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The complex temporal dynamics of an emerging infrastructure innovation: revisiting the 'failure' of the 'successful' innovation of Wireless Broadband (WiBro) in South Korea

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ABSTRACT

This paper explores the complex temporal dynamics of innovation through a longitudinal study encompassing the dramatic 'failure' of South Korea's flagship WiBro (wireless broadband) technology and services to achieve widespread uptake, following their apparently 'successful' development and launch. WiBro emerged in Korea by enrolling diverse actors with diverging orientations around a compelling broad vision and expected national and international markets. Launched in 2006, with buoyant expectations, WiBro failed to establish critical mass in mainstream markets in the face of growing competition from rapidly evolving mobile telephone technologies. Though players committed to WiBro managed to establish some specific niche markets, the service was finally terminated in 2018. This eventual failure was rooted in a sequence of decisions as orientations shifted over the course of WiBro's innovation. Generic and largely untested expectations were initially productive in enrolling a wide range of players in developing WiBro. However, tensions became acute as roll-out approached when the growing investments required to install a novel telecommunications infrastructure and launch WiBro services provoked more stringent assessment of specific options. As the stakes became higher, alignments shifted in a changing sociotechnical landscape; submerged differences in orientation resurfaced and commitments unravelled.

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Distributed governance of innovation; generic expectations; temporal dynamics; wireless broadband

Introduction

This paper explores the complex temporal dynamics of innovation, thrown into sharp relief by the unanticipated but dramatic 'failure' of WiBro technology and services to achieve widespread uptake, following their apparently 'successful' development. The novel wireless broadband technology that became known as WiBro, emerged through a South Korean R&D programme and was standardised, nationally and globally, under the vision of developing a 'home-grown' technology as an alternative pathway to efforts to extend 3rd Generation mobile telephony. Notwithstanding some generalised expectations about the scope for wireless data transmission, there was no clear prior understanding of how these technologies might be configured into novel telecommunications infrastructures. In a context in which no single policy or innovation player had the knowledge and cognitive authority

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needed to define innovation pathways, WiBro emerged through a gradual process of mutual sense-making and alignment, weaving together a range of industry, research and policy actors with more-or-less diverging orientations (Suh 2014). We conceptualised this as the *distributed governance of innovation* (Shen 2019).

Launched in South Korea in June 2006 with buoyant expectations, WiBro services failed to deliver expected national and international market growth, to the surprise of the players involved, who struggled to understand why this apparently 'successful' innovation 'failed to diffuse'. This paper examines the challenges encountered during the commercialisation of WiBro in the face of growing competition from rapidly evolving mobile telephone technologies and services. Though some niche markets were eventually established, WiBro failed to achieve critical mass in mainstream markets and the service was finally terminated in December 2018. WiBro's failure has been attributed to 'reverse salients' such as lack of demand and lack of investment, rooted ultimately in shortcomings in government policies (Park, Kim, and Nam 2015). Our goal is to go beyond such hindsight accounts to explain *why* WiBro initially prospered but ultimately failed as a result of the *complex temporal dynamics* surrounding the distributed governance of innovation. This paper thus explores the roots of WiBro's eventual failure in the challenges of sustaining interlocking commitments amongst diverse actors over time. Our analysis of temporal dynamics highlights how coordination challenges changed over the course of WiBro's innovation. Tensions became acute at the roll-out phase, when greatly increased investments were required to install a novel telecommunications infrastructure and launch WiBro services in Korea (see Figure 1). Key players reappraised previous generic commitments and focused on their specific options around WiBro and competing global technologies/services. Commitments progressively unravelled as alignments shifted and submerged differences in orientation resurfaced.

The temporal dynamics of alignment in emergent innovation

The concept of distributed governance highlights the intricate processes of shared sense-making and mutual alignment (and misalignment) in emergent innovation (Shen 2019). This paper explores further how players involved may make and unmake commitments over the innovation journey. These intricate processes were often overlooked in early innovation studies which saw the alignment of network members as a requirement for legitimacy and successful operation of innovation networks (Coombs and Metcalfe 1998). Here, and in many institutionalist accounts, individual players are portrayed as becoming aligned with and committed to collective visions arising from a field or dominant player (Jørgensen 2012), overlooking the possibility that players may be involved for opportunistic reasons and may not be fully committed. Less attention is paid to the convoluted web of interests and stakes for diverse players and their uneven agency which may generate conflicts and tensions and require compromises and trade-offs. Recent work has begun to redress these processes most strikingly in work on the orchestration of innovation networks (Hurmelinna-Laukkanen, Möller, and Nätti 2022)

Contributions from Science and Technology Studies, conversely, often highlight the fragility and reversibility (Callon 1990) of the processes through which players are enrolled in technoscientific projects, *inter-alia,* through the mobilisation of visions and expectations (Budde and Konrad 2019). Collaboration in innovation is a 'complex and *multi-level game*' in which participants have various covert goals as well as the publicly shared goals of a project (Williams, Stewart, and Slack 2005, 89). Those involved may seek to mobilise uncertainty as well as mitigate it (de Vasconcelos Gomes et al. 2018). Complex sets of choices must be negotiated between players with multiple, more-or-less-well-articulated interests which evolve through their interactions and as they address changing contingencies over time. Commitments are subject to multiple tensions and pressures (Jørgensen 2012) which may change in the course of an innovation project. As players are confronted by shifts in expected costs and opportunities over time, tensions may be rekindled and submerged differences may surface (Geels 2002; Deuten, Rip, and Jelsma 1997). Players may accordingly seek to slow down

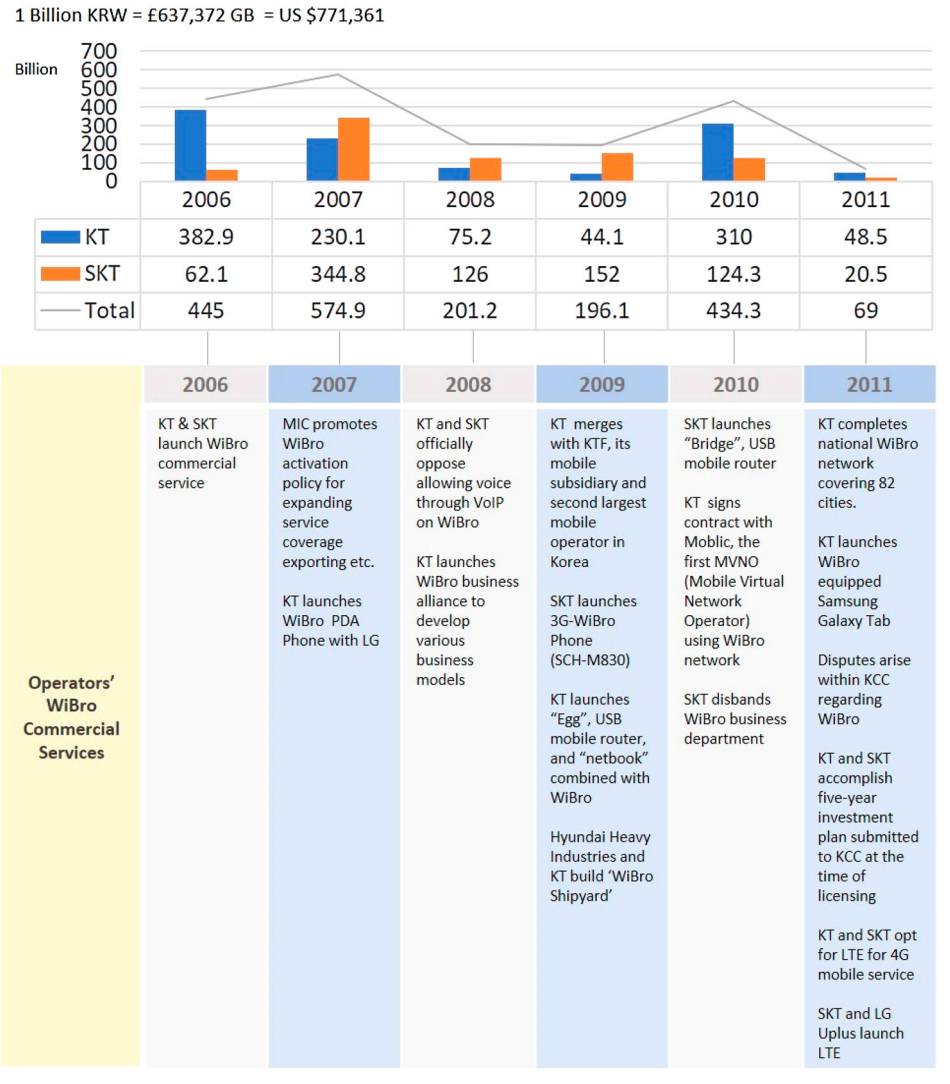


Figure 1. Operators' investment in WiBro (2006–2011). The graph has been created using <Tables 2–4> in Chung et al. (2011). Korea Communications Commission, 6.

innovation in the face of uncertainty or may find tactical advantage in accelerating innovation and undermining such 'waiting games' (Bakker and Budde 2012). Campagnolo, Nguyen, and Williams (2019) explored these temporal complexities in public-funded R&D for a projected new digital infrastructure. Formal statements of support and loose initial commitments from industrial players around a long-term future vision were subjected to different kinds of test as the project moved towards commercialisation. Established firms proved unwilling to make the significant investments needed – particularly as the novel infrastructure might 'cannibalise' their existing business operations. Analogous temporal complexities figure centrally in WiBro's innovation and ultimate failure.

The exigencies of coordination vary between different stages in an innovation (Shen 2019) and may become particularly acute as the investments required ramp up approaching commercial roll-out. Prevalent models of technology diffusion are weakly theorised (Sørensen 1996). Coordination challenges vary between socio-material settings and may be particularly acute when building novel telecommunications infrastructures (like WiBro) where network externalities and returns to

sunk investments lock-in incumbents (Lyytinen and Damsgaard 2001; Shen 2019), requiring challengers to coordinate their efforts for example through interoperability standards (Shapiro and Varian 1999). Large investments are needed to develop alternative technologies and to bring them to the market and prove and roll them out at sufficient scale to achieve 'critical mass' and deliver the performance/price needed to compete with existing entrenched infrastructures. Shen charts the coordination challenges arising at key junctures and especially as a technology moves from research and development to adoption, when the 'substantial investments needed to physically materialise and mature the prototype infrastructure to the point where it could compete in a market' (Shen 2019, 512) give rise to an emerging 'momentum gap'.

Methodology

To test and refine our understanding of the distributed governance of innovation and its intricate temporal dynamics we undertook a detailed longitudinal examination of the development of WiBro, from its initial conceptualisation to its market launch and uptake over an extended period (spanning 2001-2013). Our examination encompassed various key settings for WiBro's development including public sector research, standardisation, and spectrum licensing, and examined the commercial adoption of WiBro systems and services in an evolving technological and service environment. The key players included the government research institute: ETRI, Samsung Electronics, and the two major network operators, Korea Telecom (KT) and SKT. In addition, standardisation bodies such as Korea's Telecommunications Technology Association (TTA), IEEE and WiMAX also played a major role and contributed to developing specifications of WiBro technology and service.

We utilised multiple data collection methods and sources including analysing documents and archival records, interviews, and direct observations. The primary source was a series of semi-structured interviews undertaken during 2008–2012 with 24 key industry, research and policy players, many of whom had been directly involved in WiBro and who were exceptionally informative (detailed in Appendix 1). We also directly observed meetings and conferences during 2009-2011, where WiBro issues were addressed (detailed in Appendix 2). To capture the earlier emergence of WiBro, supplement contemporary ethnographic sources and document the wider context, we also collected policy documents, online sources including industry reports and news archives, trade and policy papers and journal articles. Triangulation of data enhances the validity of accounts of a particular phenomenon (Yin 2009), and it has allowed deeper and more reliable insights. Data analysis involved several rounds of coding and classification (Dey 1993) by applying labels, concepts and categories.

Retrospective analysis tends to focus on the self-evident reasons for an innovation's success and fails to treat symmetrically approaches that did or did not subsequently prevail (Pinch and Bijker 1984). Such hindsight accounts may underplay the profound uncertainties confronting actors at the time and the complexity of aligning interests. This paper seeks a more adequate account of technology emergence (and eventual downturn) through a detailed longitudinal study of a development from the earliest stages, drawing insights from the Biography of Artefacts and Practices perspective (Hyysalo, Pollock, and Williams 2019). Focusing on changing visions, interests and relations over time, our analysis tracks the extended biography of WiBro from initial conception to roll out. We chart this highly dispersed innovation process, highlighting the reciprocal processes whereby diffuse interactions give rise to partial and temporary technological closures and institutional stabilisations which in turn pattern social processes in agonistic ways which may sustain or transform these relations.

Findings

Diversity within the generic vision

Our detailed empirical account of the distributed governance of innovation focuses upon decisions made by the various players (system and device vendors and service providers) involved in building

the new WiBro infrastructure, summarised in Figure 2. To unpick the complex temporal dynamics of innovation, we chart the conflicts and contingencies that came to the surface particularly in commercialising WiBro devices and services and embedding them in the Korean market. WiBro technologies and standards were also being pursued in wider global markets. The exigencies surrounding national and global development were markedly different and the key players differed in their strategies and orientations towards these.

At a 2004 public hearing on WiBro Licensing Policy, Korea's Ministry of Information and Communication (MIC) put forwards its vision of WiBro as a service that would enable high-speed wireless Internet access. WiBro was positioned between existing mobile telephony and wireless LAN with regard to data-transfer speed, mobility (maximum travelling speed for handsets), and cell coverage (MIC 2004). WiBro was expected to complement high-speed broadband Internet and fixed wireless LAN by providing mobility, while providing wireless Internet access with higher data-transfer speed at lower cost than mobile telephony. The evolution of WiBro was anticipated to embrace diverse applications including Voice over Internet Protocol (VoIP) and to increase data-transfer speed from 1 Mbps to 50 Mbps at the current mobile device maximum velocity of 60 km/h. WiBro was

Year	Events
2006	• KT launches WiBro commercial service – one type of WiBro terminal available in the market: PCMCIA card for laptops • SKT and KTF launches commercial HSDPA (3.5G) mobile service
2007	• SKT opposes KT's plan for Voice over Internet Protocol • KT commercialises WiBro-enabled PDA • Mobile WiMAX (OFDMA TDD WMAN) approved by ITU as a new terrestrial radio interface for IMT-2000 • Modem developers release USB WiBro modems for dual usage (e.g. WiBro+DMB, WiBro+MP3, WiBro+HSDPA) • 2.3~2.4GHz frequency designated as spectrum band for 4G mobile communications by ITU
2008	• Korea Communications Commission (KCC) decides to allow Internet telephony (VoIP) on WiBro-enabled devices • Samsung and ETRI develop 'WiBro-evolution' (with increased download speed up to 149Mbps while moving at 350km/h) • Samsung launches WiMAX-enabled devices (Mobile PC and card) in the US
2009	• KT launches WiBro-enabled contents services by collaborating with content providers including Freechal, Soribada, etc. • KT merges with KTF (KT's mobile subsidiary) • SKT launches "Full-touch WiBro phone (SCH-M830), using 3G WCDMA for voice and WiBro for data service • KT launches WiBro "Egg" hotspot router (KWD-B2300) and "netbook"(small sized laptop) • POSDATA (WiBro system developer) gives up mobile WIMAX business • iPhone introduced in the Korean market using 3G • Hyundai Heavy Industries and KT build 'WiBro Shipyard' • KCC announces WiBro Vitalization Policy and requires KT and SKT to submit reports on service coverage
2010	• SKT launches "Bridge" WiBro hotspot router • KT and LG Telecom chooses to use LTE(Long Term Evolution) in 800/900MHz spectrum frequency band • KMI (Korea Mobile Internet) applies for WiBro service license • KT signs contract with Moblic, the first MVNO (Mobile Virtual Network Operator) using WiBro network • WiBro (IEEE802.16m) and LTE-Advanced accepted as 4G standard (IMT-Advanced) • KCC approves/invites applications for WiBro MVNO operators • Samsung expands its Mobile WiMAX reach by entering into agreement with telecoms in Bulgaria and Ukraine to upgrade Mobile WiMAX service with Samsung's equipment • SKT disbands WiBro business department • KCC disapproves KMI's application for WiBro service license
2011	• KT completes national WiBro network covering 82 cities. • KT launches WiBro implemented Samsung Galaxy Tab • ETRI and HHI collaborates on developing Digital Shipbuilding Yard Technology using WiBro network • Samsung Heavy Industry installs WiBro network with KT at Geoje Shipyard • Mobile operators SKT and LG Uplus launch 4G-LTE commercial service • KT launches 3W(3G, WiFi, WiBro) Smartpohone • Disputes arise regarding WiBro policy within Korea Communications Commission (KCC) • KCC rejects spectrum license applications from KMI and IST(Internet Space Time) for 4G-WiBro license

Figure 2. Timeline of WiBro service 2006–2011.

expected to play a complementary role to mobile telephony while competing to an extent with Wideband Code Division Multiple Access (WCDMA) which was being introduced for advanced mobile data services in the evolution of existing mobile communications networks. Table 1 compares WiBro with Wireless LAN and Mobile telephony.

In January 2005, Korean wireless spectrum licenses were allocated to KT, SKT and Hanaro Telecom. Though they had all been brought-in to the generic vision of WiBro, their specific visions for implementing WiBro service differed. KT, then the largest fixed-line carrier in Korea, envisioned a service providing seamless ubiquitous Internet access through fixed-mobile convergence network (Hwang 2004). By applying handover and roaming solutions, various services including Multimedia Messaging Service (MMS), Location Based Services, games, and Video-on-Demand (VoD) were expected to stimulate the diffusion of WiBro. Though KT's primary interest lay in entering the mobile market (as the fixed-line market was near saturation), it also positioned its mobile subsidiary, KTF, as a collaborator for developing bundled services for fixed-mobile convergence services (Ko 2005). On the other hand, Hanaro Telecom, Korea's second largest fixed-line broadband Internet carrier, envisioned WiBro as a service evolving from fixed-line Internet technology that would eventually compete with 3G and High-speed Downlink Packet Access (HSDPA) coming onstream in mobile networks. Hanaro Telecom thus insisted that WiBro licenses should not be allocated to 3G/HSDPA operators. As a broadband carrier, it aimed to deliver new services through WiBro such as VoIP and IP-TV (Galbraith 2005). Meanwhile, SK Telecom (SKT), the leading mobile operator, positioned WiBro as complementing their existing mobile services by offering enhanced services with high-speed data-transfer capability. SKT thus planned to provide data-intensive services such as VoD and other multimedia services at a lower flat rate. As WiBro was being built on technologies such as OFDM, then regarded as the evolving path towards next-generation mobile communications, SKT saw WiBro as laying within the boundary of mobile telephony. The visions and goals of the candidate operators thus diverged due to their varying historical backgrounds, current market positioning and relations to particular technologies.

Sensemaking and diverging choices

WiBro was not confined to the domestic market. MIC presented WiBro to the world at the November 2005 APEC meeting. KT, in close collaboration with Samsung, demonstrated advanced WiBro handsets, showcasing various applications such as multimedia messaging, VoD and video telephony as well as home networking using Tablet PCs connected to the WiBro network. Manufacturers like Samsung and LG had been developing their global strategies through the WiMax Forum, established in 2001 to certify broadband wireless products based on IEEE Standard 802.16. System vendors, including Samsung and POSDATA, had differing intentions and goals for commercialising WiBro. Samsung's commercialisation strategy was closely linked to their attempts to build overseas sales of their own products, where time-to-market would be critical for successful introduction. However, network operators wanted to secure wider interoperability of standards through collaboration among international operators and vendors, prior to or in parallel with the domestic implementation of systems and services. The vendors' demand for early commercialisation to provide a

Table 1. Comparison between WiBro, Wireless LAN and Mobile Telephony (MIC 2004).

Classification	Wireless LAN	WiBro	Mobile telephony
Application service	Wireless Internet	Wireless Internet	Voice and wireless Internet
Data speed/ subscriber	1Mbps and up	Approx. 1Mbps	Approx. 100kbps and up
Mobility	Walking	60 km/h and above[a]	250 km/h and above
Terminal	Desktop, laptop, PDA	Laptop, PDA, Mobile phone	Mobile phone, some PDA
Cell radius	Approx. 100m	Approx. 1km	1 km~3 km
Tariff system	Flat rate	Volume rate + Flat rate	Volume rate

[a]Data transfer speed gradually decreases with the increase in device velocity above 60 km/h.

'reference site' for successful implementation posed particular difficulties for operators. Furthermore, in parallel with these developments, mobile communications technologies were rapidly evolving worldwide beyond existing 3G. High-speed downlink packet access (HSDPA), was increasingly viewed as a key step towards what became characterised as 3.5G. WiBro was thereby positioned as a competing service rather than complementary to HSDPA (Na 2005).

Concerned about the substantial investments required with little prospect for a return, Hanaro Telecom returned its license and abandoned its implementation plans (Song 2005). WiBro service was henceforth to be implemented solely by KT and SKT. Their roadmaps for implementing WiBro differed in important respects. SKT, the leading mobile operator, had consistently insisted that WiBro play a complementary role to its own 3G network. However, as the relationship between the two networks evolved, SKT came to see WiBro and WCDMA as competing rather than being complementary to each other. SKT, as a mobile operator, was concerned about possible cannibalisation of its existing mobile services:

> from SKT's point of view, … we did participate very actively from the stage of writing up business plans for WiBro, but there was a dispute from the beginning with matters concerning cannibalization. There was an extent of overlap between mobile telephony and WiBro. (SKT Director, interviewed 13 September 2010)

Meanwhile, KT envisaged VoIP and various WiBro services converging including WLAN, DMB, GPS and CDMA, through multi-mode, multi-band mobile terminals. (Jang, Lee, and Han 2005).

SKT remained firmly opposed to deploying VoIP in the WiBro network, asserting that the 3G and WiBro licenses belonged to different classifications of communications services: 3G for voice and WiBro for data, reflected in the huge differences in the income generated by government auctions for 3G mobile (1.3 trillion KRW) and WiBro (175 billion KRW) licenses. These unresolved disputes, rooted in KT's and SKT's differing concepts and strategies, further delayed the development of mobile phones for WiBro. When the WiBro service was finally launched, as scheduled, on 30th June 2006, (MIC 2006), there was only one type of WiBro terminal on the market – the PCMCIA card for laptops.

Challenges in aligning choices in WiBro deployment

By 2009, mobile devices using WiBro were available including mobile PCs and smartphones, in addition to modem-type devices such as PCMCIA cards and USB modems (Kim 2009; Lee 2009). However, they suffered from low market adoption for various reasons including limited coverage and failed to deliver the original vision of WiBro as a data-intensive mobile service.

The Korean government, led by the Korea Communications Commission (KCC: responsible for regulating communications services), implemented various policy measures to tackle the key problems identified as causing sluggish market adoption. KCC pushed the operators to implement the plans they had submitted at the time of spectrum licensing, permitting VoIP (KCC 2008). However, KCC's efforts did not provide a quick remedy for the 'diffusion lag'.

Developing and deploying WiBro products and services faced challenges of aligning various choices taking place simultaneously in diverse markets including 3G, fixed-line broadband Internet, and broadcasting services (e.g. Digital Mobile Broadcasting). WiBro network coverage remained limited compared to mobile telephony (Kim 2009) and by October 2010 extended only to Seoul and the major cities in the suburbs, six metropolitan cities, and major highways (Seok, Lee, and Song 2011). Nationwide network coverage was a critical precondition for early and timely uptake of WiBro's generic capabilities by device manufacturers, applications developers, and content service providers (Jang, Lee, and Han 2005). The slow expansion of coverage made it harder to convince suppliers to invest in WiBro devices and services, creating additional problems in competing with existing mobile phones. As one manufacturer told us: 'if there is large demand, it's worth investing and if it's not we won't'. The limited sales of WiBro-embedded mobile phones in turn resulted in low quality of service in mobility, stability, battery life, and security (Kim and Lee 2008).

> We … thought we needed a phone … to enter the mass market … but it wasn't easy … There were various technical difficulties and bugs, and insufficient design aspects. There were already 45,000,000 very nice phones on the market. To make our [WiBro] phones as nice as them, we would have to order several hundred thousand or a million phones … but we had only tens of thousands of phones, and as a result, although the size was big, the design was not very nice. The phone got disconnected easily, and the screen would black out … … We may be developing phones in the future but for now, phones are difficult to develop. Using common sense, it's really good to have WiFi, 3G, and WiBro on one phone. But if they are included, the size becomes bigger, there is higher power consumption, the battery doesn't last long, software gets entangled inside, and thus difficult technically. It would seem nice to have everything included together, but that is not easy. (KT Director, 27 May 2010)

A vicious circle arose in which the lack of nationwide coverage of commercial WiBro services in the early years created challenges for expanding the user base; the limited coverage and rather slow expansion prevented the operators from attracting a wider array of device manufacturers, which in turn impeded extension of coverage and improvement in products and services.

Searching for the niche: struggles to create novel alignment

Confronted by obstacles that could not be resolved in the short-term, KT searched for niche applications where WiBro could build the momentum needed to support further diffusion. KT and SKT in 2009/2010 launched a router that used the WiBro network to connect WiFi devices such as iPod Touch, laptops and netbooks, and Nintendo DS. This slightly increased the rate of adoption of WiBro services, along with sales of small-sized laptops: 'netbooks' (Seok, Lee, and Song 2011). The success of these WiBro-enabled mobile routers prompted KT to develop business-to-business solutions using the WiBro network. KT's mobile router, Egg, was implemented in one of South Korea's largest private taxi companies. KT and ETRI (one of the core WiBro developers) collaborated with Hyundai Heavy Industry (Park et al. 2010) to develop and deploy WiBro services in the challenging shipbuilding environment (Cheong 2009).

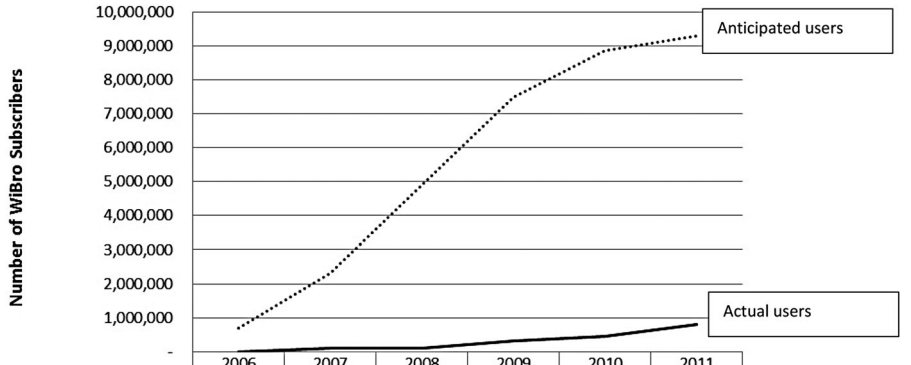
Despite the efforts to develop niche services, WiBro remained peripheral in the evolving telecommunications market. There was no 'killer' application to drive the use of WiBro beyond its simple Internet-access service. Mobile VoIP had been considered a potentially important application for WiBro. The Korea Communications Commission (KCC) eventually allowed commercial deployment of VoIP using WiBro – including use of the same prefix number (010) as existing mobile telephones in December 2008 (KCC 2008). However, this did not turn around the telecommunications market. KT's 2009 merger with its mobile subsidiary KTF, then the second largest mobile operator in Korea, resulted in a radical shift in KT's orientation to WiBro. KT, as an operator of both mobile telephony and WiBro, now redefined WiBro as a data only service. Crucially, VoIP was no longer pursued as it would now cannibalise KT's mobile telephony business:

> From KT's viewpoint, there was no need for WiBro voice. There had been, before the merger with KTF. At first, we had pursued a triple-play concept that would enable voice with video, broadcasting, and Internet. … For HSDPA, a subset technology to WCDMA, voice is the key. It has nationwide coverage. However, the capacity falls short for data [service]. … WiBro is data-service centered. Coverage focuses on big cities. Apart from those places, the usage is not heavy, and therefore HSDPA can be used. (KT Director, 16 October 2009)

By 2011, five years after WiBro's commercial launch, the gap between the initial visions and the actual adoption of the service became evident. WiBro had initially been expected to carry data intensive mobile multimedia services, reaching 8.5–10.5 million subscribers, with sales up to 7 trillion KRW by 2010 (MIC 2004). However, by November 2011, there were only 799,464 WiBro subscriptions (KCC 2011b; TTA 2006). The slow growth of WiBro subscriptions and sales prompted deepening concerns about the viability of WiBro services in the evolving telecommunications market (Figure 3).

Reshaping the generic vision of WiBro (2011–2013)

Alongside the struggles to promote domestic WiBro services, wireless data technologies, including IEEE802.16e for WiBro and WCDMA for 3G mobile communication, were being further developed



	2006	2007	2008	2009	2010	2011
WIBRO Subscribers (Annual Statistical Report by KCC)	1,011	106,153	106,422	316,800	465,549	799,464
Number of Subscribers anticipated by KISDI (2004)	706,000	2,309,000	4,898,000	7,484,000	8,853,000	9,297,000

Figure 3. Anticipated and actual number of WiBro subscribers (2006–2011) (adapted from Lee et al. 2011).

globally to meet evolving visions of next-generation, '4G' mobile communications technologies. WiBro/IEEE802.16e had been acknowledged as a 3G mobile communications technology by the International Telecommunications Union in 2009 (ITU). A later evolution, IEEE802.16 m, was proposed for the next generation of (4G) standards for global wireless broadband communications known as WirelessMAN-Advanced, alongside the 3rd-Generation Partnership Project (3GPP) proposal for Long Term Evolution labelled LTE-Advanced (ITU 2009). The two technologies were then largely regarded as competing standards for 4G next-generation mobile technology (ITU 2012).

> The 4G war has begun at the verge of opening up WiBro … At this stage, how are we going to advance WiBro while at the same time accepting LTE? We shall not be closed … We should accept it. Yet, we need a strategy, such as controlling the time of release, etc. I believe we need to be the global mobile testbed by being successful with WiBro as well as adopting the 4G [LTE] technology. New services shall find a way forward by being tested in our nation. We shall then be the central nation for 4G mobile communications, creating national wealth, and exporting our products. (Speech by Lee BK, KCC, at 4G Communication Symposium, 29 October 2009)

However, the development of two differing standards (WiBro/IEEE802.16e and HSDPA) towards 4G created dilemmas for operators which would need to invest in and operate both networks. KT and SKT, though carrying both networks, clearly chose their innovation path for mobile telephony towards LTE (in response to the rapid increase in the use of smartphones following the success of the Apple iPhone). They launched LTE services in July 2011 (Lee 2011). Operators around the globe also increasingly opted for LTE. Market research predicted faster growth for LTE than mobile WiMAX leading to a 83:17% division of the global subscriber market (Kim 2012a). A cascade of mutually-reinforcing decisions by producers, implementors and end-users led to the rapid exclusion of minority providers internationally as well as within Korea as WiMAX operators opted for LTE to replace existing WiMAX services in their continuing transition to 4G (Jang 2013).

The dilemma about promoting two competing services raised concerns about the need to reorient WiBro policy. Although Korean government policy measures continued to promote the domestic WiBro service (e.g. by encouraging low price data services), disputes arose over whether the government should promote WiBro domestically or concentrate on expanding overseas markets for Mobile WiMAX. KCC needed to decide about the renewal of the spectrum licenses for WiBro before the initial spectrum licenses expired in 2012. This decision became coupled with assessments of progress to date and future prospects for developing WiBro services. Given the low uptake of WiBro services, a debate arose over whether, instead of renewing the license for use by the two operators, the spectrum should be reallocated (KCC 2011a).

Though KCC eventually approved the renewal of KT and SKT's WiBro spectrum-licenses, its announcement on 16 March 2012 (KCC 2012) confirmed profound changes in the generic vision that had guided WiBro policy since its inception. WiBro promotion policy for the domestic market shifted to advancing WiBro in a complementary relationship to 3G, evolving to 4G LTE. Plans to promote WiBro thus included expanding service coverage around areas with large floating populations, such as subways and highways, as well as deploying mobile public routers in cities and intercity buses. WiBro was redefined as being data-centred: primarily operating on laptops, tablet PCs, and mobile routers.

This did not end the controversy around the use of the spectrum for WiBro. Some saw the repositioning of WiBro as a data-service network as confirming the failure of the WiBro policy. Growing voices argued for reallocating the WiBro spectrum for other uses, and in particular Time-Division Duplex (TD or TDD), the alternative to Frequency Division Duplexing (FDD) for the Long-Term Evolution (LTE) mobile communication technologies approved by 3GPP (Yeo 2012). An increasing number of global WiMAX operators such as P1 in Malaysia, Clearwire in the US and Yota in China opted to shift to TD-LTE for their mobile communications services (WiMAXForum 2012). The global TD-LTE alliance was expanding as global operators and system and terminal manufacturers joined to implement the technology (Ayvazian 2013; Samsung Electronics Co. 2012).

KCC firmly opposed KT's intention to opt for TD-LTE. However the government came under criticism for its inflexibility in the fast-evolving technological landscape. What had earlier been portrayed as a strength – a ground-breaking opportunity to project Korean standards and IP internationally – was now seen as a weakness – and compared to Japan's 'Galapagos Effect': unproductive unique, innovations isolated from the rest of the world (Chung 2012). Differing perspectives emerged within government (Yeo 2012). In October 2013, the new Ministry of Science, ICT and Future Planning (MSIP which integrated some KCC functions into the former Ministry of Education and Science Technology) announced a plan to allocate 2.5 GHz spectrum – the frequency band used more widely for mobile WiMAX service around the world (KCC 2011a) – for *either* WiBro *or* LTE TDD, whichever was chosen by the new operator (MSIP 2013). This step followed WiMAX Forum's September 2013 decision to accommodate and guarantee full compatibility with LTE TDD, to support the continued evolution of the WiMAX ecosystem.

However, despite repeated allocation plans and auctions for the 2.5 GHz frequency band in Korea, KCC failed to find a new operator (Jahng 2017). WiBro services were terminated on 31 December 2018 before KT and SKT's licenses expired in March 2019. The world's first mobile WiMax service ended after 12 years, as KT and SKT, operating both WiBro and LTE clearly chose their pathway to LTE, and no other operator was licensed to operate LTE TDD.

Analysis and conclusions

This investigation started with a puzzle – an apparently successful technological development that unexpectedly failed to diffuse into anticipated markets (Park, Kim, and Nam 2015). Through a detailed longitudinal study, we have tracked the intricate processes through which diverse actors with more or less aligned perspectives, capabilities and strategies, were initially woven together around their anticipated contribution to a future envisaged infrastructure. Commitments were secured by articulating a compelling generic vision of Wireless Broadband through which diverging agendas were accommodated (Levy 2008). This process, conceptualised as the distributed governance of innovation, is particularly challenging when building novel telecommunications infrastructures given the sustained effort and substantial investments that must be coordinated amongst multiple diverse actors (Shen 2019; Suh 2014). We examined how these intricate sets of relations became subject to contradictory pressures and tensions, as the technology was commercialised and rolled out.

Our account of the temporal complexity of this dynamic process emphasises the multiplicity of commitments unfolding over time across a heterogeneous array of actors. Their different and

changing orientations are rooted in their resources and capabilities – shaped by their history, context and prior commitments and ongoing interactions – and the threats and opportunities actors accordingly perceive. We explored empirically how alignments are built and sustained in a complex multi-level game. Coordinating the innovation of highly elaborate technological assemblages like novel telecommunication infrastructures – comprising multiple interconnecting complementary technologies and services – is particularly challenging. Nested sets of commitments to particular innovation pathways and standards need to be secured in an orchestrated manner from diverse actors operating more or less independently. Outcomes are strongly affected by the behaviour of others involved in the proposed (and competing) programmes nationally and internationally. Their commitments differ, in part because of their different stakes, which may vary, contingent upon other perceived opportunities and threats in a rapidly changing context.

Rather than treating organisations as homogeneous, stable actors, our account highlights complex interdependencies, instabilities, tensions and differences in orientation – resulting from their differing history, structure and location in an evolving coordinated environment. Initial generic commitments to a promising innovation may not be tested until organisations are required to commit the substantial investments needed to build a new infrastructure (Campagnolo, Nguyen, and Williams 2019). In the WiBro case, apparently strong interlocking commitments of diverse industry players, united by reinforcing generic expectations of national and international markets, faltered – particularly when players were required to make substantial concrete commitments to invest in and implement WiBro in their networks, especially when the two main operators increasingly positioned WiBro as complementary to 4G/LTE services while investing 15Tn Kwon/US$12bn to roll-out national LTE networks in 2011–2013 (Cho 2014). In such a context, commitments were reappraised. There was, however, no single decision point to withdraw from WiBro. Instead, as actual achievements deviated from confident projections of roll-out and market growth, we observed a mutually reinforcing cascade of decisions that closely parallel the kind of vicious circle leading to market exclusion of 'losers' in standards wars. In this process WiBro was downgraded from a pervasive general infrastructure, around which an increasing range of services would be expected to converge, to a niche-specific solution where viable discrete application markets could be established.

Complex temporal dynamics of innovation governance – particularly for novel infrastructures

There is an enduring tension, as an innovation unfolds over time, between the benefits of aligning effort around particular visions versus the need for diversity and flexibility in an uncertain and turbulent contexts (Williams, Stewart, and Slack 2005). Collingridge (1992), observing that tight alignment of innovation and policy players around particular conceptions could lead to failure in changing settings, argued the value of loosely coupled arrangements to ensure flexibility and hedge in case one pathway proved unproductive.

In the WiBro case, the loose-coupling of the internally-diverse ecology seems to have played a generative role in facilitating the emergence of a novel, embryonic technology around a generic 'vision' that satisficed a diverse array of interests. Initially only modest levels of immediate investment and weak future commitments were required. A thicket of broad, mutually-reinforcing positive expectations assisted alliance building, diverting attention away from risks of failure and potential conflicts of interest. Participants were able to suspend judgement about the accuracy of particular promises until their prospects could be more reliably addressed. Compelling visions can protect a collective enterprise from particular tests (e.g. demonstrating return on investment) that could not be reliably assessed at that moment. Innovators may have a range of motives to align with a promising emerging technology – for example to publicly signal their capabilities (Bakker and Budde 2012) – as well as securing early access if a technology eventually succeeds, without at that stage necessarily committing the much higher level of resources needed to bring it to market (Campagnolo, Nguyen, and Williams 2019).

These considerations help us understand the complex temporal dynamics surrounding highly-elaborate technological innovations. These are particularly challenging with novel telecommunications infrastructures given the huge investments required not just to install a new physical infrastructure but also to prove equipment and services and roll them out at scale needed to achieve critical mass, reduce price and develop sustainable services (Shen 2019).

The degree of commitment of a player to a particular innovation pathway is liable to change over time as competing strategic opportunities open and close. WiBro's emergence had been coordinated through generic visions and future expectations. As WiBro moved towards roll-out, a different register came to the fore. Earlier loose generic promises gave way to more concrete assessments of market prospects as investment requirements ramped up (Paik, Kim, and Park 2010; Park, Kim, and Nam 2015) (see Figure 1). Proposals were subjected to more stringent appraisal. Options came to be seen differently as the broader landscape for telecommunications technology and services evolved. Alternative pathways to WiBro for mobile data services – in particular mainstream 4G [LTE], then evolving towards 5G – were becoming entrenched nationally and internationally. Organisations reassessed their previous commitments. Disputes emerged as individual players shifted position. When WiBro market opportunities did not materialise in ways anticipated, while others realigned with mainstream global mobile markets, players committed to WiBro technology were driven to identify alternative markets offering realisable returns, culminating in the identification of niche markets where WiBro had particular advantages. In this process the generic vision of WiBro came to be replaced by a set of more specific conceptualisations.

Policy implications

Our exploration of the distributed governance of innovation highlights both the opportunities through effective intervention to catalyse radical innovation (Korea's success in establishing a novel communications technology, driven by the goal of Korea's government and major corporations to be producers rather than users of intellectual property and standards [Kim 2012b]) and also the potential pitfalls in adhering to initial visions and alignments. The case highlights the difficulties besetting attempts to 'pioneer' in technological innovation (i.e. to develop indigenous technologies), that face uncertainty and changing contingencies, especially in thoroughly globalised technological fields such as telecommunications. National strategies need to be closely correlated within global developments (Molina 1998) to avoid the risk of creating unique innovations isolated from the rest of the world (Chung 2012). National policy needs to take into account the temporal dynamics of distributed innovation governance and flexibly respond to changing contingencies surrounding sociotechnical innovations.

Strengths, weaknesses and opportunities for further research

The strength of this investigation has been its engagement with a multi-faceted collaborative innovation journey, through detailed study encompassing multiple actors and nexuses of interaction over an extended period. This investigation revealed the interaction between multiple choices and how these are orchestrated through the mutual alignment and sensemaking processes we characterised as the *distributed governance of innovation*. Our analysis captured the intricate and changing dynamics – from initial emergence to commercial launch and the escalating sequence of shifts which resulted in ultimate failure. Our empirical engagement over extended duration across a network of players was achieved (in the context of finite research resources) at the expense of depth. This limited our ability to engage with processes within particular organisations and thereby examine how intra-organisation configurations patterned the unfolding of inter-organisational interactions. Detailed organisational studies might resolve the questions raised in this paper about the criteria by which projects were assessed and how these change as an innovation moves from experiment to roll out.

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References

Ayvazian, B. 2013. "WiMAX Advanced to Harmonize with TD-LTE in the 2.3, 2.5 & 3.5 GHz Bands Opportunities & Challenges for WiMAX 2." https://files.wimaxforum.org/Document/Download/WiMAX_Advanced_to_Harmonize_with_TD-LTE last sampled.

Bakker, S., and B. Budde. 2012. "Technological Hype and Disappointment: Lessons from the Hydrogen and Fuel Cell Case." *Technology Analysis & Strategic Management* 24 (6): 549–563. doi:10.1080/09537325.2012.693662

Budde, B., and K. Konrad. 2019. "Tentative Governing of Fuel Cell Innovation in a Dynamic Network of Expectations." *Research Policy* 48 (5): 1098–1112.

Callon, M. 1990. "Techno-Economic Networks and Irreversibility." *The Sociological Review* 38 (Suppl. 1): 132–161. doi:10.1111/j.1467-954X.1990.tb03351.x

Campagnolo, G. M., H. T. Nguyen, and R. Williams. 2019. "The Temporal Dynamics of Technology Promises in Government and Industry Partnerships for Digital Innovation: The Case of the Copyright Hub." *Technology Analysis & Strategic Management*, doi:10.1080/09537325.2019.1580358.

Cheong, Y. S. 2009. "IT Convergence in Shipyard." *IT Convergence International Conference* 2009 (in Korean).

Cho, J. 2014. "Korea Pours $4b a Year into 4G LTE Networks." *ZDNet*. https://www.zdnet.com/article/korea-pours-4b-a-year-into-4g-lte-networks/. last sampled.

Chung, Y. H. 2012. "WiBro, Like Japanese Electronics Industry? Deepening Sense of Crisis." *ZDNet* Korea. (in Korean).

Chung, I. J., J. H. Yeo, D. M. Lim, and J. Y. Kim. 2011. *A Study on the Renewal and Pricing Policy for Radio Spectrums, Broadcasting and Communications Policy Research*. Korea Communications Commission.

Collingridge, D. 1992. *The Management of Scale: Big Organizations, Bid Decisions, Big Mistakes*. London: Unwin Hyman.

Coombs, Rod, and Stan Metcalfe. 1998. *Distributed Capabilities and the Governance of the Firm, CRIC Discussion Paper No 16*. Centre for Research on Innovation and Competitiveness, University of Manchester.

Deuten, J. J., A. Rip, and J. Jelsma. 1997. "Societal Embedding and Product Creation Management." *Technology Analysis & Strategic Management* 9: 131–148. doi:10.1080/09537329708524275

de Vasconcelos Gomes, L. A., M. S. Salerno, R. Phaal, and D. R. Probert. 2018. "How Entrepreneurs Manage Collective Uncertainties in Innovation Ecosystems." *Technological Forecasting and Social Change* 128: 164–185. doi:10.1016/j.techfore.2017.11.016

Dey, I. 1993. *Qualitative Data Analysis: A User-Friendly Guide for Social Scientists*. London: Routledge.

Galbraith, M. 2005. *Thrunet takeover to Stabilize Korean Broadband Market*. Telecom Asia.

Geels, F. W. 2002. "Towards Sociotechnical Scenarios and Reflexive Anticipation: Using Patterns and Regularities in Technology Dynamics, Chap. 13." In *Shaping Technology, Guiding Policy: Concepts, Spaces and Tools*, edited by K. H. Sørensen, and R. Williams, 359–385. Cheltenham: Edward Elgar.

Hurmelinna-Laukkanen, P., K. Möller, and S. Nätti. 2022. "Orchestrating Innovation Networks: Alignment and Orchestration Profile Approach." *Journal of Business Research* 140: 170–188. doi:10.1016/j.jbusres.2021.11.084

Hwang, H.-T. 2004. "KT WiBro Service Provision Plan." (Unpublished Presentation Document in Korean).
Hyysalo, S., N. Pollock, and R. Williams. 2019. "Method Matters in the Social Study of Technology: Investigating the Biographies of Artifacts and Practices." *Science and Technology Studies* 32: 3. doi:10.23987/sts.65532
ITU. 2009. *IMT-Advanced (4G) Mobile Wireless Broadband on the Anvil*. ITU Press release 21 October 2009 reposted at https://developingtelecoms.com/telecom-business/telecom-regulation/2329-imt-advanced-4g-mobile-wireless-broadband-on-the-anvil-says-itu.html.
ITU. 2012. *IMT-Advanced Standards Announced for Next-Generation Mobile Technology*. ITU Press Release https://www.itu.int/net/pressoffice/press_releases/2012/02.aspx last sampled 30.11.2021.
Jahng, J. H. 2017. Trend and Prospect on TDD, Electronics and Telecommunications Trends, 32:2, 80–89. https://ettrends.etri.re.kr/ettrends/164/0905002199/0905002199.html (in Korean) last sampled 2.12.2021.
Jang, S. K. 2013. "Would WiBro Resurrect Through 4G Mobile Communications." *Korea Economy Magazine*. https://magazine.hankyung.com/business/article/202102244615b (in Korean) last sampled 2.12.2021.
Jang, B. J., S. H. Lee, and J. Y. Han. 2005. *Telecommunications Market Structure Change Due to Fixed and Mobile Convergence*. Research Report 05-09, KISDI (in Korean).
Jørgensen, Ulrik. 2012. "Mapping and Navigating Transitions – The Multi-Level Perspective Compared with Arenas of Development." *Research Policy* 41: 996–1010. doi:10.1016/j.respol.2012.03.001
KCC. 2008. *KCC Permits '010' Prefix Number for WiBro Use*. Press release. https://kcc.go.kr/user.do?mode=view&page=A05030000&dc=K00000001&boardId=1113&boardSeq=15476. (in Korean) Korea Communications Commission last sampled 2.12.2021.
KCC. 2011a. *A Study on the Renewal and Pricing Policy for Radio Spectrums*. Broadcasting and Telecommunications Policy Research, KISDI. (in Korean) Korea Communications Commission.
KCC. 2011b. *Broadcasting & Telecommunications Industry Statistics Monthly Report* (November 2011) (in Korean), Korea Communications Commission.
KCC. 2012. *Decision on WiBro Policy Direction and Spectrum Renewal*. (in Korean) Korea Communications Commission.
Kim, Y. H. 2009. "The Current Trends of WiBro Business and Future Directions." In NARS, ed., *NARS Pending Issue Report*, 52(Dec 15 2009), National Assembly Research Service (in Korean).
Kim, S. H. 2012a. *WiBro Market Trend and Outlook and Policy Direction, Trends, Broadcasting & Telecommunications Policy* 24:23 KISDI, 72–81. (in Korean).
Kim, S. Y. 2012b. "The Politics of Technological Upgrading in South Korea: How Government and Business Challenged the Might of Qualcomm." *New Political Economy* 17 (3): 293–312. doi:10.1080/13563467.2011.574687.
Kim, D. H., and S. J. Lee. 2008. "Mobile Communications Handsets." In S. Securities, ed., *In-depth Report*, Seoul, Korea. (in Korean).
Ko, J.-S. 2005. KT WiBro Business and Network Construction Plan: *Telecom*, v. 21. 68–78 (in Korean).
Lee, E. Y. 2009. "SKT Launches Full Touch WiBro Phone." *Electronic News*, Seoul, South Korea. https://www.etnews.com/200905190021 (in Korean).
Lee, J. H. 2011. "Issues and Future Outlook Regarding Domestic Three Mobile Operators' Choice upon LTE and WiBro." *4G Era Special Theme* Summer Vol 57, 14–20, Korean Telecommunications Operators Association, Seoul, Korea (in Korean).
Lee, Y. S., J. R. Chung, S. H. Park, and S. W. Kim. 2011. *A Study on Policies for the Activation of WiBro Market: Korea System Dynamics Research*, 12.
Levy, David L. 2008. "Political Contestation in Global Production Networks." *Academy of Management Review* 33 (4): 943–962. doi:10.5465/amr.2008.34422006
Lyytinen, K., and J. Damsgaard. 2001. "What's Wrong with the Diffusion of Innovation Theory?" In *Diffusing Software Product and Process Innovations. TDIT 2001. IFIP – vol. 59*, edited by M. A. Ardis, and B. L. Marcolin. Boston, MA: Springer. doi:10.1007/978-0-387-35404-0_11
MIC. 2004. *WiBro (Portable Internet) Licensing Policy Scheme*. Ministry of Information & Communications. Press release (in Korean).
MIC. 2006. *WiBro (Portable Internet) World's First Commercial Service Launch*. Ministry of Information & Communications. Press Release (in Korean).
Molina, A. 1998. "The Nature of 'Failure in a Technological Initiative: The Case of the Europrocessor." *Technology Analysis & Strategic Management* 10 (1): 23–40. doi:10.1080/09537329808524302.
MSIP. 2013. *MSIP Decides on WiBro Policy Direction*. Ministry of Science & ICT and Future Planning. Press release (in Korean).
Na, J. H. 2005. *HSDPA, Tsunami of Mobile Communications Market is Coming*. http://www.lgeri.co.kr/uploadFiles/ko/pdf/pub/indus826_1_20050401114241.pdf.
Paik, J. H., M. K. Kim, and J. H. Park. 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* 7 (1): 36–49.
Park, J., S. Kim, and C. Nam. 2015. "Why has a Korean Telecommunications Technology Failed: A Case Study on WiBro." *Telematics and Informatics* 32 (4): 603–612. doi:10.1016/j.tele.2015.01.002.
Park, J. H., J. M. Kim, M. K. Oh, D. S. Lim, and H. S. Ham. 2010. "Convergence Between Ship Industry and IT towards the Best of Best in the Global Ship Industry." *Weekly Technology Trends*, NIPA.

Pinch, Trevor J., and Wiebe E. Bijker. 1984. "The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other." *Social Studies of Science* 14 (3): 399–441. doi:10.1177/030631284014003004

Samsung Electronics Co., L. 2012. *Timing the Move to TD-LTE*. Suwon, Gyeonggi-do, South Korea.

Seok, W. H., K. S. Lee, and Y. K. Song. 2011. "Current Status and Prospect of WiBro Market." *Electronics and Telecommunications Trends*, v. 26.

Shapiro, Carl, and Hal R Varian. 1999. *Information Rules: A Strategic Guide to the Network Economy*. Boston: Mass.: Harvard Business School Press.

Shen, Xiaobai. 2019. "Building 'Mass' and 'Momentum' – A Latecomer Country's Passage to Large Technological Systems – The Case of China." *Technology Analysis & Strategic Management* 31 (5): 503–516. doi:10.1080/09537325.2018.1519184.

Song, J. R. 2005. "Hanaro Telecom Gives Up WiBro: Where to Find its Growth Power." *ZDnet* Korea, 26 April. (in Korean).

Sørensen, Knut H. 1996. "Learning Technology, Constructing Culture: Sociotechnical change as social learning." *STS Working Paper* 18/96, Trondheim: Norwegian University of Science and Technology.

Suh, J. H. 2014. "The Co-Evolution of an Emerging Mobile Technology and Mobile Services: A Study of the Distributed Governance of Technological Innovation Through the Case of WiBro in South Korea." Unpublished Doctoral Dissertation, University of Edinburgh, Scotland.

TTA. 2006. Standardization Roadmap for IT839 Strategy. *2006 ICT Standardisation White Paper*, Telecommunications Technology Association, Chapter 3, 276–279 (in Korean).

Williams, R., J. Stewart, and R. Slack. 2005. *Social Learning in Technological Innovation: Experimenting with Information and Communication Technologies*. Aldershot: Edward Elgar.

WiMAX-Forum. 2012. *WiMAX Forum Newsletter* (November 2012).

Yeo, J. H. 2012. Next-generation Mobile Communications Network and Spectrum Policy Direction. In KISDI, ed., *KISDI Premium Report*. (in Korean).

Yin, R. K. 2009. *Case Study Research: Design and Methods Applied Social Research Methods Series; v. 5*. Thousand Oaks, CA: Sage.

Appendices

Appendix 1: Interviews conducted

Organisation affiliation[a]	Position	Field of Expertise[b]	Interview	Date of interview
Samsung Electronics	Executive director	Marketing	1	4 Mar 2010
Samsung Electronics	Head of dept.	Mobile device	1	2 Sep 2009
Samsung Electronics	Manager	Mobile device	1	2 Sep 2009
Samsung Electronics	Manager	Mobile device	1	2 Sep 2009
Samsung Electronics	Senior researcher	Standardisation	1	29 Sep 2009
Samsung Electro-mechanics	Deputy head	System R&D	2	16 Aug 2009/12 Feb 2012
ETRI	Director	System R&D	1	31 May 2010
University (Telecommunications Technology Association)	Professor (Head)	Standardisation	1	15 Oct 2009
KT	Director	Standardisation	1	16 Oct 2009
KT	Manager	Network R&D	1	2 Apr 2010
KT	Assistant manager	Network R&D	1	2 Apr 2010
KT	Senior researcher	Network R&D	1	10 Sep 2009
KT	Director	Marketing	1	27 May 2010
SKT	Director	Corporate policy	1	13 Sep 2010
RAPA Korea Radio Promotion Association. (Thrunet)	Director (Director)	Spectrum licensing	1	26 May 2011
Department of Knowledge & Economy, Ministry of Information and Communication	Secretary	Government policy	1	14 Oct 2009
National Assembly Research Service	Head of Dept.	Government policy	1	21 Dec 2012
Hyundai Heavy Industry	Head of Dept.	Application	1	10 Feb 2010
Hyundai Heavy Industry	Deputy head	Application	2	5 and 10 Feb 2010
Hyundai Heavy Industry	Staff	Application	1	10 Feb 2010
Hyundai Motor Company	Manager	Application	1	19 May 2010
MODACOM	CTO	Mobile device	1	15 Jul 2010
SeAH (POSDATA)	(Chief engineer)	System R&D	1	28 May 2010

[a]Prior affiliations and positions in brackets.
[b]Field of expertise categorized by the researcher and generally complies to the role or department the interviewee belonged to.

Appendix 2: conferences and meetings attended for research

Event name	Date	Organised by
Next-generation Mobile Communication Technology and Industry Trend Seminar	20 August, 2009	Korea Electronics Technology Institute (KETI)
The 3rd Communication Vision	24 September, 2009	MegaNews, ZDNet Korea
4G Communication Technology Core Technology and Evolution Strategy Symposium	29 October, 2009	Korea Institute of Communications and Information Sciences (KICS)
The 4th WiBro Convergence Service Technology Workshop	4–5 March, 2010	Korea Institute of Communications and Information Sciences (KICS)
The 5th Communication Vision: Outlook on the changes in Mobile Ecosystem and Business in the 4G era	27 September, 2011	MegaNews, ZDNet Korea