Journal of Information Technology (2009) 00, 1–16
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palgrave-journals.com/jit/

Research article

Visualization of interfirm relations in a converging mobile ecosystem

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Abstract

The mobile ecosystem is characterized by a large and complex network of companies interacting with each other, directly and indirectly, to provide a broad array of mobile products and services to end-customers. With the convergence of enabling technologies, the complexity of the mobile ecosystem is increasing multifold as new actors are emerging, new relations are formed, and the traditional distribution of power is shifted. Drawing on theories of network science, complex systems, interfirm relationships, and the creative art and science of visualization, this paper identifies key players and maps the complex structure and dynamics of nearly 7000 global companies and over 18,000 relationships in the converging mobile ecosystem. Our approach enables decision makers to (i) visually explore the complexity of interfirm relations in the mobile ecosystem, (ii) discover the relation between current and emerging segments, (iii) determine the impact of convergence on ecosystem structure, (iv) understand a firm's competitive position, and (v) identify interfirm relation patterns that may influence their choice of innovation strategy or business models.

Journal of Information Technology advance online publication, 24 February 2009; doi:10.1057/jit.2008.34

Keywords: mobile ecosystem; innovation; convergence; network analysis; visualization

Introduction

The mobile industry is in an era of tremendous change. Driven by innovations in enabling technologies, increasing consumer and enterprise demand, and the promises of convergence, firms are racing to create and deliver compelling mobile products and services, vying to generate significant revenue streams and capture a piece of this lucrative market. This is pursued through collaboration and coordination in a large, complex network of firms.

Convergence has increased the complexity of this network multifold as firms in traditionally separate industries (e.g. cable, Internet, gaming, media and entertainment) are now also entering the market and offering integrated and complementary products and services. This has led to firms facing competition not only within their market, but also against firms beyond the traditional market boundaries. In addition, firms must cope with changing customer expectations, the pressure to innovate, technological evolution, regulatory influences, and global competition. It has also led to the formation of new partnerships and alliances, mergers and acquisitions, and emergence of new actors. Indisputably, these dynamics have created significant challenges and much uncertainty about the survival and success of firms, the identification of key catalysts, and the resulting market structure.

The confluence of these factors has direct implications on strategies and business models as well. The observation that value is created and delivered through a complex network of firms requires new strategic thinking. Previous research suggests that firms in complex value networks must carefully orchestrate interfirm relationships, maintain and develop core competencies, and develop business models that take network position and network value creation and delivery into account (Chesbrough, 2003; Dhanaraj and Parkhe, 2006; Klein and Poulymenakou, 2006; Möller and Rajala, 2007). Indeed, business models must move beyond the individual firm and consider the complex network of actors involved. Chesbrough (2006) supports this argument by stating that two key functions of business models include (i) defining the structure of the value chain required to create and distribute the offering and (ii) describing the firm's position in the overall value network.

The objective of this study is to use network visualization techniques to portray the complexity of interfirm relationships in a converging mobile ecosystem and provide both theoretical and practical insights to the structure, dynamics, and potential evolution of this network. In particular, this study examines the structure of the entire ecosystem, rather than the conventional focus on a partial set of players (e.g. Rosenkopf and Padula, 2008). In addition to examining firm-level relations, this study also explores relations between current and emerging segments of the mobile ecosystem.

In doing so, this study aims to discover the impact of convergence (technology, product, and service) on the mobile ecosystem and identify key players, segments, and their roles. Consequently, our study provides a deeper visual understanding of strategic relations that have been formed and offers a basis for identifying future interfirm innovation opportunities in a converging mobile ecosystem.

Since visualization is both an art and science, this paper draws on a broad range of disciplines, including information visualization, graph theoretical mathematics, cognitive science, complex systems, strategic management, marketing, industrial ecology, social network theory, and innovation.

The remainder of the paper proceeds as follows. The next section briefly reviews the theoretical background and describes the current mobile ecosystem and the converging forces acting upon it. The following section reviews the art and science of visualization and identifies measures of interest for business ecosystem analysis. The subsequent section follows with a description of the research method and the penultimate section provides analysis and results. The final section concludes with an overview of our contributions, the limitations of the study, and recommendations for future research.

Theoretical foundation

Interfirm relationships and collaboration

The literature on the creation, management, and performance of interfirm relationships is extensive (Oliver, 1990; Anderson *et al*., 1994; Gulati *et al*., 2000). Interfirm relationships come in numerous forms, including alliances, partnerships, joint ventures, consortia, supply agreements, technology licensing, manufacturing collaborations, and marketing agreements (Nohria and Garcia-Pont, 1991; Podolny and Page, 1998). Firms establish interfirm relationships within and across industries for a variety of reasons (Oliver, 1990; Gulati *et al*., 2000).

These reasons can be broadly explained by three theoretical perspectives, namely transaction costs (Williamson, 1981), resources dependency (Pfeffer and Nowak, 1976), and organizational learning (Levitt and March, 1988). Gulati (1998), for example, argues that firms enter alliances to reduce transaction costs, enhance their competitive position or market power, and to gain organizational knowledge. Parise and Henderson (2001) suggest that interfirm relations with suppliers and customers leads to tighter integration, consequently resulting in reduced cost, improved efficiencies, and improved quality for the focal firm.

Since many firms are constrained by technological, political, and cognitive limits, a resource exchange view suggests that firms will establish interfirm relations when one firm has resources or capacities beneficial to, but not possessed by, another firm (e.g. Dyer and Singh, 1998). Indeed, necessity and resource dependence are often the most commonly cited reasons why firms enter interfirm relations (Ross and Robertson, 2007). This is particularly the case for firms that provide complex products and services; in many instances they are often dependent on numerous complementary resources (Basole and Rouse, 2008).

Institutional pressures or regulatory requirements can also lead firms to enter interfirm relationships. In many instances, firms enter into reciprocal relationships, which emphasize collaboration and coordination, enabling firms to share and leverage complementary resources as well as pursue new markets and activities (Oliver, 1990). Particularly in a converging mobile ecosystem, cooperating with complementary firms is critical in gaining access to new information, technologies, and markets.

Interfirm relationships also have the ability to reduce environmental uncertainty, caused by resource scarcity and imperfect knowledge of market and competitor behavior (Pfeffer and Nowak, 1976). Thus, by forming interfirm relationships firms can absorb uncertainty more effectively and in turn create more operational and strategic stability. This is particularly evident in dynamic and technology-driven industries, such as the mobile industry, where high level of competitiveness and short innovation cycles often place firms into vulnerable positions (Eisenhardt and Schoonhoven, 1996)

Although many interfirm relationships are based on direct ties, many of the aforementioned benefits can also be gained through indirect ties (Ahuja, 2000). In his seminal work, Granovetter (1973) argued that weak tie relations give firms greater access to new information and opportunities. Subsequent studies have shown that indirect relations can serve as bridges to information and resources unavailable in the immediate circle of an actor and thus form a vital source of social capital (Burt, 2005). Since individual firms in the mobile ecosystem can pursue only limited number of technologies and lines of research, indirect ties have the ability of enhancing a firm's access to potentially valuable information, knowledge, and resources.

Interorganizational network analysis

Although past interfirm research has largely tended to adopt a dyadic or triadic perspective to relationships (Fombrun, 1982), there has been an increasing interest in understanding interfirm relationships at the network level (Barringer and Harrison, 2000; Borgatti and Foster, 2003; Amaral and Uzzi, 2007; Möller and Rajala, 2007; Rouse, 2007). The shift towards network thinking gained particular traction with the realization that firms do not operate in a vacuum and that they are embedded in a large complex system of actors (Granovetter, 1985; Gulati *et al*., 2000). Porter's model of a value chain (Porter, 1985) thus evolved into the conceptualization of value networks, or value webs, where there are no clear linear flows of tangible and intangible entities and many direct and indirect interfirm relationships exist (Moore, 1993; Håkansson and Snehota, 1995; Allee, 2000; Iansiti and Levien, 2004a; Möller and Rajala, 2007). The idea of value networks has been applied to study numerous contexts, including product, service, innovation, and knowledge flow (Strogatz, 2001; Iansiti and Levien, 2004a). Indeed, virtually all products and services are created and delivered by a complex networked system (Basole and Rouse, 2008).

As a result, there are a growing number of studies investigating how strategic alliances, partnerships, and collaborations are formed in a network context and what impact network formation, structure, and participation have on firm performance, innovation, and market evolution (Gulati, 1998; Ahuja, 2000; Gnyawali and Madhavan, 2001; Dhanaraj and Parkhe, 2006; Schilling and Phelps, 2007). Most of these studies tend to have a foundation in the theories of transaction cost economics (Parkhe, 1993; Dyer, 1997), resource dependence (Eisenhardt and Schoonhoven, 1996; Das *et al*., 1998), stakeholder theory of the firm (Jarillo, 1988), agency theory (Eisenhardt, 1989), organizational learning (Hamel, 1991; Gulati and Gargiulo, 1999), actor-network theory, (Latour, 2005) and institutional theory (Galaskiewicz and Wasserman, 1989).

A common research method employed to study these issues is network analysis (Wasserman and Faust, 1994). Although a complete review of the literature is beyond the scope of this paper, it is important to note that network analysis has been applied to study several interorganizational issues in a variety of contexts. For a more comprehensive review of the literature, readers are referred to Barringer and Harrison (2000), Borgatti and Foster (2003), and Provan *et al*. (2007).

Illustrative issues include the examination of social capital (e.g., Tsai and Ghoshal, 1998), leadership (Balkundi and Kilduff, 2006), knowledge transfer (e.g. Tsai, 2001; Reagans and McEvily, 2003; Owen-Smith and Powell, 2004; Bell and Zaheer, 2007), innovation and collaboration (Powell *et al*., 1996; Ahuja, 2000; Dhanaraj and Parkhe, 2006; Cowan *et al*., 2007; Fleming *et al*., 2007; Schilling and Phelps, 2007), influence of position and environmental change on firm performance (Koka and Prescott, 2008), and evolution and transformation of interfirm networks (e.g. Venkatraman and Lee, 2004; Kim *et al*., 2006; Rosenkopf and Padula, 2008). Study contexts include competition in the biotechnology industry (Powell *et al*., 1996) and the semiconductor industry (Podolny *et al*., 1996), structure of the corporate elite in Germany (Kogut and Walker, 2001), innovation in the software industry (Iyer *et al*., 2006), and configurations of global manufacturing networks (Vereecke *et al*., 2006).

Kilduff *et al*. (2006) identifies several core ideas in this stream of research: the importance of relations between organizational actors (e.g. individuals, groups, business units, firms), the embeddedness of organizational actors in network contexts (e.g. Granovetter, 1985; Uzzi, 1997), the social utility of network relations, and the emergence of structural patterns. Based on this observation, network analysis thus shifts conventional social science research focused on atomistic explanations toward a more 'relational, contextual and systematic' understanding of organizations (Borgatti and Foster, 2003). Consequently, it has been argued that there are three broad foci of organizational network research, namely (i) structural configuration of the organizational network itself, (ii) characteristics of individual actors in the network, and (iii) antecedents, consequences, and outcomes of structure and actor interaction (Provan *et al*., 2007).

Business ecosystems as complex adaptive systems

Our broader understanding of the structure and dynamics of interfirm networks draws from a variety of fields. In particular, it has been argued that networks studied in biology and other natural sciences provide an appropriate frame of reference and useful terminology for understanding business networks (Rothschild, 1990; Moore, 1996; Peltoniemi, 2006).

In particular, it has been suggested that a biological ecosystem is a 'powerful analogy for understanding business networks' (Iansiti and Levien, 2004b). The traditional notion of a biological ecosystem describes an environment in which numerous different species coexist, influence each other, and are affected by various external forces. Within this ecosystem, the evolution of one species affects and is affected by the evolution of other species. Key phenomena observed in nature, such as 'competition, cooperation, specialization, exploitation, learning, growth, and others,' are also central to activities in economies (Rothschild, 1990) and interfirm networks (Gossain and Kandiah, 1998; Iansiti and Levien, 2004a). Applied to the organizational context, business ecosystems are thus complex networked systems in which a variety of firms coexist and interdependent and symbiotic relationships are formed (Moore, 1996).

Using the tremendous advances gained through the study of networks in biology and physics, an ecosystem perspective of interfirm network structure and dynamics thus adds an additional useful lens to our traditional thinking of economic organization (Moore, 2006).

In business ecosystems, firms compete and cooperate at the same time, or engage in co-opetition (Brandenburger and Nalebuff, 1997), as they have a mutual interest in defending, developing, and growing the ecosystem (Moore, 1996).

A key characteristic of an ecosystem is its ability to continuously adapt and evolve to changes inside and outside of it. Rouse (2007) provides an additional explanation that complex systems are dynamic entities that self-organize, adapt and evolve, often with emergent behavior. Weisbuch (1991) defines a complex system as a 'system composed of a large number of different interacting elements.' Social and economic systems, such as organizations, markets, and industries are also composed of different interacting elements. It is this combination of observations that has led to a growing recognition that organizations – the interfirm networks they are part of and the business ecosystem they are embedded in – should indeed be viewed and modeled as complex adaptive systems (Kilduff *et al*., 2006).

Similar to a biological ecosystem, participants in a business ecosystem are not all created equal and do not necessarily pursue the same strategies. Iansiti and Levien (2004a) identified three types of behaviors among species, namely keystone players, dominators, and niche players, which are useful in understanding the strategies and positioning of participants in business ecosystems.

Keystone players are active leaders in the ecosystem and tend to actively improve the overall health of the ecosystem. They maintain a low physical presence and are generally more effective at both creating and sharing value across the system through platforms. Keystones tend to assume roles of hubs in the network; they are the 'most richly connected' and often lie at the network's core.

However, any firm occupying a hub in a business ecosystem, often faces temptations to exploit their position for short-term gain. This is often characteristic of a dominator, or hub landlord, strategy. Dominators are firms that have strong physical presence and control a large part of their networks. They take most of the value for themselves and leave little for other companies in the ecosystem. In mature industries, where little innovation takes places and change is slow, dominators can have a beneficial effect. In emerging industries, this behavior can be highly destructive as it limits innovation.

Niche players constitute the largest group in any ecosystem. They are non-dominant, large, and small, companies that specialize in specific capabilities to differentiate themselves from others in the ecosystem. Niche players collectively create much of the value in a niche and generally capture the value they create. Their growth depends on their ability to leverage keystone platforms and to maintain a level of differentiation.

It should be pointed out, however, that there are also some differences between natural and business ecosystems. Moore (1996) posits that actors in the business ecosystem make conscious choices by understanding the situation and contemplating outcomes; business ecosystem actors are thus intelligent agents capable of planning and seeing the future (Iansiti and Levien, 2004a). Iansiti and Levien (2004a) further point out that ecosystems compete over members. Lastly, business ecosystems aim to deliver innovations, whereas natural ecosystems aim for survival.

The mobile ecosystem

The metaphor of a business ecosystem is particularly applicable to the mobile industry. There are several recent studies that have adopted the ecosystem perspective in the mobile industry context (Li and Whalley, 2002; Maitland *et al*., 2002; Tilson and Lyytinen, 2005; Tilson and Lyytinen, 2006). Some have examined the role of specific players in the industry, such as network operators (Peppard and Rylander, 2006) and device manufacturers (Dittrich and Duysters, 2007). Others have focused on the products and services created in the mobile ecosystem, such as mobile marketing (Becker, 2005), mobile multimedia (Balaji *et al*., 2005), mobile content (Peppard and Rylander, 2006), and mobile business (Coursaris *et al*., 2006).

Taken as a whole, these studies suggest that the mobile ecosystem consists of a variety of firms from numerous enabling and supporting segments – including, but not limited to, network operators, device manufacturers, infrastructure providers, silicon vendors, platform providers, content providers, system integrators, software providers, and application developers – and consumers that essentially use the products and services (Basole and Rouse, 2008). We suggest that there are both incumbent (i.e. currently existing) and emerging segments in the mobile ecosystem (see Figure 1). Light-grey spheres depict players in existing (current) segments; dark-grey spheres depict emerging segments in the mobile ecosystem.

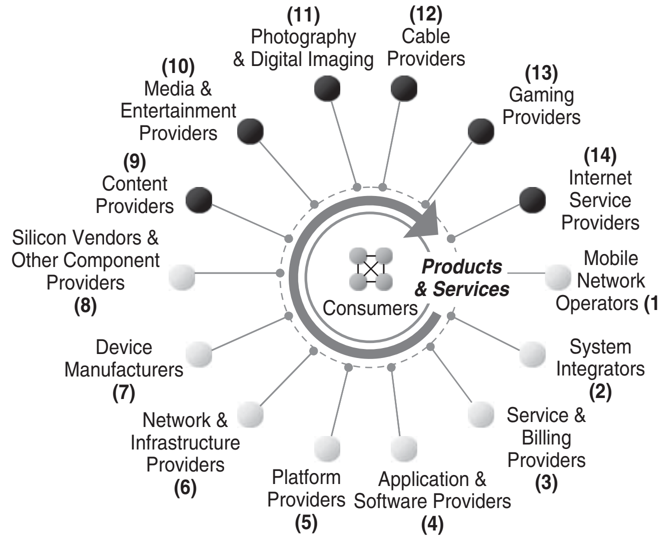

Figure 1 Segments in converging mobile ecosystem.

Both Apple and Google, for example, recently revealed their interest in participating in the mobile ecosystem. In 2007, Apple released the innovative iPhone, which sent shockwaves through the entire mobile device community. Google released a portfolio of mobile applications, announced its upcoming bid for wireless spectrum, and was the driving founder of Android, an open alliance of heavyweights in the mobile handheld industry. Many cable companies are entering the mobile space by offering quad-play services to compete with mobile carriers and Internet providers. This has led to a slew of reactions from traditional mobile ecosystem players. Nokia, for instance, is radically changing its business strategy, by transforming from a device manufacturer to a software services company. It also acquired the mobile operating system company Symbian, only to convert into an open source foundation. Mobile network operators, such as Verizon, are partnering with software companies and content providers to deliver more compelling applications to consumers. Other examples are plentiful. This has resulted in many firms reassessing their position in the mobile ecosystem, transforming their competitive strategy, and often entering new alliances and partnerships in order to prepare themselves for an uncertain future.

So, what is keeping the mobile ecosystem from realizing its potential? Undoubtedly, firms in each of the domains are facing numerous challenges and questions. It is also clear that a keystone player has yet to emerge in the mobile ecosystem. What player or segment will become the catalyst, align interests and incentives of multiple stakeholders and ignite the market? (Evans and Schmalensee, 2007). Will it be an operator, like NTT DoCoMo in Japan with its i-Mode platform, or a handset manufacturer like Nokia or Apple? Will a software platform provider become a keystone? Or will it be a content or advertising provider like Google or Yahoo? Whenever a catalyst does emerge, however, the structure and dynamics of interfirm relations in the mobile ecosystem will be vastly different than in its current shape and form. Using the business ecosystem as a complex adaptive system framework, we aim to describe and explore the current and emerging structure and potentially identify various player types in the mobile ecosystem.

The art and science of visualization

It is a common misperception that visualizations are merely artistic renderings, creative outputs, and metaphors for structure (Wellman, 1988). On the contrary, although visualizations resemble art, the scientific community has long recognized the benefits of it in data exploration, interpretation, and communication (Tufte, 1983; Meyer, 1991; Becker *et al.*, 1995; Johnson *et al.*, 2006). Visualization has enabled researchers to see the 'unseen' and identify hidden information inside data. Visualization aids humans in overcoming their cognitive limitations and make structure, patterns, relationships, and themes apparent from the underlying data (Moody *et al.*, 2005). It can be used as both an exploratory and communication tool to make sense of complex data (Tufte, 1990). Multiple representations of the same data, for example, provide an efficient means for comparisons. Visualization has been identified as an essential step in the scientific process of moving from data to knowledge (Johnson *et al.*, 2006). Indeed, visualization has led to significant advances in medicine, dentistry, computer science, and engineering. Early examples of complex visualizations included maps, cartograms, and charts (Tufte, 1990); today, powerful computing tools have enabled visualization of food webs, telecommunication networks, citation networks, crime networks, electric grids, flow of intellectual property, the Internet, and genetic networks (Bornholdt and Schuster, 2003; Newman, 2003; Johnson *et al.*, 2006). For a more comprehensive list of complex visualizations, readers are referred to visualcomplexity.com (Lima, 2008).

In contrast to the numerous applications in the natural and physical sciences, the use of visualization in the organization, social, and management sciences has been comparatively small (Meyer, 1991; Markham, 1998; Rosenkopf and Schilling, 2008). It should be emphasized that the author specifically refers to visualization of relational, or network, data. The author acknowledges that methods, such as multidimensional scaling, principal component analysis, block modeling, or correspondence analysis are alternate methods to explore and represent relational data and have been used extensively in the organizational, social, and management sciences. The majority of studies have visualized relations at the interpersonal (e.g Cross *et al.*, 2002; Fleming *et al.*, 2007) visualization of interfirm relations, particularly alliances, in whole networks have been scarce (Provan *et al.*, 2007; Rosenkopf and Schilling, 2008). Notable exceptions include recent work by (Iyer *et al.*, 2006; Lomi and Pattison, 2006; Schilling and Phelps, 2007; Rosenkopf and Padula, 2008; Rosenkopf and Schilling, 2008).

This is surprising because complex and large networks are abundant in economies, markets, firms, and societies and some prominent researchers have argued that visualization approaches can be extremely valuable for business strategy (Kaplan and Norton, 2000), scenario planning (Anthony *et al.*, 1993), and problem solving (Tufte, 1983).

Some argue visual depictions of interfirm network structures are rare because researchers prefer to solely rely on reporting summary network statistics or focus on specific, micro-aspects of networks (Rosenkopf and Schilling, 2008). An alternate explanation may be that visualization of complex systems not only is a very challenging and difficult task, but it also can lead to non-conclusive results if not implemented appropriately. Particularly in visualizing complex organizational systems, network sizes can be very large, configurations are not necessarily unique, clusters can be misleading, and no real inference can be drawn. The artificial choice of node inclusion and thus exclusion of potentially important linkages, or boundary-setting problem, requires conclusions to be carefully scrutinized for the possibility of alternative explanations (Fombrun, 1982). Along the same lines, the amount of information that is captured and presented can often be overwhelming to the end-user. In many instances, what and how complex network data are visualized depends not only on the nature of the data but also on the question that is being asked and ultimately the cognitive abilities of the user. In order to overcome the aforementioned challenges, researchers must therefore ensure a balance between detail, abstraction, accuracy, efficiency, perceptual tension, and aesthetics in their complex network visualizations (Eick, 1996; Shneiderman and Aris, 2006).

There are many techniques to visualize different types of data (Lohse *et al.*, 1994). Examples include multidimensional scaling, correspondence analysis, and blockmodeling. Each of these techniques has their advantages (see Wasserman and Faust, 1994); if, however, exploratory visual presentation of the actors and their direct and indirect connectivity is of importance, a node-link diagram is frequently preferred (Keller *et al.*, 2006).

Prior work in network visualizations has commonly used node-link representations as it is natural to use graph theoretical techniques to depict a network (Casti, 1995; Bornholdt and Schuster, 2003). A node represents an actor (firm, individual, object, etc.) in the network; a link is a tie between two nodes and represents any type of relation (partnership, alliance, etc.). Links can be undirected or directed, thus indicating the path of flow of tangible and intangible values, such as products, services, money, information, or knowledge.

In addition, complex networks often contain a wealth of additional node and link information. For instance, common node attributes include actor type, class, and geospatial position. Link attributes may include relationship type, strength, and length of relationship. Since this study is using complex networked system as a proxy for interfirm relationships in an ecosystem, there are also context-specific attributes of interest. For instance, although traditional node-link diagrams assume a single relation between two nodes, previous interfirm research has shown that for a pair of firms, multiple types of relationships, or compound relationships, often may exist (Ross and Robertson, 2007). A firm may therefore be a customer, supplier, partner, and competitor of another firm, all at the same time. Thus, the number of relationships is an attribute of interest in ecosystem research. Table 1 provides

Table 1 A summary of network elements

Element	*Description*
Node	Actor (firm), player, entity in the mobile ecosystem
Label	Actor name (e.g. Nokia, T-Mobile, Qualcomm)
Type	Type or class of a firm (e.g. supplier, partner, competitor)
Attribute (Class)	Industry segment (e.g. device manufacturer, silicon vendor, network operator), company size, company revenue, geospatial position (e.g. country, location)
Link	Relation (alliance, partnership, JV, buyer/supplier/customer)
Attribute (Class)	Strength of relation, type of relation, length of relation, type of value exchanged (e.g. knowledge, money, material, product, service)
Direction	Directed (e.g. flow from source to destination node), undirected

a non-exhaustive summary of relevant network elements and their attributes that should be considered when visualizing interfirm ecosystems.

The goal of visualization algorithms is to layout node-link diagrams as fast and effectively as possible (Eick, 1996; Herman *et al*., 2000). Visualization programs therefore commonly provide various colors, shapes, sizes, and positions (spatial groupings) to distinguish various network elements and their relevance in complex systems. Node-link diagrams can also have various layouts to emphasize different structural properties. These include force-directed layouts, geographical maps, circular layouts, temporal layouts, clustering, layouts based on node attributes, and matrix-based layouts (Becker *et al*., 1995; Eick, 1996). In addition to the algorithmic issues of visualization, it is equally important to consider the aesthetic aspects of network visualization (Ware *et al*., 2002). Previous studies have thus experimented how varying color depth, alpha-blending techniques, and edge bundling could enhance visualization appeal and usability (Morse *et al*., 2000).

Research method

Data

This study uses a unique data set that was built by integrating two data sources, namely (i) Thomson's Financial SDC Platinum database, a source frequently used in the study of alliances and joint ventures (e.g. Anand and Khanna, 2000; Schilling and Phelps, 2007; Rosenkopf and Padula, 2008), and (ii) the Connexiti database, which gathers supplier, customer, and competitor information from public filings, company publications, annual reports, major news feeds, and financial databases.

Boundary specificity is a common problem for network studies at the inter-organizational level of analysis, in that potentially important network relationships are left out (Fombrun, 1982). Most inter-organizational studies that examine industry alliances and joint ventures use applicable NAICS categories to identify firms to be included. However, since companies in the mobile ecosystem do not come from a specific set of NAICS categories, but rather from multiple, complementary categories, system boundaries can be fuzzy. Further, a high rate of firm entry and exit in the mobile industry adds to the complexity of defining boundaries. To alleviate this problem, we decided to use an alternate approach in defining our data set.

We focused our analysis on existing and newly formed interfirm relationships for the period 2006–2008. We chose this time frame based on the observation by market research firms that convergence in the mobile ecosystem is relatively recent. The data collection process was then seeded through identification of 34 companies in existing segments of the mobile ecosystem (see Figure 1) obtained from Fortune 1000 lists, industry rankings, and leading membership association directories. However, since this study is interested in the entire converging mobile ecosystem, this list increased to 108 with the inclusion of companies from emerging segments. We verified this preliminary list with multiple industry experts to ensure that our data set included all prominent companies. A search of all alliances, joint ventures, partnerships, supply relationships, and competitors of these companies in the two data sources resulted in the identification of nearly 7000 unique, global companies and over 18,000 relationships in the mobile ecosystem. It should be noted that this list was significantly larger; however, entries were removed from further analysis if a firm had seized operations or a relationship was terminated during our study period. In the case of a merger, acquisition, or operating name change, we carefully corrected our data accordingly. Consequently, we only included active companies and working relationships in our analysis.

Since our study was primarily concerned whether a link exists from one firm to another and not with the type of relationship, multiple links between the same pair of firms were treated as one relationship. Although certain types of relationships (e.g. supply link relationships) are of directional nature, we assumed that all links are bidirectional, resulting in an undirected uni-partite graph (Newman, 2003).

In addition to company (node) and relationship (link) data, we also captured industry segment and industry segment type (e.g. current and emerging) information in the database. We included this information because we are interested in understanding how various segments in the converging mobile ecosystem related to each other. We initially assigned companies to only one industry segment; this, however, raised issues of inaccurate characterization of the ecosystem given the existence of multiple segment affiliations of companies. Indeed, many of the large companies in the mobile ecosystem tend to operate in multiple segments. For example, Nokia is known worldwide as a device manufacturer; however, it is also a leading provider of network and infrastructure equipment. Assigning Nokia to a single segment would thus not appropriately describe the role it plays in the mobile ecosystem.

One approach to address the multiple segment affiliation issue is the use of a bi-partite graph or an affiliation network (Wasserman and Faust, 1994). Although we acknowledge the merit of this approach, we opted to utilize a modified classification approach, commonly used in the corporate finance literature (Lins and Servaes, 1999). Our list of 14 segments, as shown in Figure 1, was first formed by integrating Fortune 1000 industry classifications with a comprehensive review of the practitioner literature and market research reports. Next, we identified and assigned four-digit NAICS codes to appropriate segments. In most cases, we were able to obtain unequivocal matches between NAICS codes and segments. If a segment could not be associated with a reported NAICS code, we determined the segment's NAICS code according to its business description. We then used primary and secondary four-digit NAICS codes, as reported in the Dunn and Bradstreet Million Dollar Database, to assign firms to segments. We classified firms as single-segment if at least 90% of their sales were derived from one segment. Firms were classified as multi-segment if they produced more than 10% of their sales in a secondary segment. This classification scheme follows the work by Lins and Servaes (1999). For modeling purposes, if a firm operates in multiple segments, we modeled the business units as independent firms and assumed that they are tied through a cooperative relationship. The resulting assignments confirm the classification of top companies in the mobile ecosystem as provided by Fortune 1000 industry rankings.

A similar challenge is observed when categorizing a segment as current or emerging in the converging mobile ecosystem. We assigned companies to current and emerging segments with a two-step approach. First, we computed the degree centrality of each of the previously identified 14 segments and normalized them to the maximum possible degree in the mobile ecosystem. This enabled us to examine the extent to which each segment is connected within the ecosystem. We assume that higher degree centrality scores are a result, on average, of longer and more established relationships that in turn are achieved over an extended period of time. Thus, companies in segments with lower degree centrality scores are more probable to be emerging in the ecosystem. Visual inspection of the resulting graph (see Figure 2) suggests the existence of two clusters, namely (i) current segments in the ecosystem (Segment 1–8) and (ii) emerging segments (Segment 9–14). We confirmed our assignment of segments to each of the two clusters with industry experts.

Using this classification, the consequent assignment of companies to a current or emerging segment in the converging mobile ecosystem was thus straightforward. A company was defined as current if it belonged to a current segment in the converging mobile ecosystem; likewise, a company was defined as emergent if it belonged to an emerging segment in the converging mobile ecosystem. Basic characteristics of the data set are shown in Table 2 and 3.

Visualization software and algorithm

Given the scale and complexity of our network, we decided to capture all of our data in a MySQL database to facilitate addition and modification of company, relationship, and segment affiliation information. Custom scripts were then developed to export source code from the database for use in Pajek (v. 1.22). Pajek is a general, non-commercial program, for analysis and visualization of very large and complex networks (Batagelj and Mrvar, 1998). Although other visualization programs exist, Pajek was chosen due to its available functionalities for handling large data sets and its prominence in the network visualization community.)

Several standard network layout algorithms are implemented in Pajek. For the purpose of this study, both the Kamada–Kawai (KK) (Kamada and Kawai, 1989) and Fruchterman–Reingold (FR) algorithm (Fruchterman and Reingold, 1991) were used. Both KK and FR are multi-scale layout algorithms for the aesthetic drawing of undirected graphs with straight-line edges. They are based on the idea of optimizing a balanced spring system through energy minimization. Nodes that are close will pull on each other, whereas those who are distant will push one another apart. The algorithms seek to find an optimum in which there is minimal stress on the springs connecting the whole set of nodes. The KK algorithm achieves faster convergence than

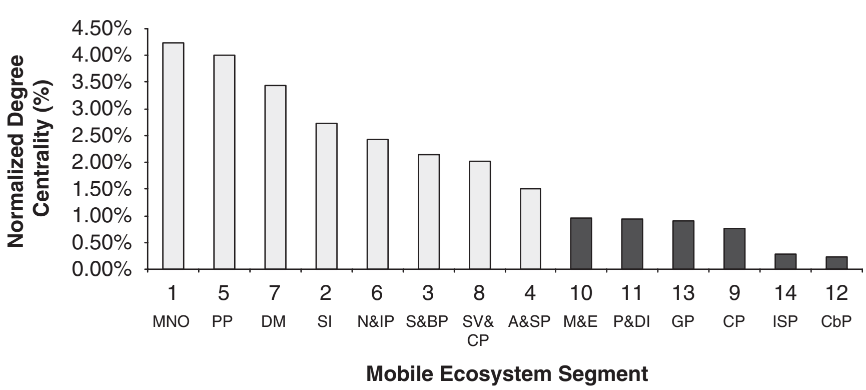

Figure 2 Normalized degree centrality of mobile ecosystem segment.

Table 2 Basic characteristics of converging mobile ecosystem

	Current segments in the mobile ecosystem (A)	*Emerging segments in the mobile ecosystem(B)*	*Converging mobile ecosystem (A+B)*
No. of firms	5873	1056	6929
No. of ties	16,585	1473	18,058
No. of segments	8	6	14

Table 3 Segment characteristics

No.	*Segment*	*No. of firms*	*Percentage of converging mobile ecosystem (%)*
1	Mobile network operators	134	1.9
2	System integrators	157	2.3
3	Service and billing provider	89	1.3
4	Application and software providers	1835	26.5
5	Platform provider	53	0.8
6	Network and infrastructure provider	2016	29.1
7	Device manufacturer	136	2.0
8	Silicon vendors and other component providers	1453	21.0
9	Content providers	579	8.4
10	Media and entertainment	108	1.6
11	Photography and digital imaging	162	2.3
12	Cable providers	34	0.5
13	Gaming providers	69	1.0
14	Internet service providers	104	1.5
	Total	6929	100

the FR algorithm and can be used to layout networks of all sizes. The advantage of the FR algorithm is that it generates an aesthetically more pleasing layout. Given the size of our network, we therefore first applied the KK algorithm to generate an approximate layout and then used the FR algorithm to create visually more attractive renderings.

Measurement of structural properties

The quantitative inquiry of structural properties of ecosystems is complementary to visualization. There are several measures drawn from graph theoretical mathematics that are useful in the description of ecosystem structures. These include network density, centrality, cutpoints, and bridges.

Network density represents the degree of interaction in an ecosystem (Meagher and Rogers, 2004). It is based on the idea that the more actors are connected to one another, the denser, or more cohesive, the ecosystem is. Network density is the proportion of all existing ties in a network over the maximum possible number of ties that could be present if the network were complete (Wasserman and Faust, 1994; Scott, 2000). It is measured as:

$$\frac{T}{n(n-1)/2} \quad (1)$$

where n is the number of actors and T is the number of existing ties in the network.

One of most common methods to understand ecosystems and their participants is to evaluate the location of actors in the network. A primary measure used to evaluate network position is the *centrality* of an actor. It has been argued that centrally located firms occupy strategic positions that enable them to have greater access to information, knowledge, and resources. This particularly applies to the context of the mobile ecosystem where potentially complementary technologies, information, products, and services are dispersed among numerous firms. Collaborations provide firms access to these resources that are difficult to obtain by other means and improve firm performance and innovation (Ilinitch *et al.*, 1996; Kale *et al.*, 2000; Kogut, 2000; Oliver, 2001).

Freeman (1979) distinguishes between three types of centrality, namely degree centrality, betweenness centrality, and closeness centrality. Of these three, the most commonly used is degree centrality. Degree centrality refers to the number of ties an actors has. Since our study assumes that the relationship between two actors does not have direction, our analysis does not distinguish between in-degree or out-degree centrality (Scott, 2000). Actors with a large degree are generally connected or adjacent to a lot of actors and should be considered a prominent location where 'value' flows. Low degree tends to characterize actors at the periphery.

However, degree centrality may be criticized because it only takes into account immediate ties an actor has, rather than indirect ties to all others. In many instances, a firm may be tied to a large number of other firms, but these others may be rather disconnected from the network as a whole.

In order to overcome this deficiency, it has been argued that closeness centrality overcomes this deficiency in that it emphasizes the 'nearness' of an actor to all others in the network by using the reciprocal of the geodesic distances (Scott, 2000). It is computed as:

$$\left[\sum_{i=1}^{n} dist(a_i, a_k)\right]^{-1} \quad (2)$$

where $dist(a_i,a_k)$ is the shortest path from actor k to actor i.

Betweenness centrality measures the extent to which actor k lies on the path 'between' the various other actors in the network: an actor of relatively low degree may play an important 'intermediary' role and so be very central in the network. The existence of such a structural hole allows the relevant actor to act as a broker (Freeman, 1979). It is measured as:

$$\sum_{i<j} \frac{g_{ij}(a_k)}{g_{ij}} \quad (3)$$

where g_{ij} is the number of geodesics that connect actors a_i and a_j *and* $g_{ij}(a_k)$ is the number of geodesics which connect a_i and a_j and contain the actor a_k.

The aforementioned centrality concepts can also be applied to the entire network. Centrality at the level of the network is commonly referred to as *centralization*, or global centrality (Scott, 2000). Similar to density, centralization provides information about the compactness of the overall structure of the network. While density indicates the overall level of network cohesion, centralization measures the degree to which an entire network is focused around a few central nodes (Wasserman and Faust, 1994). In the context of our study, network centralization thus refers to the degree to which an ecosystem is dominated by a few firms. These firms tend to assume catalysts role in the ecosystem and connect firms from different segments. If these firms are removed, the ecosystem can fragment into unconnected sub-networks. *Network centralization* is computed as

$$\frac{\sum (c_{\max} - c_i)}{\max(\sum (c_{\max} - c_i))} \quad (4)$$

where $c_{\max}$ is the maximum degree centrality of any actor in the network, and c_i is the degree centrality of actor i.

Although centrality is an important measure for network status, 'boundary spanning' characteristics are also considered critical in networks. Past research has shown that firms in structural holes, positions between actors that are not directly linked, are often influential gatekeepers and tend to enjoy both efficiency and control benefits (Burt, 1980). An actor who spans a structural hole thus benefits by brokering and controlling information, knowledge flow, and relationships between unconnected actors in a network. Thus, two other structural properties of particular interest in our study are the identification of *cutpoints* and *bridges*. An actor is considered a cutpoint if its removal results in disintegration of the network into two or more disconnected subnetworks (Wasserman and Faust, 1994). If an actor is a cutpoint, it is considered to play a brokerage role in the network (Scott, 2000). If a link between two actors is removed and results in two disconnected subgraphs, the link represents a bridge between system actors. Bridges are therefore of strategic importance in interfirm networks.

Analysis and discussion of results

The objective of this study is to gain a deeper understanding of the structure and complexity of interfirm relations in a converging mobile ecosystem. In order to achieve this objective, the data were partitioned into two sets, namely (1) all firms from current segments and (2) all firms in emerging segments of the mobile ecosystem. Together these two sets constitute the converging mobile ecosystem.

In order to visually differentiate between the elements from the two sets, various node and link colors, shapes, and sizes were used. Specifically, current segments and related firms were depicted with yellow spheres, emerging segments and related firms were depicted by blue spheres. Ties within current segments were represented by black links; ties between current and emerging segments were visualized with blue links.

Conceptually, network visualizations were generated in a 'top-down' manner by first creating a global view of the converging mobile ecosystem. In a global view, the network is shrunk by collapsing all firms within a segment into a single new vertex. This enables examination of relations between segments. Figure 2 shows the global relation between all segments. Given that some segments may consist of more firms than other segments, summation of links between two segments could construe the measure of tie strength. In order to overcome this issue, we normalized the actual number of ties with the potential number of ties between two segments. The result is normalized tie strength; the edge size is proportional to this value.

There are several key observations that stand out from the visualization. First, contrary to our intuition, there appears to be no central segment (or hub segment) in the ecosystem. Mobile network operators seem to be the most central segment in the current ecosystem, whereas platform providers seem to assume a central position in the converging mobile ecosystem. Emerging segments appear to be relatively peripheral to the rest of the ecosystem. Although the network is undirected, this representation nevertheless illustrates to a certain extent the interdependence between segments.

Second, there seems to be a strong relation between mobile network operators, network and infrastructure providers, silicon vendors and component providers, and device manufacturers. This confirms our prior knowledge that these segments tend to form the technological foundation of the mobile ecosystem. It is also no surprise that (a) mobile network operators and network and infrastructure providers and (b) device manufacturers and silicon vendor and other component providers have the strongest established ties in this foundation. Many of the new mobile devices that are emerging are highly dependent on new innovations in the component industries, such as chips, processors, screens, and power. Similarly, mobile network operators depend on network infrastructure providers to create the infrastructure needed to offer their products and services.

A third observation is the strong relationship between platform providers and application and software providers. This confirms our common understanding that developers of application and software are largely enabled and supported by the underlying platform. However, an interesting observation can be made regarding the position platform providers assume relative to current and emerging segments. The ties between platform providers and firms in the technological foundation of the ecosystem (e.g. mobile network operators, device manufacturers) are weak. On the other side, platform providers are well connected with firms in the emerging segment. This suggests that platform providers appear to take on a brokerage, or intermediary, role between current and emerging segments. Consequently, platform providers are in a prime position to become a key hub in the mobile ecosystem by driving and enabling the integration of application and software as well as content, gaming, and media and entertainment.

A fourth important observation includes the position of service and billing providers. Service and billing providers provide software systems necessary for provisioning, billing, and customer service. These backend systems enable mobile network operators, cable providers, Internet service providers, content providers, and others to monetize the products and services they offer. Service and billing providers thus form a critical core, albeit unheeded, segment in the mobile ecosystem. As technologies, content, and offerings converge, the ability to seamlessly provision and price new, bundled services becomes even more important. The relatively central position of the service and billing provider segment and its direct relations to emerging segments shown in Figure 3 confirms this argument.

To complement the visual evaluation and gain further insight into the structure of the converging mobile ecosystem, several network metrics were computed (Table 4).

The first measure is network density. Network density is the number of actual relations between firms divided by the number of possible relations. In interfirm relation networks, higher density indicates a greater degree of interaction among the firms. Network density decreases by over 10% as the mobile ecosystem converges, indicating that there are more relations in the current ecosystem than in the converging mobile ecosystem relative to network size.

Although this observation is no hard-set rule, density decrease is to be expected in an interfirm context. As

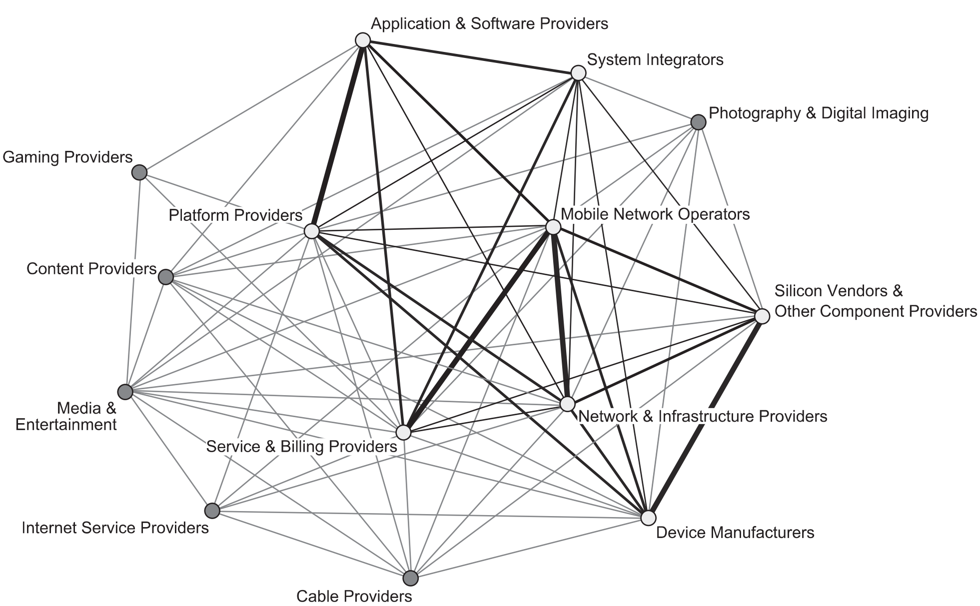

Figure 3 Relation between current and emerging segments in the converging mobile ecosystem.

Table 4 Summary of select network metrics

Metric	*Current segments in the mobile ecosystem*	*Converging mobile ecosystem*	*Change (%)*
Density	0.78572	0.70330	▼10.49
Degree centralization	0.28571	0.34615	▲21.15
Centrality: closeness	0.37500	0.46888	▲25.03
Centrality: betweenness	0.28571	0.11116	▼61.09

network size increases due to firms entering the ecosystem, network density is likely to decrease, as it becomes problematic, and in some instances not sensible, for firms to retain and create new ties with a significant proportion of ecosystem members. An alternate explanation for this observation may be due to specialization of firms as suggested by Iyer *et al.* (2006). As firms in the mobile ecosystem become increasingly specialized, due to strategic objectives, institutional pressure, or competitive forces, they become more focused in their partnering activities, which in turn reduces the overall density of the network.

Another measure of interest is network degree and betweenness centralization. Centralization identifies the most visible actor in the ecosystem. An ecosystem with high degree centralization is likely to have a few nodes with many ties and many nodes with few ties, such as a hub in a pinwheel structure. Similarly, betweenness centralization compares the observed disparity in betweenness centrality in a network (Wasserman and Faust, 1994). Low scores indicate that every firm is connected to every other firm, whereas high scores indicate that some members have many more relations than others. The centralization scores thus indicate the degree of asymmetry in the distribution of relations in the ecosystem. Since this study uses undirected relations, in- and out-degrees do not apply. Instead, the overall centralization is computed.

In this context, results show that betweenness centralization decreases significantly (61%) as the mobile ecosystem converges, suggesting that firms are more interconnected and a hub has yet to emerge. On the one hand, this observation supports the common perception that the mobile ecosystem does not have a single keystone. This could be viewed upon negatively, because industries without catalysts often grow slowly (Evans and Schmalensee, 2007). On the other hand, this can be a sign of opportunity and ecosystem stability. The lack of a single hub suggests that the mobile ecosystem is more resilient to firm changes and other disturbances, because there is no single point of failure.

To facilitate visualization and analysis, McGrath *et al.* (2003) suggest that it is appropriate to break down a large network into a representative subset. As a result, the data set was reduced to the top companies in each of the segments. This resulted in a network of 76 companies and 448 relations.

The energized drawing in Figure 4 identifies several companies, such as Nokia, Cisco, and Qualcomm, as central players in the mobile ecosystem. This result supports our prior understanding of the mobile ecosystem.

The visualization also underscores the dense structure of companies in current segments and the relatively sparse structure between companies in current and emerging segments. Intuitively, it is expected that firms in current segments have formed more established relationships among each other over time. It is, therefore, not surprising to identify a natural clustering of firm from current and emerging segments. Firms in current segments occupy a concentrated portion of the lower right quadrant of the visualization, whereas firms in emerging segments are distributed across the top half.

An interesting observation is that many of the niche players (e.g. NVIDIA) from current segments are peripherally located in the energized drawing. Similarly, we find that companies in emerging segments, with the exception of

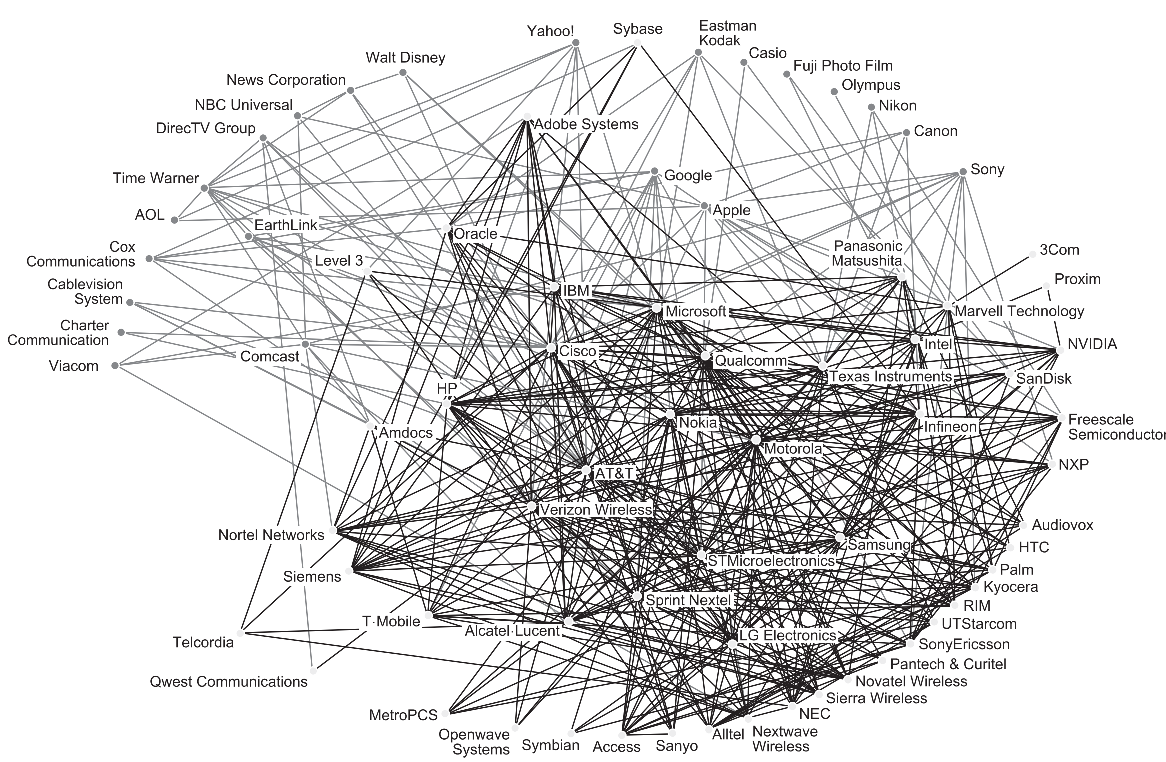

Figure 4 Firms and their relation in the converging mobile ecosystem.

Google and Apple, are peripherally located in the mobile ecosystem. This may have two potentially important implications to the evolution of the ecosystem. First, both Apple and Google are potentially well positioned to take a more central hub role in the ecosystem by providing platforms to other members and sharing the value created. The potential of becoming hub firms is further reflected by the number of ties that both firms have to companies in current and emerging segments. This conclusion supports our previous line of reasoning that platform providers may become keystones in the converging mobile ecosystem. Second, companies in emerging segments (i.e. content, gaming, and media/entertainment) are attractive candidates for new interfirm relationships. As a result, established firms in the mobile ecosystem may thus strategically evaluate and seek out emerging firms with favorable value adds.

Next, the study used a network reduction approach to obtain a contextual view of the mobile ecosystem. In a contextual view all segments are shrunk except the ones of interest. Shrinking refers to the process of collapsing all firms associated with a segment into a single node. Although each segment is worthy of further investigation, this study explores the device manufacturer segment. Rapid integration of numerous enabling technologies in mobile devices is spurring the development of numerous new applications for consumers and enterprises. Similarly, mobile network operators require innovative mobile devices to offer new products and services to their customers. The relative position of mobile device manufacturers to the other segments in the converging mobile ecosystem is therefore of great interest. Figure 5 shows a contextual view of how companies in the device manufacturer segment (depicted by squares) are related to other segments.

As expected, all of the device manufacturers are closely connected to platform providers, silicon vendors/component providers, and mobile network operators. Interestingly, however, of all firms in the device manufacturer segment, Apple tends to have the greatest and potentially closest set of relationships with emerging segments, in particular content providers, photography and digital imaging, and media and entertainment. It should be noted that Sony Ericsson also has a relatively strong tie to the media and entertainment segment, but this is primarily a consequence of its direct corporate relation with Sony Corporation. Strategically, this may be a sign of concern for other device manufacturers, such as Nokia, Motorola, or Samsung, because digital media and content is a key value-add to next-generation device adoption.

Conclusion

The mobile industry is undergoing tremendous transformation. The convergence of technologies, products, and services is creating both opportunities and challenges for existing and emerging firms. With these market dynamics in place, firms are forced to fundamentally rethink their existing strategies and business models in order to successfully prepare for an uncertain future in a complex network context. Building on theories of interfirm relationships and using the ecosystem metaphor as a new referent for strategy formation, this study visually explores the structure of the converging mobile industry. The results illustrate that the mobile ecosystem is growing and increasing in complexity rapidly.

In highly competitive environments and short product life cycle environments, such as the mobile industry, firms will have to learn to adapt to a network-centric mindset in order to compete and survive in today's global market. This

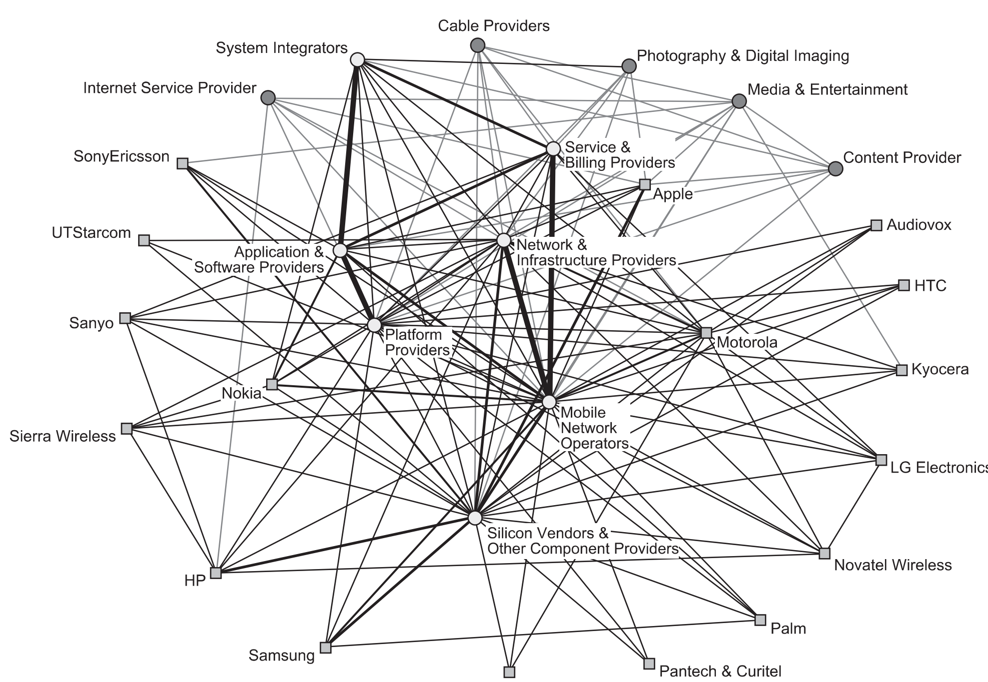

Figure 5 Contextual view of device manufacturer segment.

will also require a fundamental transformation of existing strategies and business models. Chesbrough (2003) states that an understanding of the ecosystem is critical to developing effective business models. By visualizing the structure and potential dynamics of interfirm relations of the converging mobile ecosystem, the network approach presented in this study will thus help firms construct more valuable business models.

In contrast to existing work, this study does not focus on specific segments of the mobile industry. Rather, the emphasis is on the entire mobile ecosystem. In doing so, our research provides a more comprehensive representation of interfirm relations in the mobile industry. Another key differentiation of this paper to previous studies is its analysis and evaluation of tie strength between segments, providing a valuable alternate perspective on the structure and dynamics of the converging mobile ecosystem.

The results of our study highlight that many firms in the mobile ecosystem have already started to partner and collaborate with firms from various segments for the development, manufacturing, and provision of new mobile products and services. The benefits firms often reap include flexibility, speed, innovation, and access to new markets. The approach presented in this study provides a network analysis enabled visual dashboard for understanding competitive and cooperative interactions between firms, which in turn can provide a context for strategy formation and implementation. Firms within the mobile ecosystem can use the visualizations as starting points to their strategy formation. Likewise, firms that are considering entering the mobile ecosystem can use the network depictions as means to understand the current state, structure, and development of the industry.

Along the same lines, our approach can be used to evaluate the mobile ecosystem from a single firm's perspective. For example, we could examine how a firm's direct and indirect ties influence or shape their position in the mobile ecosystem in comparison to any of their current or future competitors. As a result, the focal firm could then make an assessment on how to preserve, protect, or transform this position through potential alliances and strategic partnerships.

Using the ecosystem metaphor as a lens to analyzing and understanding the mobile industry also enables us to describe the various roles firms play. Three roles or functions appear to be of key importance (Iansiti and Levien, 2004a; Iyer *et al*., 2006): the hub (a firm or segment with a disproportionately large number of ties), the broker (a firm or segment that creates a tie between two sets of firms/segments, and the bridge (a relationship that is critical to the connectedness of the ecosystem).

Our visualizations confirm our prior understanding that device manufacturers, infrastructure providers, silicon vendors, and mobile network operators are the technological foundation of the mobile ecosystem. However, our analysis reveals that a single hub segment has yet to emerge. Although there are several firms in prime position to take on this role, the how and when is not clear. Given the highly interconnected nature of the mobile ecosystem, however, it is clear that it will take an orchestrated effort to succeed. As more firms enter the mobile ecosystem, it is evident that firms must match their innovation strategy to the ecosystem and form the right balance of relationships with a variety of players (Adner, 2006). One important finding of this study is that platform providers are in a critical brokerage position, connecting the 'incumbent' segments with the emerging segments of the mobile ecosystem. Not surprisingly, the battle for platform leadership is dynamic and fierce.

In summary, this study makes several important theoretical and practical contributions. First, it provides decision makers a means to understand their firm's competitive position in a network context. In particular, the study illustrates the application of an approach – visualization – to the study of interfirm relationships and ecosystems that has broader potential and that can complement other approaches to this and related subjects of study. Second, it illustrates the importance of relationships in the new converging ecosystem. Third, the study emphasizes the idea that business models must adapt to a network-centric thinking. In doing so, this study adds to the theoretical stream-of-thought that markets can be viewed as complex systems, consisting of various actors that coexist and coevolve to ultimately deliver a product or service to the end-customer.

Future research opportunities

Visualization of complex systems is an area of tremendous research potential in the management, organization, and decision sciences. Visualization facilitates the creative thinking process (Shneiderman, 2007) and provides a unique way to discover and communicate complex phenomenon.

Mapping interfirm relationships is an important first step to understanding patterns and structures of firms engaged in innovation and value creation. An important future research would include differentiating networks by purpose. In our study, we collapsed multiple relationships between firms into one type of tie. A comparison of interfirm networks differentiated by purpose will provide further insight into how firms compete and collaborate (Kambil, 2008).

Another potential future research direction includes the clarification of the space in which the network is mapped. In this study, our visualization space is not dimensionalized. Identifying the coordinates within this frame will provide insight in what type of space we are placing firms, what these positions mean, and consequently provide a more systematic way to understand the structure and evolutions of interfirm networks over time.

In conjunction with organizational simulation (Rouse and Boff, 2005), visualization can also provide decision makers with an immersive environment that enables experimentation of what-if scenarios as well as operational and strategic decision support, while receiving visual feedback. For example, future studies could include the comparison of different alliances, such as Windows Mobile or Android, or visualization of the actors involved in creating new mobile services. Similarly, visualization may help discover what structures and dynamics facilitate or inhibit growth of the mobile ecosystem. Along the same lines, it may help identify the most likely candidates for catalyzing the mobile ecosystem. The results in this study provide merely a step towards this vision.

There are also ample opportunities in advancing and refining visualization methods and techniques. For example, visualization of temporal aspects (e.g. pace, sequence) to represent change and evolution in ecosystem – all the while maintaining readable representations and preserving users' mental maps – is still a tremendous challenge (Tufte, 1990; Moody *et al.*, 2005). In order to generate effective representations and decision support, these hurdles must be addressed.

Limitations of the study

The results and conclusions drawn in this study should not be overstated. Like any other exploratory research, this study has a number of limitations. The accuracy of the visualization depends largely on the quality of the underlying data. Although every precaution was taken to validate the completeness and accuracy of the data, it is possible that some firms and relations were not captured. Most alliance databases, including SDC, are inherently incomplete in that they do not capture all announced alliances. Similarly, a substantial number of firms in the mobile ecosystem are not necessarily public organizations, but rather small firms or start-up ventures. Many technological innovations often occur in the small and medium enterprise segment. However, given the relative high percentage of large, public companies in the mobile ecosystem, and their influence in developing and providing mobile products and services, we believe that our data set is representative of the mobile ecosystem.

Although theoretically elaborated, this study did not differentiate between multiple relation types or direction of influence. Similarly, it was assumed that each firm only belonged to one segment. This simplification may have biased our results.

The use of static analysis for dynamic networks is another potential limitation of our study. Networks tend to change over time. This is particularly the case for the mobile ecosystem, in which the speed of technological innovation and business lead actors to enter and exit and form new relationships on an ongoing basis. Although there is value in studying an ecosystem network at a specific instance of its evolution cycle, this study is merely a starting point for a more comprehensive longitudinal analysis.

The empirical study also did not include end-customers as an integral node in the mobile ecosystem, contrary to the theoretical ideas, due to data limitations. In fact, previous research has argued that end-customers not only drive or cocreate value, but that their demand will lead to an increase of the overall complexity of the mobile ecosystem (Basole and Rouse, 2008). Each of these limitations represents an exciting area for future research.

Acknowledgements

The author is grateful to the editor, Dr. Jonathan Wareham, and two anonymous reviewers for insightful comments and suggestions. He thanks Dr. Bill Rouse for advice on earlier versions of this manuscript, Kristi Kirkland for support in data collection, and participants of the 2008 Annual INFORMS Meeting and Seventh International Conference on Mobile Business (ICMB) for helpful discussions pertaining to this research. All remaining errors and omissions are the sole responsibility of the author.

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