39	0.04	0.03	−0.04	−0.05	−0.05	0.04	0.21	1
Mean	0.87	0.52	0.83	0.75	0.08	0.04	0.13	0.54	0.02	0.40	0.21	0.34	0.02	506.1	4.39	1,234	0.11	0.06	0.01
S.D.	0.34	1.42	8.41	0.43	0.28	0.19	0.34	0.50	0.13	0.48	0.56	0.04	0.01	252.8	2.83	674	0.28	0.23	0.02

Notes. $N = 3{,}293$. Correlations above 0.005 are significant at $p < 0.05$.

Table 3 Results of Regression Analyses Predicting Sponsor's Partner Strategy: Qualcomm

	Model 1			Model 2			Model 3			Model 4			Model 5			Model 6		
	Coef.	S.D.		Coef.	S.D.		Coef.	S.D.		Coef.	S.D.		Coef.	S.D.		Coef.	S.D.	
1990–1996	−1.56	2.13		−0.81	2.11		−0.22	2.07		3.90	3.09		4.11	3.07		0.30	2.25	
1997–2000	−2.68	1.82		−2.13	1.80		−1.68	1.76		2.39	2.79		3.09	2.85		−0.44	2.05	
Public	0.65	0.32	*	0.64	0.32	*	0.64	0.32	*	0.58	0.32	+	0.54	0.32	+	0.60	0.31	+
Firm patent stock	0.12	0.07		0.12	0.06	+	0.12	0.06	+	0.14	0.06	*	0.13	0.06	*	0.12	0.06	+
Firm patents–CDMA	0.02	0.00	***	0.02	0.00	***	0.02	0.00	***	0.02	0.00	**	0.02	0.01	***	0.02	0.01	**
Equipment manufacturer	0.49	0.29	+	0.50	0.28	+	0.43	0.28		0.57	0.28	*	0.58	0.28	*	0.48	0.27	+
Phone company	0.28	0.34		0.31	0.34		0.21	0.35		0.19	0.35		0.17	0.35		0.24	0.35	
Complement maker for end users	1.09	0.37	**	1.12	0.36	***	1.05	0.34	**	1.22	0.36	***	1.25	0.35	***	1.12	0.34	***
Common geographic region	−0.63	0.22	**	−0.63	0.22	**	−0.67	0.22	**	−0.70	0.22	***	−0.68	0.21	***	−0.64	0.22	**
Prior tie_Q	1.16	0.52	*	1.10	0.52	*	1.04	0.53	*	1.05	0.53	*	0.98	0.54	+	0.91	0.52	+
Isolate_Q	3.93	0.41	***	4.01	0.41	***	4.03	0.42	***	4.08	0.43	***	4.16	0.44	***	4.20	0.46	***
Network cohesion	0.40	0.41		0.28	0.43		0.42	0.44		0.44	0.44		0.54	0.45		0.64	0.48	
Common third party	−0.07	0.15		−0.28	0.20		−0.37	0.22	+	−0.38	0.24		−0.37	0.23		−0.38	0.23	
Network centralization	−8.88	4.84	+	−10.48	4.82	*	−11.47	4.74	*	−18.02	6.20	**	−19.94	6.68	**	−12.56	5.14	*
Network density	−79.93	25.31	**	−91.25	25.08	***	−98.19	24.61	***	−164.47	42.37	***	−158.21	39.20	***	−104.02	27.09	***
CDMA_adoption										0.00	0.00	*						
TIAclock_CDMA													−0.33	0.13	*			
CDMA_patents																0.00	0.00	
Wide-bridge_Q				1.23	0.58	*	1.23	0.57	*	1.28	0.57	*	1.23	0.57	*	1.15	0.57	*
Peer-to-peer_Q							−1.32	0.80	+	−1.36	0.81	+	−1.38	0.81	+	−1.38	0.79	+
Centrality	28.94	7.66	***	34.04	7.69	***	39.39	8.46	***	39.06	8.59	***	39.17	8.55	***	39.29	8.55	***
Wald χ^2	−117.9		***	−111.1		***	−109.05		***	−107.51		***	−106.72		***	−107.25		***
Pseudo-likelihood	932.15			918.24			901.06			882.47			885.35			923.11		

Note. The analysis is based on 3,036 firm-year observations (three-year alliance duration window) covering 723 firms and 77 events of Qualcomm's alliances.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Table 4 Results of Regression Analyses Predicting Sponsor's Partner Strategy: Ericsson

	Model 1			Model 2			Model 3			Model 4			Model 5			Model 6		
	Coef.	S.D.		Coef.	S.D.		Coef.	S.D.		Coef.	S.D.		Coef.	S.D.		Coef.	S.D.	
1990–1992	7.76	4.34	+	6.75	4.06	+	6.07	4.04		5.77	8.49		3.23	8.66		4.09	8.77	
1993–2000	3.90	3.32		3.09	3.07		2.51	3.11		2.18	8.12		−0.45	8.17		0.54	8.05	
Public	−0.54	0.56		−0.28	0.44		−0.18	0.45		−0.15	0.43		−0.22	0.43		−0.21	0.42	
Firm patent stock	0.20	0.13		0.10	0.15		0.14	0.16		0.15	0.16		0.13	0.16		0.13	0.16	
Firm patents–TDMA	0.01	0.01	+	0.01	0.01	+	0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01	
Equipment manufacturer	0.65	0.65		0.57	0.53		0.65	0.54		0.71	0.56		0.67	0.56		0.67	0.56	
Phone company	0.60	0.93		0.40	0.92		0.42	0.96		0.51	0.98		0.45	0.95		0.44	0.94	
Complement maker for end users	1.53	0.88	+	1.46	0.77	+	1.39	0.70	*	1.37	0.68	*	1.35	0.68	*	1.37	0.68	*
Common geographic region	0.36	0.74		0.18	0.72		0.12	0.67		0.16	0.66		0.17	0.69		0.16	0.68	
Prior tie_E	−0.81	0.82		−0.70	0.82		−0.69	0.79		−0.57	0.82		−0.69	0.79		−0.69	0.79	
Isolate_E	6.19	0.79	***	6.37	0.78	***	6.67	0.94	***	6.66	0.98	***	6.66	0.96	***	6.66	0.95	***
Network cohesion	−0.39	0.98		−0.74	1.10		−1.38	1.64		−1.39	1.67		−1.49	1.79		−1.47	1.83	
Common third party	2.24	0.98	*	2.77	1.11	*	1.89	1.25		1.88	1.23		1.82	1.20		1.84	1.20	
Network centralization	−23.21	8.73	**	−22.43	8.65	**	−21.52	8.30	**	−21.62	12.15	+	−17.53	13.09		−18.54	13.57	
Network density	−234.2	68.06		−210.2	63.61		−211.90	61.31		−212.88	162.44		−161.66	147.42		−181.41	137.42	
TDMA_adoption										0.00	0.00							
TIAclock_TDMA													0.15	0.35				
TDMA patents																0.00	0.00	
Wide-bridge_E							2.11	1.96		2.15	2.00		2.26	2.17		2.22	2.19	
Peer-to-peer_E				2.47	1.09	*	2.59	1.17	*	2.63	1.21	*	2.67	1.27	*	2.65	1.29	*
Centrality	−16.52	18.63		−30.63	24.99		−0.62	24.96		0.87	25.83		2.02	26.53		1.29	26.63	
Wald χ^2	474.95		***	533.68		***	419.39		***	487.48		***	492.87		***	491.96		***
Pseudo-likelihood	−30.03			−27.82			−27.03			−27.01			−26.92			−26.97		

Note. The analysis is based on 3,212 firm-year observations (three-year alliance duration window) covering 725 firms and 17 events of Ericsson's alliances.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Comparing control variable effects for both sponsors, we found some meaningful differences. First, Ericsson pursued neither technologically capable partners (firms with many TDMA patents) nor central parties in the network for alliances (Table 4), whereas Qualcomm did (Table 3). In contrast to Qualcomm, Ericsson's alliance tendency was not influenced by uncertainty reduction over time. The existence of a prior tie increased the likelihood that Qualcomm would form an alliance with a firm, but had no influence on Ericsson's partnership choices. This is in line with Qualcomm's technology being at an earlier stage of development. Similarly, as network density increased, Qualcomm formed fewer ties, whereas this variable had no effect on Ericsson's tie formation. This is consistent with Qualcomm's need for redundant ties to diffuse its technology. A similar effect for both sponsors is that they allied with isolates. When looking at the industry background of the isolates, we find that many are entrants into telecom, with Ericsson's isolate partners coming from the software industry and Qualcomm's isolate partners being equipment makers.

Supplemental Analyses

The number of alliances formed overall is fairly low, especially for Ericsson, so we also ran rare event logistic regression (RELOGIT) analyses to assess the robustness of our results. RELOGIT predicts the likelihood of an event while correcting for biases that arise from excessive numbers of zeros (King and Zeng 2001). The results are qualitatively consistent (in significance and direction) with the piecewise hazard models supported in Tables 3 and 4.

Peer-to-peer alliances are more likely when a firm has a low number of alliances, so we needed to determine whether the number of alliance ties could have driven our results for Ericsson. We examined this empirically and with a probability model. First, we estimated the models controlling for the number of alliances formed to date and with the number of cliques in the adopter network; each is indicative of a sponsor's opportunity to form peer-to-peer ties.[19] Both controls were insignificant in the models, and their inclusion did not change our estimates or the results of our hypothesis tests. Then, we developed a probability model to estimate the likelihood that a sponsor could have randomly formed ties that follow a particular pattern. If the tie formation process is random, then the likelihood of choosing a peer-to-peer partner should match the likelihood of any firm being a peer-to-peer candidate. The likelihood of Ericsson forming a wide bridge or isolate tie should also match the proportions of these types of firms in the risk set. The probability model showed that, when a sponsor adds ties, the likelihood of forming a peer-to-peer tie declines faster than the likelihood of forming a wide-bridge or an isolate tie. In contrast, increasing the number of ties raises the likelihood of forming a wide-bridge tie. When using the number of cliques, isolates and potential wide-bridge ties in our data, we calculated that even Ericsson, with its low number of ties, was overall more likely to form wide-bridge than peer-to-peer ties. In fact, the likelihood of Ericsson randomly forming a wide-bridge tie after 1991 is always greater than the likelihood of it forming a peer-to-peer tie, with this likelihood varying between 1.88 and 10 times in favor of wide-bridge ties. Only in the first year of our data series is Ericsson more likely to randomly form a peer-to-peer tie than it is to form a wide-bridge or an isolate tie. Based on this, we conclude that it is extremely unlikely for the peer-to-peer pattern we observe for Ericsson to have emerged through a random process, in which forming fewer ties favors a peer-to-peer pattern. (This model and all of our robustness analyses are available upon request.)

Finally, we regard our use of cliques as a conservative test of a peer-to-peer diffusion strategy. Cliques can diffuse technologies faster than bridges or central actors, since any member can activate any other member in the clique. However, bridges and central actors also have the capacity to efficiently activate groups of potential adopters. As a further test of our theory and to rule out the results being contingent upon our specific measures, we examined whether a partner occupied a bridging position between otherwise disconnected cliques and whether a partner had a betweenness centrality that situated it in the top 25% most "between" actors in the adopter network. On average, 65% of Ericsson's alliance ties were to actors occupying a bridging position in the adopter network (the annual range was from 33% to 100%, from 1990–1999), and 64% were in the top 25% of betweenness centrality. By contrast, only 14% of Qualcomm's partners were bridges and 29% of its partners were in the top 25% of betweenness centrality in the adopter network. This difference is consistent with our theory.

To further assess our theoretical mechanisms, we conducted three additional analyses. First, to ensure we were not missing key factors affecting tie formation, we estimated multinomial logit models to predict partner choices. Although our theory emphasizes sponsor choices, ties form by mutual agreement. In the main models, we assume that there are no matching constraints on either the two focal firms (Ericsson and Qualcomm) or on their potential partners (Mindruta 2013): i.e., when Ericsson partners with firm X, firm X can also partner with Qualcomm. Thus, we have a friendship model rather than a marriage model of partnering (Mindruta 2013). We use an unordered set of multiple discrete choices for candidate partners: each candidate can partner with Ericsson, partner with Qualcomm, or form no partnership (Greene 2003). The results reported in Appendix B show that public firms are more likely to partner with Qualcomm than with Ericsson, as are makers of complementary products aimed at end users and firms that already have had at least one alliance with Qualcomm. European and U.S.

firms are more likely to partner with Ericsson. Since there are many firms with any of these characteristics, there is no reason to believe that the estimates in our main models are biased (Mindruta 2013, Mindruta et al. 2015). On the network level, we find that network cohesion and density matter for how likely candidate partners are to ally with Qualcomm, but not with Ericsson. Again, the numbers of firms that do form ties are vastly smaller than the potential pool of firms, suggesting the main results should be unbiased.

Second, we examined how the sponsors' network strategies evolve along the technology life cycle as installed base increases and technological uncertainty decreases. We created two interaction variables by multiplying the installed base variables, *CDMA_adoption* and *TDMA_adoption*, with each of the two network strategy variables, *Peer-to-peer* and *Wide-bridge*. Similarly, we tested the interaction between the technical uncertainty variables, *TIAclock_CDMA* and *TIAclock_TDMA*, and the two network strategy variables, *Peer-to-peer* and *Wide-bridge*. Negative and significant coefficients for the moderators ($p < 0.05$) showed that Qualcomm relied more on a peer-to-peer strategy than wide-bridge strategy as its CDMA standard evolved from high to low uncertainty. We found no such moderating effect in the Ericsson model and concluded their strategy was less sensitive to time effects, essentially staying the same over the 2G technology cycle. Qualcomm's greater embrace of peer-to-peer ties as uncertainty about its technology lessens is consistent with our contention that a technology's stage of development shapes its sponsor's diffusion strategy.

Continuing with this reasoning, partner choices should also vary according to whether the competing technologies have proven their advantages in the market. Specifically, potential partners should be more inclined to choose CDMA if they have indirect ties to Qualcomm, whereas the same would not be expected for a decision to partner with Ericsson. Moreover, as more phone companies obtained CDMA licenses (relative to the number that obtained TDMA licenses), indirect ties should have had less bearing on partners' tendency to choose Qualcomm because actual adoption replaces the need for assurance by potential adopters. The results reported in Appendix B, for *Indirect ties* and their interactions with 2G *License catch-up*, support these predictions and provide direct tests of, and support for, our theoretical mechanisms.

Finally, we examined the pattern of alliances that Qualcomm and Ericsson formed during the emergence of 3G wireless standards. A comparison of Ericsson's and Qualcomm's alliance strategies from 2G to 3G is interesting because during the 3G battle, the sponsors' technologies were in reverse situations. Qualcomm sponsored cdma2000, which was "a fairly uncontroversial extension of CDMA, involving relatively incremental equipment upgrades" (Weiss 2015). In contrast, Ericsson's technology, WCDMA, was complex and diverged substantially from the predominant 2G technologies (Grindley et al. 1999). Also, its commercial deployment lagged cdma2000 by about four years, making it the relatively unproven choice for phone companies (see Weiss 2015). Appendix C illustrates a dramatic shift in the sponsors' alliance ties as the technologies they championed confronted different adoption challenges. The differences are consistent with the idea that unproven technologies diffuse through wide bridges, whereas proven technologies diffuse through simple contagion, with implications for alliance formation.

Discussion

The literature on technology battles encompasses standards wars, in which network effects figure prominently (McIntyre and Subramaniam 2009); platform competition, where the two-sided nature of markets is focal (Economides and Katsamakas 2006); and competition to establish a dominant design (Anderson and Tushman 1990). Sponsors act strategically to build support for their new technologies by participating in standard development organizations (Leiponen 2008, Dokko et al. 2012), launching media campaigns (Theoharakis et al. 2007), and forming alliances to accelerate their technologies' development (Wade 1995, den Uijl and de Vries 2013). Alliance ties and social networks also shape the diffusion of new technologies and thereby influence the outcome of technology battles (Abrahamson and Rosenkopf 1997, Schilling 2002, Suarez 2005, Ranganathan and Rosenkopf 2014), yet few studies have examined whether sponsors choose partners that confer social network advantages. We theorize that sponsors promoting technologies at different stages of development will form alliance ties that leverage distinctive structural features of the adopter network.

In particular, we theorize how the stage of a technology's development affects the type of contagion needed to diffuse it and hypothesize how this will shape sponsors' partner preferences. We demonstrate that during the design competition phase of a standards battle, a sponsor prefers partners that are structurally situated to activate either complex or simple contagion, as is appropriate to its technology's maturity.

Studies of technological change illustrate the vigorous debates that can accompany the emergence of novel technologies (Van de Ven and Garud 1989, Kaplan and Radin 2011, Trapido 2015). Research on new technology diffusion has suggested that sponsors should target influentials—highly central actors who can affect other adopters' opinions (Katz and Lazarsfeld 1955, Iyengar et al. 2015). However, the importance of influentials has also been challenged, as they may be insufficient to accelerate diffusion of unproven technologies (Granovetter 1978, Centola and Macy 2007, Centola 2015) and irrelevant to the diffusion of technologies that are well understood (Watts and Dodds 2007).

We theorized that the stage of a technology's development affects the type of contagion needed to activate diffusion and demonstrated that sponsors emphasize alliance ties that are consistent with these differences. A sponsor of a proven technology selects partners that can activate simple contagion through peer-to-peer ties, while a sponsor of an unproven technology chooses partners that create wide bridges, which can activate complex contagion. Although the diffusion and network literatures recognize that ambiguous technologies spread differently from those that are well understood (Katz and Shapiro 1994, Gibbons 2004), the stage of technology development has not been a focus of this theorizing (McIntyre and Subramaniam 2009).

That the desire to activate simple or complex contagions influences partner choice suggests an extension to theory on alliance formation. In addition to selecting partners to share risks and to access complementary resources, markets, and knowledge flows (Columbo and Grilli 2006, Mitsuhashi and Greve 2009), firms might also anticipate converting partners into agents—proponents or progenitors of their technology. Early followers help to deradicalize a choice, increasing the likelihood that others will also adopt, and this is especially crucial to unproven technologies (Granovetter 1978). Qualcomm appears to have formed alliances with this intent. For example,

> In the late 1990s the company undertook a series of initiatives designed to expand its reach into emerging cell phone markets in Asia. The biggest prize was China .... Despite a number of promising tests of CDMA technology in the Chinese marketplace, however, China continued to favor GSM .... After failing in its initial bid to forge a strategic alliance with China Unicom, one of the country's largest cellphone companies, Qualcomm signed research-and-development deals with seven Chinese cellphone manufacturers in June 2000, in the hope that the increased presence of CDMA on the production level might stir up greater interest among the larger Chinese telecomm companies. (Pederson 2002, pp. 337–343)

Scholars could further extend the theory on social networks as vehicles for influencing standards battles by examining when certain kinds of partners take on the role of proponents or progenitors of a sponsor's technology. For example, in the 2G case, phone companies were locked into the technology they selected and thus would have had strong incentives to act as its proponents. By driving up demand for the equipment, they might accelerate reduction in its costs, assure a competitive supply, and stimulate continual improvements in its performance. Equipment manufacturers took on the role of progenitors by creating components that embodied a sponsor's technology. Although they were not locked into the technologies they chose to supply, they would have had an incentive to encourage other manufacturers to produce components they did not and to boost overall demand for their technology products. Research could further extend our findings by considering how firms' embeddedness in multiple networks simultaneously shapes their strategies for diffusing new technologies (Ranganathan and Rosenkopf 2014).

Limitations

Although we found strong evidence to support our theory, additional work must determine how these patterns affect contagion processes and interact with other strategies (e.g., participation in standards committees, use of the media, management of intellectual property) through which sponsors exert their influence on selection processes before we can understand the implications for who wins technology battles and when. In addition to garnering allies, sponsors can seek to publicly discredit their rivals (Garud et al. 2002, Theoharakis et al. 2007), offer their intellectual property for free or at low cost to gain support (Boudreau 2010), and exert influence through standard development committees (Leiponen 2008, Simcoe 2012, Ranganathan and Rosenkopf 2014, Delcamp and Leiponen 2014). In fact, Ericsson seems to have deployed all of these tactics during the 2G battle, particularly in Europe, where standards committees could enforce a uniform standard through public policy (Grindley et al. 1999, Hemphill 2009, Potter and Cohen 2010). Further research on how technology battles unfold could examine when and how sponsors' committee, media, and intellectual property strategies complement their alliance strategies.

Additionally, there is ample room to theorize further on how sponsors leverage and affect network structures. For instance, Centola (2015) demonstrates that local clustering and wide bridges are both essential for activating the complex contagions needed to diffuse risky choices through a population. Scholars could investigate whether and how sponsors build wide bridges between clusters, such as through multiparty alliances. Also, adopters differ in ways that can affect their threshold for activation (how many exposures to prior adopters are required before they are ready to make a decision). Sponsors that attend to heterogeneity in adopter populations might form alliances that follow a path of least resistance, with interesting structural implications. Extant theory predicts that the way new technologies diffuse through a population is contingent upon the strength of homophily and the level of consolidation that characterizes the population[20] (Blau and Schwartz 1984, Centola 2015). When consolidation is very low, members of different groups (e.g., late and early adopters) are more likely to interact, creating pathways for contagion to travel across distinct types of adopters. In populations with very high consolidation, influence will more likely operate with a strong local bias (Lee et al. 2006), requiring sponsors to connect directly with each group.

Moreover, adopters might belong to distinctive structural groups, such as to different clusters, which connect certain actors to one another more than to others in a population (Rosenkopf and Padula 2008). Our theory could be extended by accounting for alliance partners' cluster memberships. Viewed through a contagion lens, the marginal benefit of each partner is its capacity to influence subsequent adoption. With each alliance, sponsors confront a trade-off: whether to form a tie that extends their reach through the adopter network or one that adds redundancy in regions to which they are already connected. For a proven technology, the opportunity cost associated with forming ties for reach over redundancy is low, since redundancy has decreasing marginal benefits for activating simple contagion. The sponsor of an unproven technology faces a different trade-off. Since the marginal benefit of redundancy, for activating complex contagion, is increasing (i.e., two redundant ties are better than one), the opportunity cost of forming efficient ties for reach over redundant ones is high.

Leveraging clusters in the adopter network might enable a sponsor to gain the benefits of reach without entirely relinquishing the benefits of redundancy, or vise versa. A sponsor could extend its reach by forming ties with several different clusters and at the same time form redundant ties within each of those clusters. Or, it might concentrate its partnerships within the main component cluster, but spread its ties within that cluster to partners with whom it has no or few redundant ties. Either of these patterns would attenuate the trade-off between forming alliances that extend reach versus reinforce redundancies.

Boundary Conditions

We considered the boundary conditions for our theory. Following the literature on technology, we have assumed that a dominant motivation of both sponsors was to accelerate the diffusion of their technologies. Accordingly, our focus was on offensive reasons to form alliance ties. However, sponsors that benefit from an early mover advantage, such as when network effects are strong[21] or when incumbent advantages are robust, such as when preexisting complementary assets add value to a new technology (Gans and Stern 2003), might prefer to defend their lead. This could produce a different pattern of ties, possibly shifting a sponsor of a proven technology from forming sparse peer-to-peer ties to emphasizing redundant ties to solidify its position.

Our focus was on business adopters. While the principles of contagion we build upon are agnostic as to whether an adopter is an individual or a business, the difference could affect the modes and mechanisms involved in transmitting information and exerting influence, and the resulting frictions that condition the diffusion process could vary (Ghosh and Rosenkopf 2015). Sponsors might, for instance, seek to influence individual adopters and to address political frictions through media campaigns and standards committees. Nonetheless, we have not identified a reason why this would change the predicted pattern of alliance tie formation during design competition.

We assumed that the sponsors had a naïve understanding of the relationships among potential adopters. To test our hypotheses, we concentrated on the structural relationships between sponsors' current alliance partners and other potential partners in the adopter network. Sponsors need primitive knowledge of the adopter network to consider these relationships as they form alliances, and though cliques and indirect ties might be imperfectly observed prior to an alliance, sponsors become more aware of their partners' connections through the alliances they form (Gulati 1995). However, Ozcan and Eisenhardt (2009) show that sponsors of new technologies can vary greatly in their network savvy. In their sample of wireless video game developers, some firms astutely recognized the connections that existed between firms and formed ties with an appreciation for the social networks connecting them, whereas others myopically focused on one potential partner at a time. In technology battles fought by many heterogeneous competitors, ideal networking strategies might be employed to different degrees and could explain variation in the performance of competitors that are alike in other ways.

Conclusion

While there is little disagreement that sponsors of new technologies need to enlist the support of others, less attention has been focused on whether sponsors form ties to leverage the social networks that connect potential adopters. In conjunction with emerging work on technology diffusion and contagion, our study suggests that further attention to the distinction between complex and simple contagion and their implications for technology battles is warranted. Future research could extend our understanding of technology battles and social networks by investigating how endogenous forces that shape tie formation within networks combine with the actions of sponsors that are exogenous to those networks to simultaneously affect the dynamics of contagion and the evolving structure of the network.

Acknowledgments

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Appendix A Method for Establishing the Risk Set and Boundaries of the Potential Adopter Network

Figure A.1 Inclusion Criteria

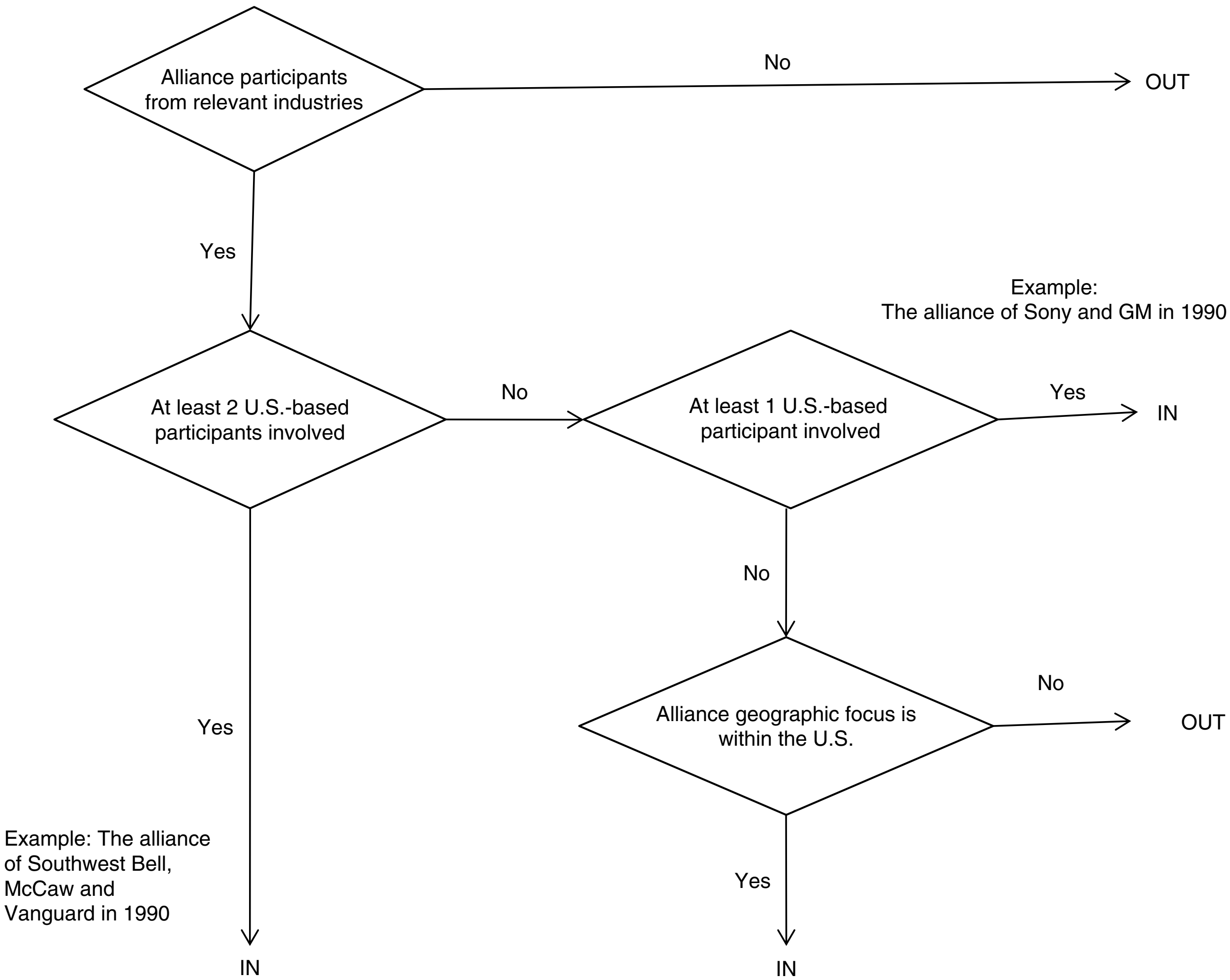


Table A.1 Main Industries for Included Firms

Category	SIC	Frequency	Percentage (%)
Equipment manufacturer	3663	284	39.2
Equipment manufacturer	3661	33	4.6
Equipment manufacturer	3674	31	4.3
Equipment manufacturer	3577	18	2.5
Equipment manufacturer	3679	17	2.3
Equipment manufacturer	3571	13	1.8
Equipment manufacturer	3669	12	1.7
Equipment manufacturer	3575	4	0.6
Phone company	4812	47	6.5
Phone company	4813	45	6.2
Maker of complementary products for end users	7372	33	4.6
Maker of complementary products for end users	3651	12	1.7
Maker of complementary products for end users	7375	5	0.7
Maker of complementary products for phone companies	4899	16	2.2
Maker of complementary products for phone companies	7373	9	1.2
Maker of complementary products for phone companies	7376	2	0.3
Others	5045, 7371, 3825, 5065, 3812, 4832, 4841, 3823, 3312, 3714, 3721, 3873	143	19.8
Total		724	100.0

Appendix B

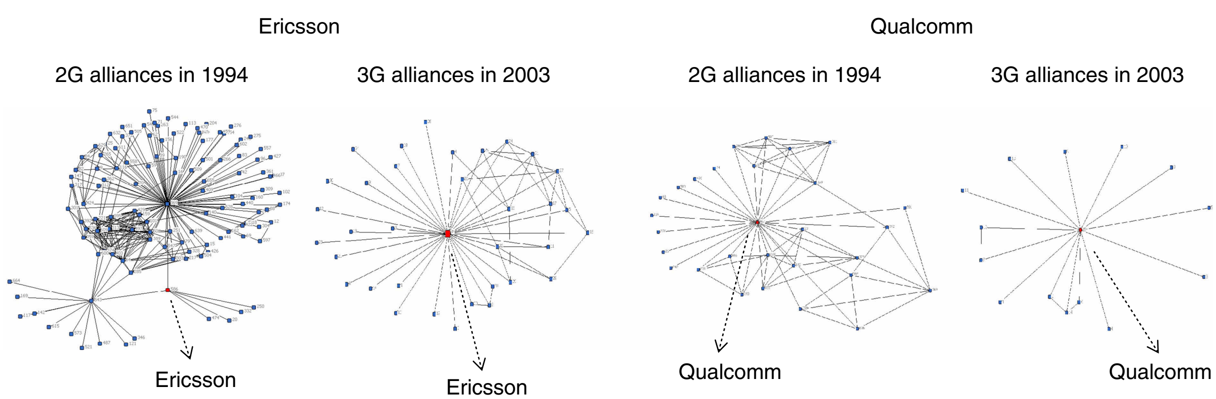
Table B.2 Multinomial Logit Analyses Predicting Candidates' Partnership Choices Among Ericsson, Qualcomm, and No Partnership ("No Partnership" Is the Baseline Model for Interpreting the Coefficients)

	Model 1				Model 2			
	Ericsson		Qualcomm		Ericsson		Qualcomm	
Public	0.919		1.719	***	0.878		1.725	***
Firm patent stock	0.179		0.163	+	0.172		0.173	*
Firm patents–CDMA	0.057	**	0.063	***	0.055	**	0.057	**
Firm patents–TDMA	−0.065	**	−0.070	***	−0.056	**	−0.057	***
Equipment manufacturer	0.197		0.798		0.191		0.802	
Phone company	1.780		0.621		1.462		0.601	
Complement maker for end users	1.167		1.477	**	1.345		1.554	**
Common geographic region_Q	13.105	***	−0.104		12.495	***	−0.232	
Common geographic region_E	14.324	***	1.398		13.748	***	1.248	
Prior tie	−1.262		1.624	+	−1.258		1.706	+
Isolate	4.733	**	3.962	***	4.769	**	3.764	**
Network cohesion	−2.914	+	−2.159	***	−2.487		−1.791	***
Indirect ties with Ericsson	0.349		−0.036	**	0.770		0.131	
Indirect ties with Qualcomm	0.809		1.029	**	−0.095		0.460	
Network centralization	−15.098		−1.281		−7.989		3.023	
Network density	80.692		80.884	**	89.663		94.084	*
2G *License catch-up* (*Ratio of CDMA to TDMA*)	30.802	**	12.233	*	19.427	*	4.418	
Indirect ties with Qualcomm × 2G *License catch-up*	−14.632	*	−9.066	*				
Indirect ties with Ericsson × 2G License catch-up					3.349		1.824	
Pseudo-likelihood	-150.53				-158.19			
Pseudo-R^2	0.485				0.459			

Note. The analysis is based on 724 firm observations.
$^+p < 0.10$; $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Appendix C

Figure C.1 (Color online) Comparison of Sponsor Alliance Formation in 2G vs. 3G; Qualcomm's 2G Technology Was Unproven and Ericsson's 3G Technology Was Unproven (Sponsors Are Shown in Red)



Endnotes

[1]Institutional logics are socially constructed practices, assumptions, values, beliefs, and rules, such as evaluative criteria and routines (Thornton et al. 2012).

[2]The idea that sponsors might strategically build alliance networks to establish their technology as the standard has been raised in a few prior studies (e.g., Chen and Hwang 2008, Soh 2010), but authors have not specifically examined partner network position or stage of technology development as the reason a sponsor might choose them.

[3]This stage of the technology life cycle is characterized by continued product development and intense product feature competition (Tushman and Anderson 1986, Suarez 2004), and it culminates in a set of design features that best satisfies the needs of the majority of the market (Adner 2002, Murmann and Frenken 2006). Standards battles exhibit all the patterns of design competition, as competing standards are substitutable for one another, while emphasizing different performance dimensions.

[4]For example, TDMA and CDMA were variants of the digital discontinuity in wireless communications.

[5]Ericsson introduced two variants of its TDMA technology into the U.S. battle: the IS-54 standard, issued in 1991, and the PCS-1900 standard, issued in 1995. The fundamental difference between Qualcomm's and Ericsson's technologies was in their approaches to sharing the spectrum between calls—time division or code division—so for simplicity we refer to Ericsson's technology as TDMA and Qualcomm's as CDMA.

[6]In contrast, in 2012 there were 139 million landlines and 310 million cellular phones in use. The ratio of cellular to landline use has, thus, gone from 0.3% to 66% as the technology has moved from analog through multiple digital generations (The World Bank 2016a, b).

[7]Up to 75% of all 1G cell phones were not actively used, since it was too expensive to make and receive calls. At the same time, there were congestion problems in dense urban areas since bandwidth was inefficiently used. As a consequence, phone companies were very focused on fixed investments as well as call capacity (Calhoun 1988).

[8]Representative quotes include the following: "In early 1989, when he [Irwin Jacobs, cofounder and then CEO of Qualcomm] first approached phone companies to pitch CDMA, no Las Vegas bookie would have given Qualcomm any odds of success. AT&T, Motorola, and others had already opted for the so-called TDMA (time division multiple access) digital standard" (Nee and Chen 2000). "Many are not convinced, saying the time-to-market issue simply precludes CDMA from having an impact." "CDMA will not be in commercial phase for a long time," says Dalenstam. "Our guess is you will not have commercial systems available for two to three years from today" (Vittore 1995). Doubts about CDMA persisted through the end of the 2G battle. Quotes like this one appeared in the media worldwide: "Industry insiders are concerned about the choice of CDMA (Code Division Multiple Access) as a replacement for Australia's analog (AMPS) network, considering it a largely unproven technology. Telecommunications analyst Paul Budde said that CDMA had been unsuccessful in parts of the world. 'Singapore and Thailand both launched it and then put it on the backburner because of poor voice quality, while Hong Kong had problems with voice dropouts,' he said. While CDMA networks do exist in Korea and North America, it is estimated there are only 18 million users worldwide, compared with more than 100 million GSM users" (Amjadalia 1999).

[9]For instance, if what is being spread is a disease, then biological mechanisms are at work, whereas cultural artifacts or attitudes may require affective and sociological mechanisms for their transmission. Simple information may be passed along via brief encounters, whereas complex information may require intensive, repetitive interchange.

[10]Clusters refer to groups of actors that are more densely connected to one another than to other members of a network (Rosenkopf and Padula 2008). However, simple contagion could also be activated through direct ties to cliques, defined as four or more actors, each connected to every other actor (Kilduff and Tsai 2003). Since clique members are densely connected, a sponsor requires only one tie to a clique for peer-to-peer diffusion. Similarly, a sponsor could target bridges that connect cliques or clusters, or actors that are high in betweenness or closeness centrality, to activate simple contagion through peer to peer contact. In each case, the sponsor requires very few ties to activate many potential adopters.

[11]The name of this standard is IS-54, and it is also known as D-AMPS. A higher capacity version, IS-136, was approved in 1994. In addition to TIA's endorsement of TDMA, GSM, which was also based on TDMA, was selected as the European 2G standard by the Groupe Special Mobile committee in 1987 and formally published in 1990.

[12]The name of this standard is IS-95, and it is also known as cdmaOne.

[13]The predominant 1G wireless analog phone system in the United States was AMPS, and it used frequency division multiple access (FDMA) to share the radio frequency spectrum among calls. FDMA shared the radio spectrum by assigning calls to separate radio frequencies, which were dedicated to a single user. TDMA was a component of the 2G digital wireless systems IS-54 and IS-136, which were also widely known as D-AMPS (digital AMPS). TDMA split each of those frequency channels into multiple time slots, which allowed users to take turns using a channel, and it could be layered on top of FDMA. CDMA allocated unique codes to each user, so that each frequency channel was simultaneously shared among multiple users.

[14]The main reason for avoiding roaming was the fee structure for making phone calls, with not just outgoing but also incoming calls being charged for, making customers very price sensitive and careful with where they used their phones (Bekkers 2001).

[15]Initial formulations of the TDMA and CDMA standards were updated during the 2G cycle, increasing technical performance on key metrics such as call capacity. The 3G shift in 2001 was regarded as a second discontinuity by some (e.g., Leiponen 2008), but here Ericsson and Qualcomm reversed roles. Qualcomm's 3G offering, cdma2000, was a relatively straightforward extension of its 2G technology, whereas Ericsson's CDMA-based alternative, W-CDMA, was very different from its TDMA-based 2G technologies. The sponsors faced a great deal of uncertainty about the market demand for 3G digital data services (Tilson and Lyytinen 2006), until about 2007 when the iPhone was introduced. The 3G battle began with Qualcomm's cdma2000 about four years ahead of Ericsson's W-CDMA both in terms of technological development and commercial deployment (Weiss 2015).

[16]The risk set was carefully constructed to contain potential adopters with an interest in supplying or using wireless technology in the United States. We researched all companies that we considered with respect to industry membership and we also read the deal contents of thousands of alliances to assure that we captured firms with clear relevance to the 2G battle in the U.S. market. Nonwireless SIC codes stand for prepackaged software, household audio/video equipment, information retrieval systems, computer services, computer integrated systems design, and computer facilities management systems.

[17]The IV is set to 0 when a potential partner is not in a clique. This partner could be in a triad (with only three firms) or could be an isolate. We set an isolate/triad's value to 0 and instead control for whether the firm is an isolate or in a triad to not spuriously overestimate the effect of peer-to-peer connection on alliance likelihood.

[18]TDMA-specific classes are H04B7/2643, H04B7/2046, H04B7/212, H04B7/2643, H04B7/2671, and H04B2215/061. Mixed TDMA/FDM classes are H04B7/2043 and H04B7/2615. CDMA-specific classes are H04B1/707, H04B1/216, H04B1/2628, H04B1/2668, H04B2201/70719, and H04B2201/70726. Class H04B7/2618 is for patents pertinent to both TDMA and CDMA.

[19]There is entry and exit in the risk set throughout this time period, and the number of cliques present in the adopter networks varied from year to year as follows: 1990, 2; 1991, 5; 1992, 9; 1993, 17; 1994, 29; 1995, 30; 1996, 16; 1997, 12; 1998, 11; 1999, 13; 2000, 15.

[20]Homophily refers to the propensity to form ties with similar others, whereas consolidation refers to the correlation between actors' positions in the multiple domains in which they might meet other members of a population.

[21]In this case, the first to build the larger install base may gain an insurmountable lead, since install base drives a substantial component of a technology's value to adopters, either through direct communication benefits or indirect complement benefits (Arthur 1989).

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