Kim, D.-H., Lee, H. and Kwak, J. (2016) Comparison of WiBro and TD-LTE deployment networks: implications for standards competition. *International Journal of Services and Standards*, 11(4), 318. (doi:10.1504/IJSS.2016.082428)

COMPARISON OF WIBRO AND TD–LTE DEPLOYMENT NETWORKS: IMPLICATIONS FOR STANDARDS COMPETITION

ABSTRACT

It has been an enigma for the communities of practice and academia in the field of standards as to why, when the capabilities of a technology are not much different or even superior to those of their competitors, only some standards lead to commercial success. Previous literature indicates that a standard needs organisational support and legitimacy among audiences, including distributors, influenced by network connectivity and configuration. Using a social-network analysis, this paper visualises and compares the networks of wireless broadband and time domain–long-term evolution deployment in the global market. The results show that the presence of a few key sponsors with financial resources and a large installed base is more important than the size of the network. Consequently, we draw some implications for sustainable deployment of future standards.

Keywords— WiBro, TD–LTE, Standard, Social Network Analysis

1. INTRODUCTION

The competition between the wireless broadband (WiBro) and high-speed downlink packet access/long-term evolution (HSDPA/LTE)[1] standards appears to be over, and it is evident that LTE has become a mainstream standard in the global mobile telecommunications market. Researchers are perplexed as to why some technology standards, despite their technological excellence or, at the very least, not being inferior to their competitors, fail to become a commercial success in the market. Previous research has shown that the market dominance of a standard needs organisational support and legitimacy among audiences, including distributors. These factors are substantially affected by the network connectivity and configuration of the related technology communities. This implies that examining the deployment network of WiBro and LTE can help unravel the conundrum of which non-technological factors critically affect this race for market domination.

WiBro was standardised in 2004 by the Telecommunications Technology Association (TTA) of Korea to improve the data transmission rate of mobile devices and add mobility to broadband Internet access. Samsung Electronics and the Electronics and Telecommunications Research Institute (ETRI) led the way for the standardisation of WiBro with the support of the Korean government, which regarded it as a new economic growth engine (or at least a gap-filling technology that overcame the limitations of existing technologies and satisfied the users' unfulfilled requirements) (Nam et al., 2008). WiBro was incorporated into IEEE 802.16e (mobile WiMax) in 2005, and it was approved as an International Telecommunication Union (ITU) standard in October 2007. The prominent features of WiBro are its exchange of the air interface of original orthogonal frequency-division multiplexing (OFDM) for that of orthogonal frequency-division multiple access (OFDMA) and its technological support for the handover between base stations (Steen, 2011).

Since its adoption as an international standard in 2007, the WiBro standard has been deployed globally. The WiMax Forum reported that WiBro deployments reached 146 countries as of 2009 (Larson, 2009). Nevertheless, WiBro began losing its growth momentum in 2009 as LTE began attracting worldwide attention as a next-generation technological standard. For instance, the WiMax Forum agreed to integrate some elements of the time-division–long-term evolution (TD–LTE) standard into its upcoming WiMax standard; this was a tacit admission that the telecom market had moved on from WiMax towards LTE (Har-Even, 2012). In South Korea, a country that pioneered the WiBro standard, the government allowed TD–LTE to be used in the WiBro frequency spectrum in 2013; this signalled to the market that the era of WiBro was over (BusinessKorea, 2013).

TD–LTE, also known as LTE–TDD, has recently gained currency and replaced the WiBro standard in the global mobile telecom market. The substitution was possible because WiBro and TD–LTE are technologically similar in a number of major aspects, such as operating in licensed spectrum bands and possessing a high capacity, wide coverage range and strong quality of service (QoS) mechanism (Yi et al., 2011). WiBro and TD–LTE both adopt the time-division duplex (TDD) scheme, which has technological advantages over the frequency-division duplex (FDD) scheme when there is an asymmetry in the uplink and downlink data-transmission rates. These similarities enable WiBro equipment and service providers to migrate to the TD–LTE standard. TD–LTE was jointly developed by a global coalition of companies, including China Mobile, Datang, Huawei, Nokia and Ericsson. TD–LTE was accepted as one of the ITU standards in January 2012. As of April 2015, 54 TD–LTE systems have been commercially launched in 34 countries, and 969 devices now support it, which is 37% of all LTE devices used in April 2015; this value was 29% in October 2014

[1] High-speed downlink packet access (HSDPA) is an enhanced third-generation (3G), also termed as 3.5G, wireless communications protocol in the high-speed packet access (HSPA) family. Long-term evolution (LTE) is a 4G standard evolved from HSPA.

(GSA LTE Report, 2015). Many of the Mobile WiMax service providers such as Clearwire (US), UQ (Japan) and P1 (Malaysia) have decided to provide the TD–LTE service in the global market.

Against this backdrop, this paper probes the following research questions: What are the non-technological factors that decisively influence a competition between two standards? What are the global deployment networks of WiBro and TD–LTE? How are they different in terms of network connectivity and configuration? What are the key factors that contribute to the dissimilar outcomes of WiBro and TD–LTE? To address these questions, this paper examines the network composition underpinning the deployment of the two standards. With regards to methodology, this paper relies on a social-network analysis to visualise the global networks of WiBro and TD–LTE and identifies the key players in deployment networks. Moreover, comparing the networks of the two standards, we find what their differences are and derive theoretical and practical implications.

2. LITERATURE REVIEW: STANDARDS, NETWORK EFFECTS AND LEGITIMACY

In recent years, standards have been gaining importance, particularly with respect to a firm's strategy for competing in increasingly interconnected high-technology industries. Technological advancement has gradually turned standalone products into complex systems in which the interoperability between components is crucial and the value of the network rises with the number of users and components. Compatibility standards define how components can be successfully integrated into such networks and ensure that components are interoperable with other constituents of a larger system of closely specified inputs and outputs (David and Steinmueller, 1994). The merits of compatibility (i.e. the interchangeability of complementary goods (components), ease of communication and cost savings) generates demand-side scale economies (Farrell and Saloner, 1986). The user demand function is affected by the installed base of the network, resulting in network effects (Katz and Shapiro, 1985). Direct network effects arise when the utility of a user depends on the number of other users within the same network, whereas indirect network effects result from increased demand for complementary goods. Cross-network effects also work, and in turn may affect the price structure of a two-sided market where the demands of services for both user and supplier sides are coordinated (Ding, 2014).

In high-tech industries where networks effects prevail, the size of a technology's installed base and the availability of complementary goods are critical in determining a dominant design or a *de facto* standard (Schilling, 1999). A larger installed base may lead to greater availability of complementary goods and may consequently have a positive effect on the value of a particular technology, thereby increasing future demand (Hill, 1997). This self-reinforcing mechanism is also explained under the rubric of increasing returns, which states that small historical events at an early stage may have profound impacts on later outcomes, such as locking an industry into a certain technological path (Arthur, 1989). The size of the installed base sends a signal not only to the producers of complementary goods but also to consumers regarding the value or quality of a technology, especially when information about its attributes is incomplete and a high degree of uncertainty is in turn present in the market. This causes delays in building a network on a new standard and also creates 'excess inertia' (i.e. reluctance to switch to a superior new technology and thereby cementing a *status quo* bias towards the existing technology that has a large installed base) (Farrell and Saloner, 1985; 1986).

Suarez (2004) parsed the process of a battle for dominance between standards into five phases (R&D build-up, technical feasibility, creating the market, decisive battle and post-dominance) and identified the installed base, complementary assets and network effects as key success factors in the stage of a decisive battle between heterogeneous standards. Similarly, Teece (1986) pointed out that in a paradigmatic design stage, access to complementary assets and control of distribution channels takes on greater prominence, while price becomes relatively less significant. Keil (2002) showed that the alliances designed for installed bases and network effects were partially attributed to the success of the Bluetooth standard. This stream of literature indicates that firms are able to strategically manoeuvre installed bases and network effects via inter-organisational linkages, *inter alia*, with distributors. These inter-organisational linkages between firms sponsoring a specific standard constitute the network structure of a technological community.

In industries characterised by network effects and increasing returns, organisational support in technological communities, in particular, those based on sponsorship,[2] critically affects the diffusion rate of a technology, expectation of future demand and consequently technological dominance in the market (Wade, 1995). In the process of gaining organisational support, legitimacy plays a prominent role. Legitimacy is a generalised perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs and definitions (Suchman, 1995). Legitimation is achieved through a sponsoring entity's value system, and more specifically, its system goals (Parsons, 1956). Legitimacy may lead audiences to provide resources to candidate entities that they perceive to be desirable, proper, or appropriate (Parsons, 1960). By granting legitimacy to candidates, audiences (e.g. the distributors of technology standard-embedded goods or services) serve as autonomous gatekeepers that influence the dominance of a specific product in the market (Hirsch, 1972). Influenced by network effects (Besen and Farrell, 1994), diffusion of a standard and its legitimacy can be recursively reinforcing (Botzem and Dobusch, 2012): legitimacy increases the adoption rate of a standard, which in turn further increases the legitimacy.

Legitimacy can be categorised into three types: pragmatic, normative and cognitive (Suchman, 1995). Pragmatic legitimacy is predicated upon the self-interested calculations of audiences that sponsor a particular standard. Normative legitimacy, however, rests on the evaluations of the moral propriety of a standard (e.g. consequential, procedural and structural forms) in accordance with accepted rules and norms (Scott, 1977). Cognitive legitimacy involves the acceptance of a standard as necessary or inevitable, and it is grounded in some taken-for-granted cultural accounts (DiMaggio and Powell, 1991). The process of a specific standard being approved by formal standardisation organisations (e.g. the ITU) can be considered to be normative (or socio-political) legitimation, whereas the convergence on accepted standards or dominant designs (e.g. the QWERTY keyboard layout), which renders alternatives unthinkable, is cognitive legitimation (Aldrich and Fiol, 1994). The multiplicity of legitimacy allows for strategic manoeuvres (i.e. the alignment of a pragmatic legitimacy with a normative and/or cognitive one). Standardisation strategies encompass the creation of coercive or mimetic pressures (DiMaggio and Powell, 1983)[3] that drive others to adopt a specific standard; consequently, this privileges sponsoring entities by forming coalitions with audiences, including distributors (Lawrence, 1999).

Strategies to obtain legitimacy and, in turn, organisational support for a particular standard are tightly related to the network connectivity of a technological community. Some scholars (e.g. Delacroix and Rao, 1994; Hannan and Carrol, 1992) have pointed out that legitimacy depends on organisational density (i.e. the network size of a technological community). Several features of network connectivity catalyse the convergence on consensus among audiences (i.e. the core element of legitimacy). A densely interconnected network precipitates the diffusion of information on

[2] Sponsor entities holding a direct or indirect proprietary interest create inducements for other firms to adopt a particular standard (David and Greenstein, 1990).

[3] Coercive isomorphism originates from political pressure and the legitimacy problem and hinges on the interdependence of organisations and their vulnerability to inspection, whereas mimetic isomorphism stems from organisations' standardised responses to uncertainty (DiMaggio and Powell, 1983).

audiences' behaviours and definitions of collective sanctions, and signals membership in a collective entity as well as alleviates uncertainty about legitimate institutional identities (Cattani et al., 2008). This may lead to cognitive legitimacy, facilitating convergence on a dominant design and compelling audiences to take a specific standard for granted.

3. METHODOLOGY

This paper uses social-network analysis as its research methodology. This analysis type is widely used for examining the network structure of inter-organisational linkages. It conceptualises individuals or firms as nodes and their relations as lines, visualises these interactions and assesses their effects (Scott, 2012). The idea of a social network was taken up by German social theorists, such as Ferdinand Tönnies and Georg Simmel in their 'formal sociology', 'seen as a sociology of the 'forms' of interaction that carry and contain the diverse subjectively meaningful contents that motivate the actions of individuals' [Scott, (2012), p. 8]. Social-network analysis has been utilised not only in the field of sociology but also in other areas of study. In the field of business, for instance, social networking concepts such as structural holes have been used to identify factors affecting the profitability of firms. 'Structural holes', coined by Ronald Burt, exist where other nodes are connected only through a focal node, and firms that occupy structural holes are able to control the flow of information and capitalise on a larger portion of the resources, thereby leading to greater returns (Burt, 1995; Gulati et al., 2000).

Network connectivity and composition have been considered to be a resource that may confer firms a sustainable competitive advantage (Gulati et al., 2000; Gulati, 1999), i.e. a firm's competitive advantage may rest on the collaborative relationships it has with its partners, e.g. its suppliers. Particularly, in the face of technological change, the capabilities of co-opetitors (e.g. suppliers) substantially affect a firm's performance (Afuah, 2000). In industries where network effects operate, e.g. in the telecommunications industry, a firm's alliance partnerships play a critical role in winning a standards war (Shapiro and Varian, 1999). This means that the network composition of a focal firm and its partners influences the success or failure of a standard in a market.

To assess the effect of network connectivity and composition of two standards on their relative success and failure, this paper probes the global networks of WiBro and TD–LTE by analysing telecom service providers (including Internet service providers) and telecom equipment vendors (excluding chip and terminal vendors). It focuses on the data of transactions among service providers and vendors, such as procurement contracts and memoranda of understanding (MOU) for collaborations. Chip and terminal vendors are excluded from the scope of this present analysis because they do not usually make direct transactions with service providers regarding deployment of the standards.

Regarding collection of network data, the authors first examined industry reports published by the WiMax Forum and Global TD–LTE Initiative (i.e. global partnerships among industry stakeholders to promote the standards) and then identified focal firms holding a critical position in the global deployment of the standards (mostly equipment vendors). Anchoring onto the focal firms, the authors collected network data by searching the firms' homepages, blogs tailored to WiBro and TD–LTE and relevant industry news and reports. For comparing the two standards, the temporal boundary of data was set as two years after their respective adoptions as ITU standards; for WiBro, this boundary was 2009, and for TD–LTE, this boundary was 2013. During these two-year periods, these technological standards were rapidly deployed around the world, shaping the expectation regarding the success and failure of a standard in the global market. Thereafter, the deployment rates gradually declined.

The dataset comprises a total of 251 telecom service providers and equipment vendors. For WiBro, the dataset includes 165 telecom service providers (including Internet service providers) and 20 equipment vendors. Internet service providers are included in the WiBro dataset because it is a wireless broadband Internet technology. For TD–LTE, this dataset includes 52 telecom service providers and 14 equipment vendors. The dataset does not necessarily represent the entire web of global deployment of these two standards but rather considers the network data that was collected primarily from focal firms' publicly available transactions. To minimise a selection bias, the authors cross-checked the list of focal firms and their networks through various sources, such as industry reports and news articles, and confirmed that the number of the focal firms' networks collected were generally correlated with the market shares of the firms. After this step, the authors visualised the key actors' networks of WiBro and TD–LTE and analysed the differences in the global deployment of these two standards.

4. RESULTS

4.1. Visualisation of the Global Networks of WiBro and TD–LTE

On the basis of the dataset, we created a visualisation of the global networks of WiBro (Mobile WiMax) and TD–LTE (LTE–TDD). Figure 1 displays the WiBro deployment network in the global market, whereas Figure 2 exhibits the TD–LTE deployment network. The size of a circle (i.e. node) indicates the number of lines adjacent to the node. Relatively large nodes are key players in the networks as they are more involved in the global deployment of the standards.

As shown in Figure 1, the WiBro network comprises 185 nodes, which include 20 telecom equipment vendors (clustered at the centre), 42 service providers in Europe (upper left), 51 service providers in Asia (upper right), 5 service providers in the Oceania region (right), 26 service providers in North America (lower right), 16 service providers in South America (lower left) and 25 service providers in Africa (purple, left). As shown in Figure 2, the TD–LTE network comprises 66 nodes, which include 14 telecom equipment vendors (clustered at the centre), 17 service providers in Europe (upper left), 23 service providers in Asia (upper right), 3 service providers in the Oceania region (right), 4 service providers in North America (lower right), 2 service providers in South America (lower left) and 3 service providers in Africa (left).

[Figure 1 here]

[Figure 2 here]

4.2. Centralities of the Networks

Centrality shows the positions of individual nodes within the network, degree centrality measures the number of neighbours connected to each node, and eigenvector centrality calculates the extent to which each node is connected to central neighbours. Degree centrality is defined as $C_D(n_i) = d(n_i) = X_{i+} = \sum_j X_{ij}$, where degree centrality, $C_D(n_i)$, is equal to the degree of node i, $d(n_i)$, which is calculated as the sum of each row in the adjacency matrix representing the network (Freeman, 1979; Wasserman and Faust, 1994). Eigenvector centrality is defined as $C(\alpha, \beta) = \alpha(I - \beta R)^{-1}R1$ (i.e. $C_i(\alpha, \beta) = \sum_j(\alpha - \beta C_j)R_{i,j}$), where α is a normalisation constant, β reflects the extent to which you weight the centrality of others ego is tied to (this determines how important the centrality of neighbours is), R is the adjacency matrix, I is the identity matrix and 1 is a matrix of all ones (Adamic, 2013; Rodan, 2011). In degree centrality, a node plays a critical role if it has more contacts, and in eigenvector centrality, a node becomes significant if it has many central contacts (de Nooy et al., 2011).

Table 1 lists the top five central telecom equipment vendors and the top five service providers in the global deployment networks of WiBro and TD–LTE. For WiBro equipment vendors, Alvarion, Alcatel-Lucent, Samsung, Motorola and Huawei are the five most connected firms. Intriguingly, most of these firms featured as the top five WiBro equipment companies in the global market in terms of market share in 2008 and 2009, according to the data from Infonetic Research (Kim et al., 2011). This confirms that these five vendors are central actors for the deployment of WiBro in the global market. For WiBro service providers, Clearwire (US), KT (Korea), Sprint (US), UQ (Japan) and SK (Korea) are the five central firms. It is interesting to note that among the key players in the WiBro network are Korean firms (i.e. Samsung, KT, SK). This shows that Korea was not only a forerunner in the international standardisation of WiBro (Choung et al., 2011) but also a core player in getting WiBro to penetrate the global market.

[Table 1 here]

As for TD–LTE, the five central telecom equipment companies are Huawei, Nokia Siemens, Ericsson, ZTE and Alcatel-Lucent whereas the five central telecom operators are China Mobile (China), Softbank (Japan), Mobily (Saudi Arabia), Bharti AirTel (India) and STC (Saudi Arabia). Notably, there are three Chinese firms in the list (China Mobile, Huawei and ZTE). This demonstrates that China positions itself at the centre of the TD–LTE's diffusion into the global market. Moreover, the central-actor list of TD–LTE includes China Mobile and Bharti AirTel, the world's largest and fourth largest mobile operators, respectively, in terms of connections. As of Q1 of 2013, China Mobile retained 726.31 million subscribers, whereas Bharti AirTel had 259.84 million subscribers (GSMA Intelligence, 2013). This may help explain the global attention gravitating toward TD–LTE.

Weiss and Sirbu (1990) empirically demonstrated that market power (measured by market share) and financial resources (measured by net assets) serve as crucial factors that influence the choice of technologies used in standards committees. We investigated the market power and financial resources of the main sponsors of TD–LTE and WiBro. The market share and net asset data were collected from WikiInvest (www.wikiinvest.com), Google Finance (www.google.com/finance) and the firms' annual reports. The ratios of WiBro's 10 TD–LTE key sponsors' financial resources (measured by net assets (NA)), buyer market power (measured by the number of mobile subscribers a buyer has (service providers) (BMS)) and seller market power (measured by the market share of the seller (vendors) (SMS)) are 1.68, 5.94 and 1.69, respectively. The value of 1.68 means that the financial resources of the 10 central players in TD–LTE's deployment network are 1.68 times larger than those of the main sponsors of the WiBro network.[4] In addition, NA, BMS and SMS were weighted with the degree and eigenvector centrality indices, and the weighted ratios[5] (TD–LTE to WiBro) were derived: degree (4.43, 47.57, 2.22) and eigenvector (4.08, 26.54, 1.88). It is important to note that the ratios weighted with centrality indices are generally greater than the ratios without weight. The weighted ratio of BMS is particularly significant; the degree and eigenvector-weighted ratios of BMS are more than eight and four times larger than the ratios of BMS without weight. This shows that the main sponsors of the TD-LTE network with a high buyer power are more centrally located than those of the WiBro network. Figure 3 presents the overall ratios of the main sponsors' NA, BMS and SMS.

[4] The ratios should be interpreted with care since the WiBro data was collected for the year 2009 and the TD–LTE data was gathered for 2013. These base years are set by taking into account the two years following the adoption of WiBro and TD–LTE as international standards.

[5] For instance, the ratio of net assets weighted with degree centrality is derived as:

$$\text{Weighted Ratio} = \frac{\sum_i (degree \times net\ assets)}{\sum_j (degree \times net\ assets)},$$

where i represents each main sponsor of TD–LTE and j that of WiBro.

[Figure 3 here]

4.3. Key Findings

4.3.1. Rapid and Wide Penetration of WiBro into the Global Market

On the basis of the comparison of the WiBro and TD–LTE networks, this paper finds that widespread deployment of a standard at a rapid pace does not necessarily assure its success in the global market. The juxtaposition of the two graphic images of WiBro and TD–LTE networks indisputably demonstrates that the WiBro standard extensively permeated the world's market in the two years following its approval as an ITU standard in 2007. This widespread diffusion is partially attributable to the fact that Internet service providers were involved in its deployment because WiBro was originally developed as a wireless Internet service. However, despite its global penetration, WiBro failed to sustain in the market, eventually being replaced by TD–LTE.

Conversely, TD–LTE has been deployed in limited regions. It is yet to fully make inroads into the markets of North America, South America and Africa. In North America, it is considered weak because of LTE–FDD, which has established its dominance in the region. In the US, for example, the major telecom carriers such as Verizon, AT&T and T-Mobile already provide LTE-FDD services. In South America and Africa, their mobile telecom markets are not sufficiently mature for 4G technology to be commercially launched in earnest. Despite its relatively inadequate deployment, TD–LTE has been recognised as a potential competitor of LTE–FDD and has gained momentum in the global market (ABI Research, 2013).

4.3.2. Leading Role of Chinese Firms in the Global Deployment of TD–LTE

Comparing the centralisation indices of the two networks, we find that the TD–LTE network (24.038%) is more centralised than the WiBro network (19.571%). This indicates that the connections of the nodes in the global network of TD–LTE deployment are more concentrated on a smaller number of key players at the top. Those influential players are Chinese firms, especially China Mobile and Huawei; this demonstrates the prominent role China has played in the penetration of TD–LTE into the global market.

It is notable that China Mobile is one of the top central actors in the TD–LTE network. China Mobile is the world's largest mobile telecom operator; its enormous installed base can work as a competitive advantage (Langlois, 1992). In fact, its massive purchasing power attracts the attention of equipment vendors across the globe. In June 2013, for instance, China Mobile launched a massive TD–LTE tender, i.e. a plan to buy 207,000 base stations, which sparked a race among equipment vendors around the world, including Ericsson, who wanted to reap benefits from this tender (Morris, 2013a). This emphasised the domination of China Mobile in the global telecom market.

Notwithstanding South Korea's role in spearheading WiBro's international standardisation, foreign firms such as Alvarion and Alcatel-Lucent were more engaged in its global deployment than South Korean enterprises such as Samsung, KT and SK. More interestingly, Korean telecom operators KT and SK held a relatively passive role in the global diffusion of WiBro compared with China Mobile's commitment towards the deployment of TD–LTE.

The ratio of the BMS of TD–LTE's main sponsors to the BMS of the main sponsors of WiBro shows the significant effect of China Mobile's purchasing power. As we weight the ratio of BMS with degree centrality, the weighted ratio of TD–LTE to WiBro becomes eight times greater than the ratio without weight. This indicates that TD–LTE's main sponsors with a high buyer power, China Mobile in particular, were more centrally concentrated in the network than the main sponsors of WiBro. We find that this centralisation of buyer power proved to be a critical factor in enabling TD–LTE's successful deployment around the world.

4.3.3. Vigorous Participation of the World's Top Telecom Equipment Vendors in TD–LTE Deployment

Huawei, Nokia Siemens, Ericsson, ZTE and Alcatel-Lucent all held a central role in the TD–LTE network. These firms, in fact, are the world's five largest telecom gear companies (measured by the revenues posted in 2011 (Lee, 2012)). They also participated in the Global TD–LTE Initiative (GTI) Partner Forum, which was launched in 2011 to promote the technology. This indicates that they were seriously committed to the deployment of TD–LTE. Their relationship with China Mobile is noteworthy; these firms were the main vendors that won most of China Mobile's tenders for deploying TD–LTE in China.

The active engagement of Ericsson, Nokia Siemens and ZTE in TD–LTE's deployment is particularly notable because these firms did not participate in the deployment of the WiBro network. The sales revenue of Ericsson in 2010, for instance, was 203 billion SEK (approximately US $28.42 billion) (Ericsson, 2012). This was approximately 380 times larger than the sales revenue of Alvarion, the most prominent actor in the WiBro network (Alvarion, 2012). As far as the number of employees is concerned, Ericsson retained 90,261 workers by the end of 2010, which was over 125 times larger than the number of workers retained by Alvarion (Alvarion, 2010; Ericsson, 2012). This shows that more influential players were positioned in the TD–LTE network.

Moreover, Huawei, Nokia, Ericsson, ZTE and Alcatel-Lucent are active producers of LTE–FDD gear. Technically, TD–LTE and LTE–FDD equipment share the same hardware platform and a high proportion of software modules (TDIA, 2012). The compatibility of TD–LTE and LTE–FDD technology likely facilitated the participation of global top vendors in the deployment of TD–LTE.

5. DISCUSSION AND IMPLICATIONS

5.1. Discussion

The comparison of the WiBro and TD–LTE networks first identifies the widespread deployment of WiBro in the global market, including in South America and Africa. The price competitiveness and fast data speed of WiBro were the likely attributing factors for its global market penetration, particularly in developing countries. As of 2004, the price of a WiBro base station was estimated to be 130 million KRW (approximately US $113,500), which was cheaper than that of a WCDMA base station; wideband code division multiple access (WCDMA) is a third-generation (3G) mobile telecom standard (Kim, 2005). The downlink peak data rate of WiBro was 46 Mbit/s, which is almost two times faster than that of HSPA, a WCDMA-based 3.5G technology (Johnston and Aghvami, 2007). In fact, some researchers (e.g. Karanasios and Allen (2010)) noted its cost-effectiveness and discussed WiMAX as an alternative for filling the connectivity gap in developing countries.

Despite its extensive deployment, WiBro cannot effectively compete against HSDPA/LTE in the market, and it has now been replaced by TD–LTE. For instance, Clearwire (now Sprint Corporation), one of the main WiBro service providers in the US, announced its plan to shut down its WiBro network by the end of 2015 and to upgrade it to TD–LTE (Goldstein, 2014). Yota, the European partner of Samsung in the WiBro standard, also stopped providing WiBro connectivity (Chosunilbo, 2010). Intel, which was heavily involved in the development of the WiMax technology, has already migrated to LTE by acquiring Infineon Technologies (Agrawal, 2010). This substitution took place partially because of the technological similarity between WiBro and TD–LTE as well as

TD–LTE's advantages, such as its backward compatibility with legacy systems such as 2G and 3G (Ergen, 2009).

SK, the largest Korean telecom operator and one of the key players in WiBro's deployment, was rather passive in the commercialisation of the technology even though Korea was active in its international standardisation. SK maintained its competitive edge in the Korean market by focusing on the HSDPA standard, a competing technology to WiBro. This incumbent firm was concerned with the introduction of voice services into WiBro and its potential cannibalisation effect on the existing HSDPA-based services (Lee et al., 2011). In fact, the absence of a voice service was regarded as a critical hindrance to the revitalisation of the WiBro market (Lee et al., 2009). Experts also believe that a lack of engagement from incumbent firms was a critical factor contributing to the failure of WiBro in the Korean market (Paik et al., 2010). This case is consistent with the finding of Henderson (1993) that incumbent firms are more reluctant than entrants to introduce radical innovation because of the fear of cannibalising their existing technologies.

Unlike in the case of WiBro, the main sponsors played a crucial role in the deployment of TD–LTE. By examining TD–LTE's network, we confirm that Chinese firms, particularly China Mobile, acted as central players in its global deployment. China Mobile's massive purchasing power, in effect, drew the world's top telecom equipment vendors into the deployment of TD–LTE. For instance, China Mobile's tender for TD–LTE equipment triggered a fierce competition between major European vendors such as Ericsson, Nokia and Alcatel-Lucent, who wanted to reap benefits from the deal (Morris, 2013a). In 2013, China Mobile chose Nokia as the largest non-Chinese TD–LTE vendor, awarding it 11% of its first-round tender; this subsequently led to a 25% increase in Nokia's revenues in China (European Communications, 2014). China Mobile also played a leading role in organising the Global TD–LTE Initiative (GTI) with a purpose of constructing a device ecosystem for TD–LTE and rallying broader support at the industry level. The GTI was launched in 2011 by China Mobile together with other operators, including Vodafone, Bharti, Softbank and Clearwire; as of March 2015, GTI had 117 operator members. The GTI members have undertaken various activities, including conferences and workshops, aimed at exploring the key problems affecting the large-scale commercial application of TD–LTE. They share information and facilitate the development of low-cost TD–LTE terminals (TDIA, 2012). Shim and Shin (2015) argued that China Mobile capitalised on the GTI as a tool for interessement (Callon, 1986) for imposing and stabilising other actors' identities in the TD–LTE network.

Apart from China Mobile, other Chinese firms such as Huawei and ZTE were vigorously involved in the development and deployment of TD–LTE. Huawei, for example, with the aim of creating a TD–LTE ecosystem, established open TD–LTE interoperability testing labs in Xi'an and Shenzhen to accelerate cooperation on chipsets, devices and applications partners (Huawei, 2012). Huawei and ZTE won 50% of China Mobile's TD–LTE tender and assumed a crucial role in the deployment of TD–LTE in China (Morris, 2013b). Through active collaboration among Chinese firms, the presence of the TD–LTE standard was expanded not only in China but across the globe, as elucidated in the findings of our social-network analysis.

5.2. Implications for Standards Competition in terms of Network Effects and Legitimacy

This paper provides theoretical and policy implications. Regarding the theoretical implications, we find that main sponsors' financial resources and buyer-side market power are of salient importance. These factors can be critical to the successful deployment of a global standard if they are more concentrated in the main sponsors and thereby precipitate a standard-diffusion process. Regarding the installed bases and network effects, this research shows that the number of potential users more substantially affects the future expectations of a standard and attracts influential industry players than the number of sponsoring firms. Entities with large user bases are able to control the subcontracting system linked to their activities, namely the bandwagon effect, and persuade other entities to join the coalition because of their credible commitment (Foray, 1994).

This finding also contributes to the stream of research on legitimacy. Several organisational ecology scholars (Delacroix and Rao, 1994; Hannan and Carrol, 1992) have claimed that the network size of a community positively correlates with its legitimacy, and it subsequently influences the survival of a particular organisational form. We found that the characteristics (e.g. financial resources and market power) of sponsoring actors who are centrally positioned in the network topology are influential factors in the survival of a specific standard rather than the characteristics related to the size of the network. The mechanism underlying the legitimation of TD–LTE can be explained by coercive pressures from powerful organizations and the mimetic processes of following the most prominent entities under conditions of uncertainty (DiMaggio and Powell, 1983; Guler et al., 2002). This implies that the successful alignment of pragmatic legitimacy with normative and/or cognitive legitimacy can be affected by the network configuration of a technological community, particularly with respect to the centralities of focal actors sponsoring a particular standard.

We also offer implications for governments that attempt to successfully launch a new technology standard in the mobile telecom market. First, a policymaker should take into consideration possible cannibalisation effects on telecom operators' existing technology-based services when it issues a license for services based on a new standard. Second, it is advisable for a policy designer to create mechanisms that encourage influential firms with a high level of market power and financial resources to lead collaborations with other players in the development and deployment of a standard and, if necessary, coordinate the interests of different stakeholders. The Chinese government, for instance, played a multi-faceted role (e.g. project founder, risk undertaker, interest moderator, collaboration facilitator and process monitor) in the development and deployment of time division synchronous code division multiple access (TD–SCDMA), a China-driven 3G standard (Gao et al., 2014) and provided institutional support, including the licensing policy (Kshetri et al., 2011). Its support in the establishment of the TD-Industry Alliance, which included major industry players, later became useful in the development of the TD–LTE ecosystem and deployment of the TD–LTE standard (Shim and Shin, 2015). It must be noted that such attempts to successfully develop and deploy global standards should be congruent with international norms (Kim et al., 2014).

6. CONCLUSION

International standardisation has increasingly become a strategic tool for newly industrialised countries to lessen their dependence on foreign technology and cultivate their own indigenous capabilities. South Korea and China, for instance, have actively engaged in intense competition for global standards with the aim of becoming standard-setters (Lee and Oh, 2008). Capitalising on its enormous market size, China, in particular, has made several attempts to establish international standards and, through this process, has become more open to foreign firms and bound by international norms (Kim et al., 2014; Kwak et al., 2012). Reaping the benefits of these standardisation experiences, including that concerning TD–SCDMA (China-driven 3G wireless communications standard), many Chinese firms have played a crucial role in the standardisation of TD–LTE. On the basis of these cases, policy implications that try to foster the innovation capabilities of developing countries and facilitate their economic growth can be drawn. In this context, the findings of this paper are of salient significance.

Relying on a social network analysis, this paper visualised the networks of WiBro and TD–LTE deployment in the global market. We also conducted a comparative analysis of the two standards' networks and subsequently identified the following three differences: first, the rapid and wide deployment of WiBro in the global market; second, the crucial role of Chinese firms in TD–LTE's global expansion; and third, active participation of the world's top telecom gear vendors in the deployment of TD–LTE. From the analysis of these differences, we drew some theoretical and practical implications. Regarding the theoretical implications, we found that the main sponsors' financial resources and market power (on the buyer side, in particular) combined with the central network positions serve as crucial factors for the sustainable deployment of a standard. This finding makes theoretical contributions to the literature on organisational legitimacy because it shows that the central role of sponsoring actors with market power in a standards-deployment network may outweigh the overall network size in gaining organisational support in the community. For practical implications, companies, if attempting to deploy a new standard in the global telecom market, may take into consideration partnerships with industry players that have massive installed bases (buyer-side market power), such as China Mobile. For policymakers, it is advisable that they consider the possible cannibalisation of telecom service providers' old technology-based services when they issue a license for telecom services based on a new standard. Furthermore, they may want to set policies that offer incentives for influential firms with strong buyer-side market power and financial resources to play a leading role in collaboration with other players in the development and deployment of a standard and, if necessary, coordinate the interests of different stakeholders.

The findings of this paper should be interpreted with care. In this research, we mainly focused on factors related to the network composition of the deployment of standards, which some researchers (e.g. Suarez (2004)) have explained as being a crucial phase in a decisive battle between standards. Consequently, we did not comprehensively examine other factors (e.g. technological superiority and pricing strategy), which would likely have some influence on the deployment of the two standards. For instance, some scholars (Ahluwalia et al. (2010); Kim and Lee (2016)) listed the factors that constitute switching costs (e.g. reference prices, flat rate bias, status quo bias, uncertainty, transition costs, and sunk costs), and showed that those factors influence users' behavioural intentions to adopt or resist a new technological standard. Future research could investigate the interaction of the network-related factors with others factors relevant to a standard competition and delve into how these dynamics would change over time.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014S1A3A2043505). Thanks to professor Yong-hak Kim, Yonsei University and reviewers for constructive comments.

REFERENCES

ABI Research. (2013) *More Than 1 in 2 People Will Be Covered by LTE-FDD by 2018*. https://www.abiresearch.com/press/more-than-1-in-2-people-will-be-covered-by-lte-fdd. (Accessed 11 December 2013).

Adamic, L. (2013) *Network Centrality*. http://cs.brynmawr.edu/Courses/cs380/spring2013/section02/slides/05_Centrality.pdf.

Afuah, A. (2000). 'How much do your co-opetitors' capabilities matter in the face of technological change?', *Strategic Management Journal*, Vol. 21 No. 3, pp. 387 - 404.

Agrawal, M. (2010) 'Why did Intel buy Infineon's Wireless Business?' *Telecom Circle* [online] http://www.telecomcircle.com/2010/08/intel-infineon/.

Ahluwalia, P, Gimpel G and Varshney U. (2010) 'Why people aren't using wireless internet: a behavioural economics approach to technology preferences', *International Journal of Services and Standards*, Vol. 6 Nos. 3/4, pp. 271 - 294.

Aldrich, HE and Fiol, CM. (1994) 'Fools rush in? The institutional context of indsutry creation', *The Academy of Management Review*, Vol. 19 No. 4, pp. 645 - 670. doi:10.2307/258740

Alvarion. (2010) *Annual Report*. Alvarion.

Alvarion. (2012) *Annual Report*. Alvarion.

Arthur, WB (1989) 'Competing technologies, increasing returns, and lock-in by historical events', *The Economic Journal*, Vol. 99, pp. 116 - 131.

Besen, S M and Farrell, J. (1994) 'Choosing how to compete: Strategies and tactics in standardization', *The Journal of Economic Perspectives*, Vol. 8 No. 2, pp. 117 - 131.

Botzem, S and Dobusch, L. (2012) 'Standardization cycles: A process perspective on the formation and diffusion of transnational standards', *Organization Studies*, Vol. 33 No. 5-6, pp. 737 - 762. doi:10.1177/0170840612443626

Burt, RS. (1995) *Structural Holes: The Social Structure of Competition*, Harvard University Press.

BusinessKorea. (2013) *Conversion of WiBro: Korean Government Gives Up on Mobile WiMax to Turn toward LTE-TDD*. http://www.businesskorea.co.kr/article/1478/conversion-wibro-korean-government-gives-mobile-wimax-turn-toward-lte-tdd. (Accessed 9 December 2013).

Callon, M. (1986) 'Some elements in the sociology of translation: Domestication of the scallops and the fishermen of St. Brieuc Bay' in *Power, Action and Belief: A New Sociology of Knowledge*, pp. 196 - 223.

Cattani, G, Ferriani, S, Negro, G and Perretti, F. (2008) 'The structure of consensus: Network ties, legitimation, and exit rates of U.S. feature film producer organizations', *Administrative Science Quarterly*, Vol. 53, pp. 145 - 182.

Chosunilbo. (2010) 'Russia's Yota Drops WiBro for European Technology', *Chosunilbo*. http://english.chosun.com/site/data/html_dir/2010/05/25/2010052501112.html.

Choung, J-Y, Hameed, T and Ji, I. (2011) 'Role of Formal Standards in Transition to the Technology Frontier: Korean ICT Systems', *Telecommunications Policy*, Vol. 35 No. 3, pp. 269 - 287. doi:10.1016/j.telpol.2011.02.001

David, PA and Greenstein, S. (1990) 'The economics of compatibility standards: An introduction to recent research', *Economics of Innovation and New Technology*, Vol. 1, pp. 3 - 41.

David, P A and Steinmueller, WE. (1994) ‘Economics of compatibility standards and competition in telecommunication networks’, *Information Economics and Policy*, Vol. 6 No. 94, pp. 217 - 241. doi:10.1016/0167-6245(94)90003-5

De Nooy, W, Andrej, M and Vladimir, B. (2011) *Exploratory Social Network Analysis with Pajek*, Cambridge University Press.

Delacroix, J and Rao, H. (1994) ‘Externalities and ecological theory: Unbundling density dependence’, In J. A. Baum and J. V. Singh (Eds.), *Evolutionary Dynamics of Organizations*, Oxford University Press, New York, pp. 255 - 268.

DiMaggio, PJ and Powell, WW. (1983) ‘The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields’, *American Sociological Review*, Vol. 48 No. 2, pp. 147. doi:10.2307/2095101

DiMaggio, PJ and Powell, WW. (1991) Introduction. In W. W. Powell and P. J. DiMaggio (Eds.), *The New Institutionalism in Organizational Analysis,* University of Chicago Press, Chicago, IL, pp. 1 - 38.

Ding, N (2014). ‘Cross-network externality analysis of the price structure on the credit card market in China’, *International Journal of Services and Standards*, Vol. 9 Nos. 2/3/4, pp. 130 - 145.

Ergen, M. (2009) *Mobile broadband: Including WiMAX and LTE*. Springer Science and Business Media.

Ericsson. (2012) *Ericsson Reports Fourth Quarter and Full Year*. Financial Report. Ericsson.

European Communications. (2014) ‘Nokia wins again in China Mobile’s 4G LTE tender’, *European Communications*. http://www.eurocomms.com/industry-news/9938-nokia-wins-again-in-china-mobiles-4g-lte-tender.

Farrell, J and Saloner, G. (1985) ‘Standardization, compatibility and innovation’, *Rand Journal of Economics*, Vol. 16 No. 1, pp. 70 - 83. doi:10.2307/2555589

Farrell, J and Saloner, G. (1986) ‘Installed base and compatibility: Innovation, product preannouncements, and predation’, *The American Economic Review*, Vol. 76 No. 5, pp. 940 - 955. doi:10.2307/1816461

Foray, D. (1994) ‘Coalitions and committees: How users get involved in information technology standardization’, In *Standards, Innovation and Competitiveness*. Edward Elgar.

Freeman, LC. (1979) ‘Centrality in social networks: Conceptual clarification’, *Social Networks*, Vol. 1 No. 3, pp. 215 - 239.

Gao, P, Yu, J and Lyytinen, K. (2014) ‘Government in standardization in the catching-up context: Case of China’s mobile system’, *Telecommunications Policy*, Vol. 38 No. 2, pp. 200 - 209. doi:10.1016/j.telpol.2013.10.002

Goldstein, P. (2014, April 7) ‘Sprint to shutter WiMAX network by end of 2015, will turn off at least 6,000 towers’, *FierceWireless* [online]. http://www.fiercewireless.com/story/sprint-shutter-wimax-network-end-2015-will-turn-least-6000-clearwire-sites/2014-04-07.

GSA. (2013) *Status of the Global LTE TDD Market*. Global mobile Suppliers Association. http://www.slideshare.net/GSAslideshare/gsa-status-ofthegloballtetddmarket200713.

GSMA Intelligence. (2013) *The Top 20 Global Mobile Operator Groups by Connections and Revenue, Q1 2013*. https://gsmaintelligence.com/analysis/2013/07/the-top-20-global-mobile-operator-groups-by-connections-and-revenue-q1-2013/392/ (Accessed 10 December 2013) .

Gulati, R. (1999) ‘Network location and learning: The influence of network resources and firm capabilities on alliance formation’, *Strategic Management Journal*, Vol. 20 No. 5, pp. 397 - 420.

Gulati, R, Nohria, N and Zaheer, A. (2000) ‘Strategic networks’, *Strategic Management Journal*, Vol. 21, pp. 203 - 215.

Guler, I, Guillen, M and Macpherson, JM. (2002) ‘Global competition, institutions, and the diffusion of organizational practices: The international spread of ISO 9000 quality certificates’, *Administrative Science Quarteraly*, Vol. 47, pp. 207 - 232.

Hannan, MT and Carrol, GR. (1992) *Dynamics of Organizational Populations: Density, Legitimation, and Competition*. *Contemporary Sociology*,Vol. 21, Oxford University Press, New York. doi:10.2307/2075612

Har-Even, B. (2012) *WiMAX Forum embraces TD-LTE*. http://www.telecoms.com/51978/wimax-forum-embraces-td-lte/. (Accessed 9 December 2013)

Henderson, R. (1993) ‘Underinvestment and incompetence as responses to radical innovation: evidence from the photolithographic alignment equipment industry’, *The RAND Journal of Economics*, Vol. 24 No. 2, pp. 248 - 270.

Hill, CWL. (1997) ‘Establishing a standard: Competitive strategy and technological standards in winner-take-all industries’, *The Academy of Management Executive*, Vol. 11 No.2, pp. 7 - 25.

Hirsch, PM. (1972) ‘Processing fads and fashions: An organization-set analysis of cultural industry systems’, *American Journal of Sociology*, Vol. 77 No. 4, pp. 639 - 659.

Huawei. (2012) *Huawei Establishes Open Interoperability Testing Labs to Accelerate TD-LTE Development*. http://www.huawei.com/ilink/en/about-huawei/newsroom/press-release/HW_144276?KeyTemps=TD LTE IOT (Accessed 2 March 2015).

Johnston, N, and Aghvami, H. (2007) ‘Comparing WiMAX and HSPA — a Guide to the Technology’, *BT Technology Journal*, Vol. 25 No. 2, pp. 191 - 199. doi:10.1007/s10550-007-0044-2

Karanasios, S and Allen, D. (2010) 'WiMAX for development', *Information Technology for Development*, Vol. 16, pp. 320 - 328. doi:10.1080/02681102.2010.487046

Katz, ML and Shapiro, C. (1985) 'Network externalities, competition, and compatibility', *The American Economic Review*, Vol. 75 No. 3, pp. 424- 440.

Keil, T. (2002) 'De-facto standardization through alliances—lessons from Bluetooth', *Telecommunications Policy*, Vol. 26, pp. 205 - 213. doi:10.1016/S0308-5961(02)00010-1

Kim, C, Kim, S, and Hyung, T. (2011) *A Study on the Promotion Policy of WiBro Services in Korea Mobile Market*, Korea Communications Commission (in Korean).

Kim, D, Lee, H, Kwak, J and Seo, D. (2014) 'China's information security standardization: Analysis from the perspective of technical barriers to trade principles', *Telecommunications Policy*, Vol. 38 No. 7, pp. 592- 600. doi:10.1016/j.telpol.2014.02.001

Kim, D and Lee, H. (2016) 'Effects of user experience on user resistance to change to the voice user interface of an in-vehicle infotainment system: Implications for platform and standards competition', *International Journal of Information Management*, Vol. 36 No. 4, pp. 653 - 667.

Kim, Y. (2005) 'WiBro policy, business strategy and market evolution', *The Korean Journal of Economics (in Korean)*, Vol. 12 No. 2, pp. 473 - 494.

Kshetri, N, Palvia, P, and Dai, H. (2011) 'Chinese institutions and standardization: The case of government support to domestic third generation cellular standard', *Telecommunications Policy*, Vol. 35 No. 5, pp. 399 - 412. doi:10.1016/j.telpol.2011.03.005

Kwak, J, Lee, H, and Chung, DB. (2012) 'The evolution of alliance structure in China's mobile telecommunication industry and implications for international standardization', *Telecommunications Policy*, Vol. 36, pp.10 -11, pp. 966 - 976. doi:10.1016/j.telpol.2012.07.017

Langlois, RN. (1992) 'External economies and economic progress: The case of the microcomputer industry', *Business History Review*, Vol. 66 No. 1, pp. 1 - 50.

Larson, J. (2009) 'Mobile WiMax (WiBro) Development and Exports', *Korea's Information Society* [online]. http://www.koreainformationsociety.com/2009/12/mobile-wimax-wibro-development-and.html. (Accessed 3 March 2015)

Lawrence, TB. (1999) 'Institutional strategy', *Journal of Management*, Vol. 25 No. 2, pp. 161 - 188. doi:10.1177/014920639902500203

Lee, BG., Kwak, JH, Kim, KY and Kim, SJ. (2009) 'Technical innovation and 3.5 mobile phone generation: Lessons from Korea', *Telecommunications Policy*, Vol. 33 No. 5-6, pp. 296 - 308. doi:10.1016/j.telpol.2009.02.006

Lee, CY. (2012) ‘China’s ZTE Q1 Net Income Trails Forecasts’, *Reuters*. http://uk.reuters.com/article/2012/04/25/zte-earns-idUKL3E8FN8Q220120425.

Lee, H. and Oh, S. (2008) ‘The political economy of standards setting by newcomers: China’s WAPI and South Korea’s WIPI’, *Telecommunications Policy*, Vol 32 No. 9-10, pp. 662 - 671.

Lee, Y-S, Jung, J-L, Park, S-H and Kim, S-W. (2011) ‘A study on polices for the activation of WiBro market’, *Korean System Dynamics Review (in Korean)*, Vol. 12 No. 2, pp. 37 - 67.

Morris, A. (2013a) ‘Europe’s Vendors Jostle for Slice of Massive China TD-LTE Tender’, *FierceWireless*. http://www.fiercewireless.com/europe/story/europes-vendors-jostle-slice-massive-china-td-lte-tender/2013-06-26.

Morris, A. (2013b) ‘Huawei, ZTE win 50% of China Mobile TD-LTE contract’, *FierceWireless*. http://www.fiercewireless.com/europe/story/report-huawei-zte-win-50-china-mobile-td-lte-contract/2013-08-23.

Nam, C, Kim, S and Lee, H. (2008) ‘The role of WiBro: Filling the gaps in mobile broadband technologies’, *Technological Forecasting and Social Change*, Vol. 75, pp. 438 - 448. doi:10.1016/j.techfore.2007.04.008.

Paik, JH, Kim, MK and Park, JH. (2010) ‘A study on the causes of WiBro’s poor performance and the factors in 4G global market success’, *Samsung SDS Journal of IT Services (in Korean)*, Vol. 7 No. 1, pp. 36 - 49.

Parsons, T. (1956) ‘Suggestions for a sociological approach to the theory of organizations-I’, *Administrative Science Quarterly*, Vol. 1 No. 1, pp. 63 - 85.

Parsons, T. (1960) *Structure and Process in Modern Societies*, Glencoe, IL: Free Press.

Rodan, S. (2011) ‘Choosing the “β” parameter when using the Bonacich power measure’, *Journal of Social Structure*, Vol. 12 No. 4, pp. 1 - 23.

Schilling, M. (1999) ‘Winning the standards race: Building installed base and the availability of complementary goods’, *European Management Journal*, Vol. 17 No. 3, pp. 265 - 274.

Scott, J. (2012) *What Is Social Network Analysis?*. Bloombury Academic.

Scott, WR. (1977) ‘Effectiveness of organizational effectiveness studies’, In P. S. Goodman and J. M. Pennings (Eds.), *New Perspectives on Organizational Effectiveness*, Jossey-Bass, San Francisco, pp. 63 - 95.

Shapiro, C and Varian, HR. (1999) ‘The art of standards wars’, *California Management Review*, Vol. 41 No. 2, pp. 8 - 32.

Shim, Y and Shin, D-H. (2015) ‘Analyzing the development of 4th generation mobile network in China: Actor network theory perspective’, *Info*, Vol. 17 No. 1.

Steen, HU. (2011) ‘Indicators of development or dependency in disguise? Assessing domestic inventive capacity in South Korean and Chinese infrastructural ICT standards’, *Telecommunications Policy*, Vol. 35 No. 0308, pp. 663 - 680. doi:10.1016/j.telpol.2011.06.004

Suarez, FF. (2004) ‘Battles for technological dominance: An integrative framework’, *Research Policy*, Vol. 33, pp. 271 - 286. doi:10.1016/j.respol.2003.07.001

Suchman, MC. (1995) ‘Managing legitimacy: Strategic and institutional approaches’, *Academy of Management Review*, Vol. 20 No. 3, pp. 571 - 610. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.108.2768&rep=rep1&type=pdf

TDIA. (2012) *TD-LTE Industry Development Report*. TD Industry Alliance.

Teece, D. (1986) ‘Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy’, *Research Policy*, Vol. 15 No. 6, pp. 285 - 305.

Wade, J. (1995) ‘Dynamics of organizational communities and technological bandwagons: An empirical investigation of community evolution in the microprocessor market’, *Strategic Management Journal*, Vol. 16, pp. 111 - 133. doi:10.2307/2486772

Wasserman, S. and Faust, K. (1994) *Social Network Analysis: Methods and Applications*, Cambridge University Press.

Weiss, MBH. and Sirbu, M. (1990) ‘Technological choice in voluntary standards committees: An empirical analysis’, *Economics of Innovation and New Technology*, Vol. 1 No. 1-2, pp. 111 - 133.

Yi, L, Miao, K and Liu, A. (2011) ‘A comparative study of WiMAX and LTE as the next generation mobile enterprise network’, *13th International Conference on Advanced Communication Technology (ICACT2011)*, Vol. 7, pp. 654 - 658.

Table 1. Degree and Eigenvector Centralities of the WiBro and TD–LTE Networks

WiBro				
Vendors/ Service Providers	**Degree**	**Normalised Degree**	**Eigenvector**	**Normalised Eigenvector**
Alvarion	38	20.65	0.47	66.17
Alcatel-Lucent	35	19.02	0.46	64.42
Samsung	22	11.96	0.23	32.45
Motorola	19	10.33	0.05	7.12
Huawei	19	10.33	0.09	12.56
Clearwire (US)	6	3.26	0.08	10.63
KT (Korea)	6	3.26	0.06	8.32
Sprint (US)	5	2.72	0.08	11.29
UQ (Japan)	4	2.17	0.05	6.81
SK (Korea)	4	2.17	0.12	17.10
Network Centralisation (Degree) = 19.57%				

TD–LTE				
Vendor/ Service Providers	**Degree**	**Normalised Degree**	**Eigenvector**	**Normalised Eigenvector**
Huawei	18	27.69	0.40	55.79
China Mobile (China)	16	24.62	0.39	55.74
Nokia Siemens	14	21.54	0.33	46.14
Ericsson	12	18.46	0.26	36.83
ZTE	9	13.85	0.20	28.91
Alcatel-Lucent	7	10.77	0.18	25.56
Softbank (Japan)	7	10.77	0.25	34.88
Mobily (Saudi Arabia)	5	7.69	0.17	24.51
Bharti AirTel (India)	5	7.69	0.20	28.43
STC (Saudi Arabia)	4	6.15	0.19	27.10
Network Centralisation (Degree) = 24.04%				

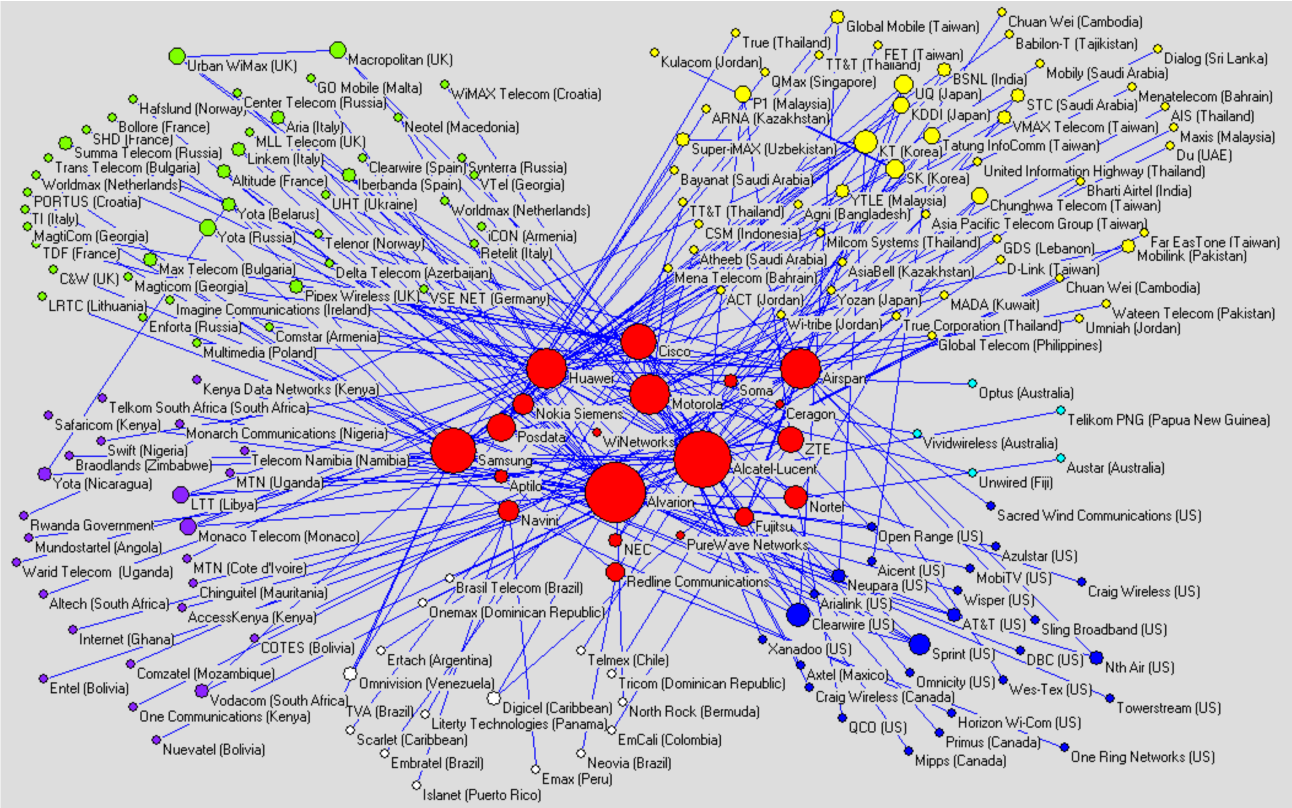

Figure 1.

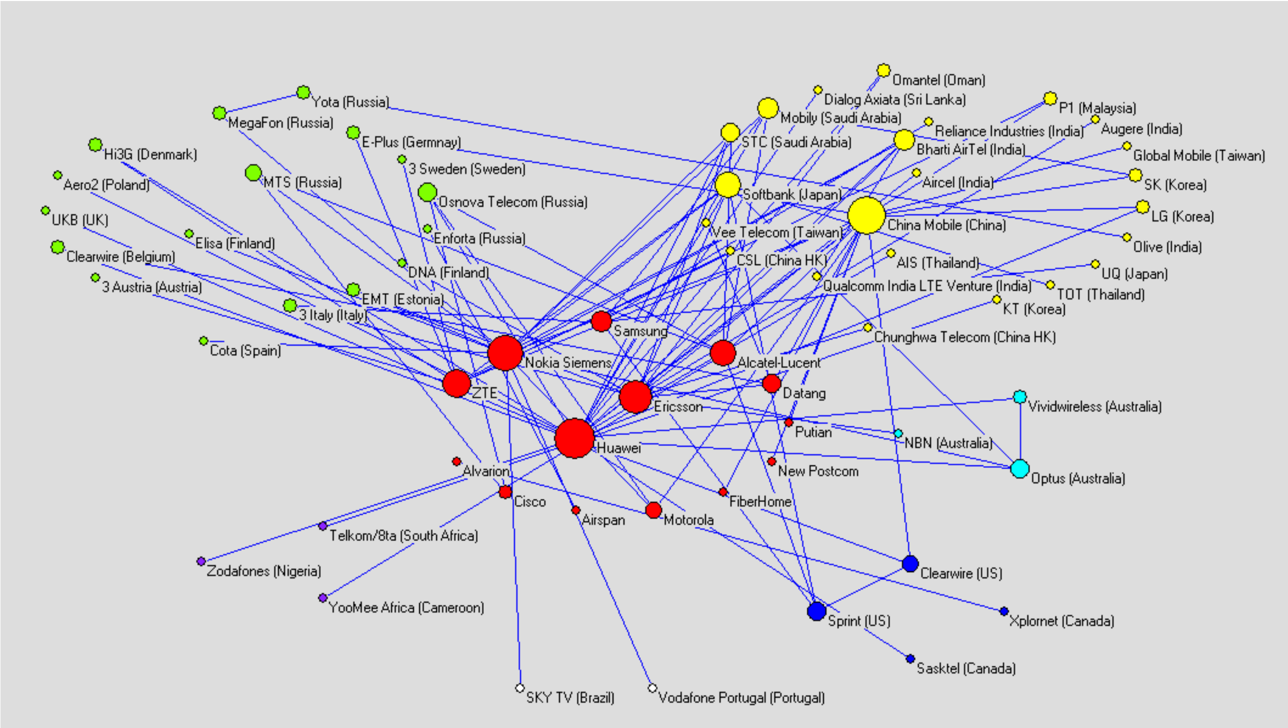
Omantel (Oman)
Dialog Axiata (Sri Lanka)
Yota (Russia)
MegaFon (Russia)
Mobily (Saudi Arabia)
P1 (Malaysia)
Reliance Industries (India)
Augere (India)
E-Plus (Germnay)
STC (Saudi Arabia)
Bharti AirTel (India)
Global Mobile (Taiwan)
Hi3G (Denmark)
3 Sweden (Sweden)
MTS (Russia)
Aero2 (Poland)
Aircel (India)
SK (Korea)
Softbank (Japan)
Osnova Telecom (Russia)
UKB (UK)
LG (Korea)
China Mobile (China)
Vee Telecom (Taiwan)
Elisa (Finland)
Enforta (Russia)
Olive (India)
Clearwire (Belgium)
CSL (China HK)
AIS (Thailand)
DNA (Finland)
UQ (Japan)
3 Austria (Austria)
Qualcomm India LTE Venture (India)
TOT (Thailand)
EMT (Estonia)
KT (Korea)
3 Italy (Italy)
Samsung
Chunghwa Telecom (China HK)
Cota (Spain)
Nokia Siemens
Alcatel-Lucent
ZTE
Datang
Ericsson
Vividwireless (Australia)
Putian
NBN (Australia)
Huawei
Optus (Australia)
Alvarion
New Postcom
Cisco
FiberHome
Airspan
Motorola
Telkom/8ta (South Africa)
Clearwire (US)
Zodafones (Nigeria)
Sprint (US)
Xplornet (Canada)
YooMee Africa (Cameroon)
Sasktel (Canada)
SKY TV (Brazil)
Vodafone Portugal (Portugal)

Figure 2.

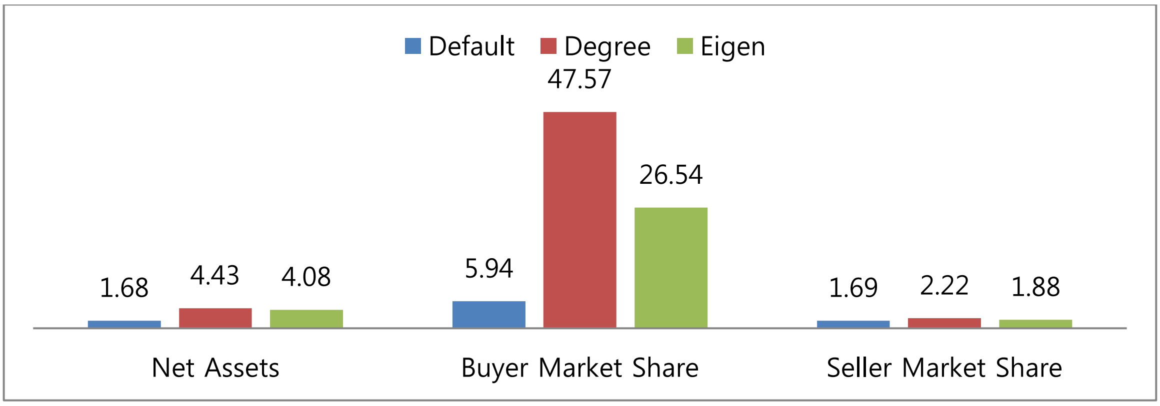

Figure 3.

Figure Captions

Figure 1. Network of WiBro (Mobile WiMax) deployment in the global market (Node (N) = 185)
Note: 20 vendors (clustered at the centre), 40 service providers in Europe (upper-left), 51 in Asia (upper-right), 5 in Oceania (right), 26 in North America (lower-right), 16 in South America (lower-left) and 25 in Africa (left)

Figure 2. Network of TD–LTE (LTE–TDD) deployment in the global market (N = 66)
Note: 14 Vendors (clustered at the centre), 17 service providers in Europe (upper-left), 23 in Asia (upper-right), 3 in Oceania (right), 4 in North America (Lower Right), 2 in South America (lower-left) and 3 in Africa (left)

Figure 3. Ratio of the main sponsors' net assets, buyer market share and seller market share (TD–LTE to WiBro)