An Evolutionary Approach to Technology Standard Competition: Focusing on 4th wireless telecommunication technology

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ABSTRACT

Technology standard competition is a fierce competition between technologies to become a de facto standard. This is because a company or a group that develops and secures a de facto standard technology can gain an edge in the market and industry.

This study applies the evolutionary perspective of natural selection to interpret the competition between technologies. By genetically interpreting the process of natural selection, the traits suitable for the environment spread to the group through generations through a mechanism called differential reproduction. By culturally interpreting the process of natural selection, the strategies to get higher payoffs spread to the group through generations by diffusion. In order to compare the payoffs between WiMAX technology and LTE technology, the measurement indicators were extracted from the patent data and defined. As a result, it was confirmed that LTE technology standard was technologically superior to the WiMAX technology standard.

The main academic contribution of this study Is to compare the technology-related indicators such as diffusion, scope and profitability to figure out strategies to get higher payoffs between the WiMAX technology standard and LTE technology standard based on the evolutionary perspective.

1. Introduction

In order for a technology to become a standard, it competes fiercely with competing technologies, a process known as standardization or standards war. Companies and groups around the world are fighting a fierce battle to establish their technology as an international standard in order to

preoccupy the world market (Oh et al., 2011). Since standards are the 'rules of the game' for the area in which they are established, companies or groups that lead the rules can naturally preoccupy their competitiveness (Kang, 2009). On the other hand, as products and technologies that have been pushed out of standard competition are withdrawn from the market, they are in a difficult situation where they cannot recover the amount invested in R&D, production line installation, and next-generation technology development in the course of competition (Kim et al., 2012). So, competition in the field of standards to dominate the rules of the game takes the form of 'technological standards competition' to dominate technological standards (Kang, 2009).

The evolutionary theory is a scientific theory that explains the diversity and complexity of living organisms and explains the observable phenomenon of evolution and consequent speciation. The evolutionary theory explains the changing aspects of ecosystems through the concept of evolution. The evolutionary theory of living organisms has gradually expanded its breadth and scope, and attempts have been made to explain various phenomena in human society. As a result, studies such as evolutionary economics, which tries to explain economic problems or economic phenomena by biological methods such as natural selection, and evolutionary psychology, which try to understand the psychology of animals, including humans, from an evolutionary perspective, have developed. This study interprets and analyzes the case of 4G wireless telecommunication technology standard competition between WiMAX technology standard and LTE technology standard from the evolutionary perspective of natural selection.

By genetically interpreting the process of natural selection, traits suitable for the environment spread to the group through generations through a mechanism called differential reproduction. By culturally interpreting the process of natural selection, strategies to get higher payoffs spread to the group through generations by diffusion. In order to compare payoffs between WiMAX technology and LTE technology, measurement indicators were extracted from patent data and defined. In this study, we regard patents as an individuals, indexed $k = \{1, 2, \cdots, K\}$ and each technology standard as a possible candidate strategy, indexed $S = \{WiMAX , LTE\}$. And we assume that individuals are "programmed" with one of the possible candidate strategy (Friedman, 1991).

This paper is organized into 5 sections excluding the introduction. In Section 2, literature review, we review standard and dominant design, evolutionary theory. Section 3, research frame, focus the main methodology of this study. Section 4, result and discussion, presents the result from the analysis and discusses the meaning of the results. Section 5, conclusion, we summarize this study comprehensively and explain the contribution and limitation of this research.

2. Literature Review

2.1 Standard and dominant design

A simple definition of a standard is 'an agreed upon method of action,' and in a business, a standard is a form of technical knowledge that can be used in all types of business activities to realize economic benefits such as efficiency (Sung, 2012). Standards are essential requirements

for interdependency of product components or users (Srinivasan et al., 2006).

Standards can be divided into two types: de facto standards and de jure standards. A de facto standard is determined by technology standard competition, and the user's choice has an important influence on determining the winner in the standardization process, and some scholars suggest that this is a market-based, market-based claimed to be standardized (Techatassanasoontarn & Suo, 2011; David & Greenstein, 1990).

On the other hand, a de jure standard is a standard established by a standard-setting body (Sung, 2012). Global System for Mobile Communication (GSM), one of the 2nd generation mobile communication technological standards, is a representative example of a de jure standard specified by a standardization organization called ETSI (European Telecommunications Standards Institute).

A dominant design is a standard that dominates the market as a de facto standard that is the winner of standards competition or as a de jure standard established by a standardization body. Utterback and Abernathy (1975), who pioneered the study of dominant design, defined dominant design as "a single architecture that establishes dominance in a product category." Afterwards, Anderson and Tushman (1990) described a dominant design in a market with a market share of 50% or more in the technology product category and a dominant strategy or product or design with market dominance that becomes the industry standard. So, if one technology becomes the dominant design, it can secure a high profit by acquiring a monopoly position in the market according to the winner-take-all rule. Suarez and Utterback (1995) described dominant design as a milestone or turning point in the life cycle of an industry.

Non-technical factors that determine the dominant design in the standard competition process include first-mover advantages, complementary assets, switching costs, and the size of the coalition. Farrell and Saloner (1986) argued that early entry into an industry can maintain a first-mover advantage. According to Schilling, if a technology is accepted by more users and compatible with more complementary assets, the technology can be successfully developed and become a dominant design by means of a self-reinforcing mechanism. Cozzarin et al. compared standards competition between VHS and Betamax in the 1980s and standards competition between Blu-ray and HD-DVD in the 2000s, and analyzed the factors that affect standard competition. claimed to be important. Users adopt a technology and then tend to stick with a chosen technology because switching to a new technology is expensive, a phenomenon Arthur described as the "lock-in effect." Chirqui empirically analyzed the cases of HD-DVD and Blu-ray standard competition, and found that the Blu-ray Alliance had 191 members supporting each technical standard alliance, and the HD-DVD Alliance had 136 companies, with members supporting both standards. It revealed that there were 66 companies, and argued that the size and geographical proximity of the federation had an impact on standards competition. Utterback and Suarez (1993) argued that if a design becomes dominant, economies of scale can occur, creating barriers to entry that prevent other technologies from entering the market.

2.2 Evolutionary theory

Nowak stated that evolution requires populations of reproducing individuals so the population

is the fundamental basis of any evolution. Individuals, genes or ideas can change over time, but only populations evolve (Nowak, 2007). The population of individuals with successful strategy increase but the other decrease. This is called population dynamics. The gene is the basic physical unit of inheritance. Genes are passed from parents to offspring and contain the information needed to specify traits. There are two versions of a gene, dominant and recessive. A dominant gene expresses itself more strongly than recessive gene. The individuals having a dominant gene express themselves more strongly than the individuals having a recessive gene.

Charles Darwin, a British biologist, was called the 'father of evolution theory' and systematized the evolution theory. Darwin argued natural selection and tree of life. Natural selection means that "In a given environment, individuals with genetic properties that are appropriate for the environment are more likely to survive or produce more offspring than those who are not" (Cho, 2021). Thee of life means that "the pattern of evolution, and the history of life is the process by which new species branch off from existing species, and the ends of the branches represent the extant species (Fig. 1). The tree of life model is an important concept that can solve the misunderstanding of the ladder of life model that lower animals gradually evolve into higher animals over time.
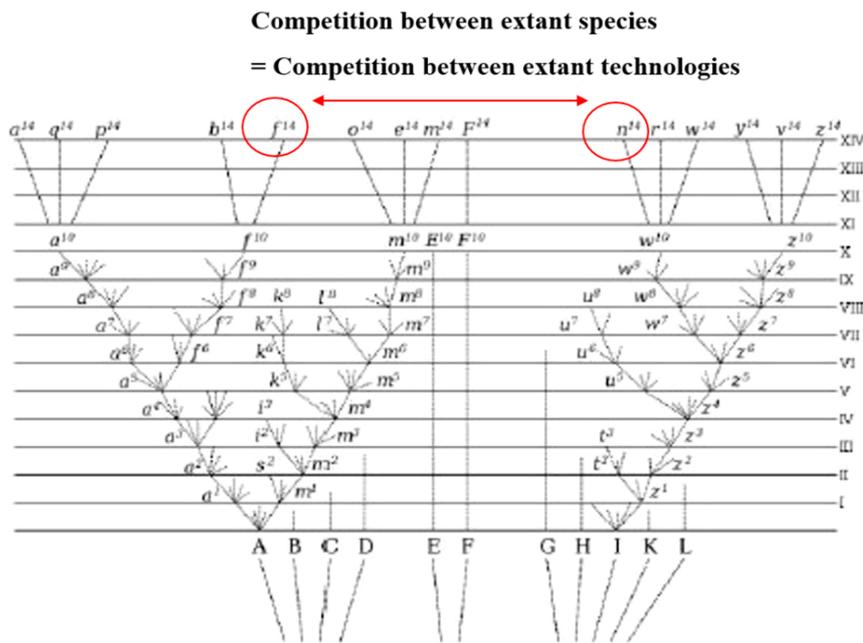

Fig. 1. Tree of life (from the origin of species by Darwin)

The figure 2 is a schematic diagram of the generation division of wireless telecommunication technology as the concept of the tree of life in evolutionary theory. Two extant technologies, LTE technology and WiMAX technology, compete for survival, and this process can be explained as a natural selection process.
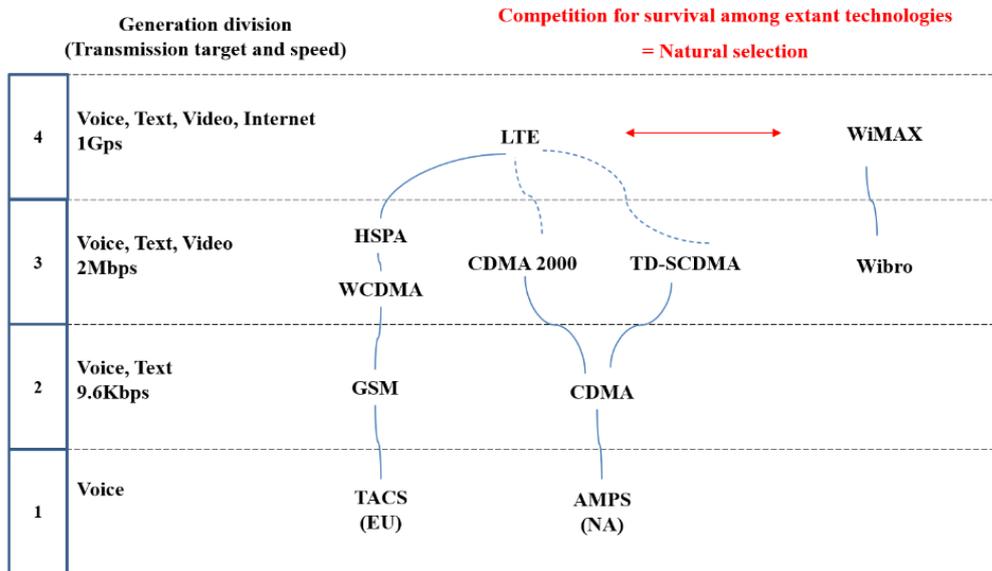
Fig. 2. Tree of life regarding 4th wireless telecommunication technologies

Wireless telecommunication technologies are divided into several generations according to data transmission speed and transmission target. It is classified into the 1st generation of analog communication technology that can only deal with voice calls, the 2nd generation that can transmit data such as text messages in addition to voice calls, the 3rd generation that can transmit video data, and the 4th generation that provides wireless LAN and Internet use with one terminal.

3. Research Framework

Based on evolutionary perspective, we regarded each patent as individuals and each patent was programmed with strategies of WiMAX technology or LTE technology. By genetically interpreting the process of natural selection, traits suitable for the environment spread to the group through generations through a mechanism called differential reproduction. By culturally interpreting the process of natural selection, strategies to get higher payoffs spread to the group through generations by diffusion.

In order to compare payoffs of WiMAX technology and LTE technology, which are two technology standards of 4th telecommunication, we built a data set by collecting related patents from the patent DB. Further, we defined diffusion, scope, and profitability, which are measurement indicators for comparing the two technology standards, and then analyzed significant differences through an independent sample t-test. We analyzed the difference in measurement indicators from 2004 to 2007, the early stage of the competition, and then accumulated data up to 2012 to further analyzed whether these differences are significant. Next, the priorities were analyzed by using the Condorcet method, which can compare and evaluate alternatives using multiple measurement indicators as well as each indicator of LTE technology standard and WiMAX technology standard. The Condorcet method

is a pairwise comparison voting method that reflects preference and is originated from the French mathematician, Marie Jean Antoine Nicolas de Caritat Condorcet (Andrew et al., 2015). The research process is summarized as shown in Figure 3.
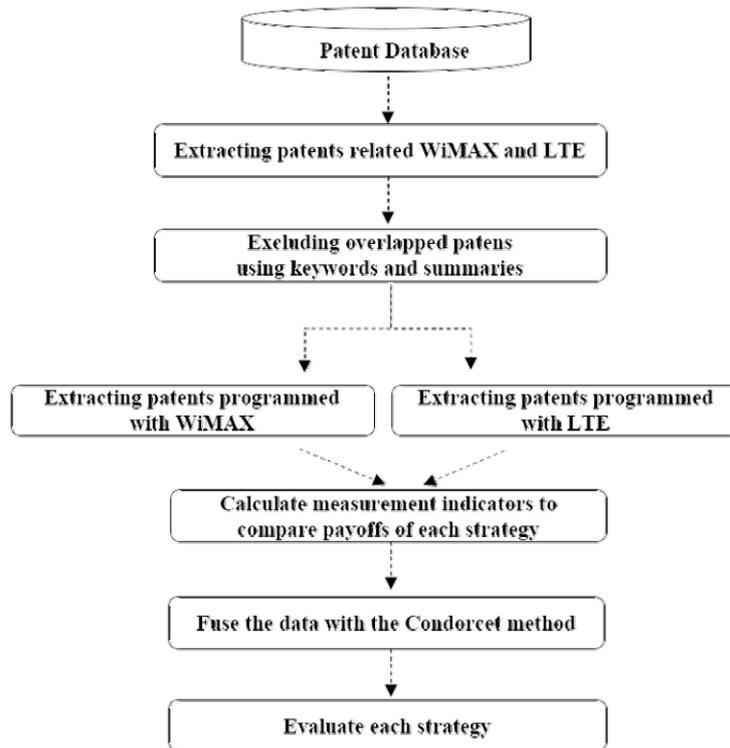

Fig. 3. Research process

3.1 Data Collection

In this study, we collected patent data of WiMAX technology and LTE technology from 2004 to 2012 using keywert, a patent database. Patent data was searched and collected from various patent databases in the US, Europe, Japan, Korea and China, which are leading countries in the telecommunications industry, and many patents related to WiMAX technology and LTE technology have been filed and registered in these countries. From the collected patent data, duplicate patents were excluded using keywords and summaries. Therefore, a study was subjected to and conducted on a total of 7,401 patent data including 1,241 WiMAX patents and 6,160 LTE patents.

3.2 Measurement indicators

Patent is a kind of intellectual properties protected by law, and is an essential element for competition in the industry where technology changes rapidly, such as the telecommunication industry. Lee

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argued that patents are useful technical indicators for empirical research related to innovation or intellectual property. First, patent is an appropriate indicator to reflect the competitive dimension of ownership and technological change as a direct result of the invention process. Second, patent registration takes a lot of time and cost, so patent applications are made only for technologies that are expected to generate more profits than costs. Third, patent is categorized by technology field, providing information on not only the speed of inventive activity, but also its direction. Fourth, patent statistics can provide large amounts of long-term and time-series data (Lee, 2013).

Svensson (2015) argued that the number of patents per capita can be useful to estimate the ranking of a country or industry sector in terms of technological superiority and innovation. Hagedoorn and Cloodt (2003) analyzed the innovation performance of individual countries through the indicators including the number of patents, the invention performance based on R&D index and the production performance of invention. Dechezlepretre and Martin (2010) compared the relative level and trend of each country with the number of related patents as an innovation index to identify the UK's level in terms of climate change-related innovation. As such, the number of patents has been used as a quantitative index to measure innovation activities and technological superiority of a country or company.

Therefore, companies seeking to have a competitive edge have been trying to increase the number of patents and improve the quality of patents in order to maintain sustainability. In addition, patent data has been regarded as an important indicator for evaluating a company's technological strengths and weaknesses and R&D performance.

3.2.1 Diffusion

Patent citation analysis has been used as a means of predicting the diffusion of various technologies (Perkins & Neumayer, 2005). When a patent is cited by a follow-up patent, it means that the cited patent is widely applied and refers to a valuable patent (Chang et al., 2009). Hall et al. (2005) argued that a backward citation is a means to understand promising technologies and to measure the economic value of technology and the innovation capability of companies. In other words, investing in a technology with a high diffusion potential can bring higher market returns. In this study, the average value of the number of backward citations by year for each group proposed by Huang and Wang (2013) is defined as a variable of diffusion for the LTE technology standard and the WiMAX technology standard.

$$\text{Diffusion} = \frac{a}{b} \tag{1}$$

  a = the total number of forward citation
  b = the total number of patents

3.2.2 Scope

The wide range of technology refers that the technology is related to various technologies and has high extensibility. The International Patent Classification (IPC) Code of patent is a kind of

technology classification system and indicates which technology field the patent is belonged to. There are patents with one IPC Code, but there are also patents with two or more IPC Codes, and these have been widely used in research on technology convergence or technology extensibility. Serkan et al. (2015) argued that the broader the scope of a technology, the more likely it is to expand into other industries and create new industries. In this study, the average IPC value by year of each group proposed by Huang and Wang (2013) is defined as a variable of scope for LTE technology standard and WiMAX technology standard.

$$\text{Scope} = \frac{c}{d} \tag{2}$$

    c = the total number of IPC codes
    d = the total number of patents

3.2.3 Profitability

A family patent refers to a patent group filed in several countries for one invention according to the territorial principle. Since patents cost for application, registration and maintenance, so applying for, registering and maintaining family patents are based on a strategic decision on high expected profit or technological competitive advantage. Therefore, the higher the number of family patents, the higher the commercial value. In this study, the average value of the number of family documents by year of each group proposed by Huang and Wang (2013) is defined as a variable of profitability for the LTE technology standard and the WiMAX technology standard.

$$\text{Profitability} = \frac{e}{f} \tag{3}$$

    e = the total number of family patents
    f = the total number of patents

## 4. Research Results

4.1 Diffusion

Table 1. shows the diffusion of LTE technology standard and WiMAX technology standard from 2004 to 20012. According to Table 1, the diffusion of LTE technology standard indicates 19.01, and the diffusion of WiMAX technology standard indicates 12.49, from 2004 to 2007. There are significant differences in variables for each technology standard, and the diffusion of LTE technology standard is relatively fast at the early stage of competition.

In addition, the gap between the diffusion of LTE technology standard and the diffusion of WiMAX technology standard is narrowing until 2012, the middle stage of competition, as seen in the Figure 4., but it can be seen that the diffusion of LTE technology standard is relatively fast.

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Table 1. Comparison of diffusion between WiMAX technology standard and LTE technology standard

Year	Technology standard	M	SD	t
2007	LTE	19.01	34.4	2.294*
	WiMAX	12.49	39.1	
2008	LTE	16.85	29.3	2.504*
	WiMAX	12.41	34.8	
2009	LTE	15.87	29.9	3.000**
	WiMAX	11.70	32.1	
2010	LTE	14.69	26.9	2.924**
	WiMAX	11.45	30.8	
2011	LTE	14.18	26.4	2.905**
	WiMAX	11.22	30.2	
2012	LTE	13.90	27.3	2.535*
	WiMAX	11.21	29.9	

* $p<0.05$, ** $p<0.01$
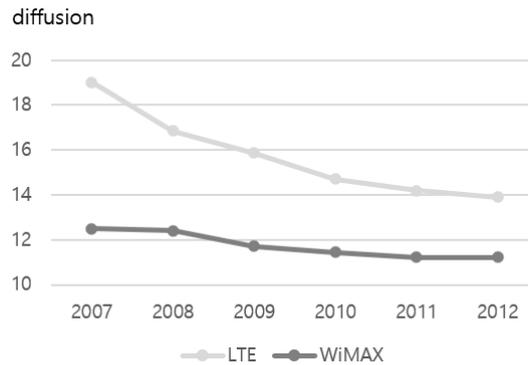
Fig. 4. The diffusion of WiMAX and LTE technology standards by year

4.2 Scope

Table 2. shows the scope of LTE and WiMAX technology standards by year. The scope of LTE technology standard indicates 1.61, and the technology scope of WiMAX technology standard indicates 1.42, respectively, from 2004 to 2007, the early stage of competition. It can be seen that there are significant differences in the variables.

In addition, it can be considered that the scope of LTE technology standard is relatively wider. Further, it can be founded that the scope of LTE technology standard is wider until 2012, which is the mid-competition stage as seen in Figure 5.

Since the range of technology is wide, it means that the technology has a high possibility of expansion and is related to various technologies, so it can be seen that LTE technology standard is a technology standard that is more likely to spread to new fields than WiMAX technology standard.

Table 2. Comparison of scope between WiMAX technology standard and LTE technology standard

Year	Technology standard	M	SD	t
2007	LTE	1.61	1.33	2.760**
	WiMAX	1.42	0.62	
2008	LTE	1.50	1.02	2.319*
	WiMAX	1.40	0.63	
2009	LTE	1.50	0.87	3.218**
	WiMAX	1.41	0.63	
2010	LTE	1.51	0.81	4.471**
	WiMAX	1.40	0.62	
2011	LTE	1.49	0.78	4.205**
	WiMAX	1.40	0.63	
2012	LTE	1.48	0.78	3.862**
	WiMAX	1.40	0.63	

* $p<0.05$, ** $p<0.01$
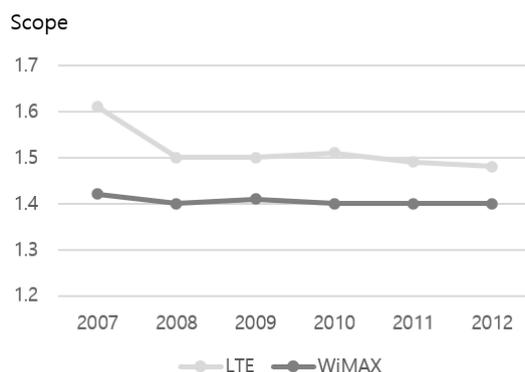
Fig. 5. The scope of WiMAX and LTE technology standards by year
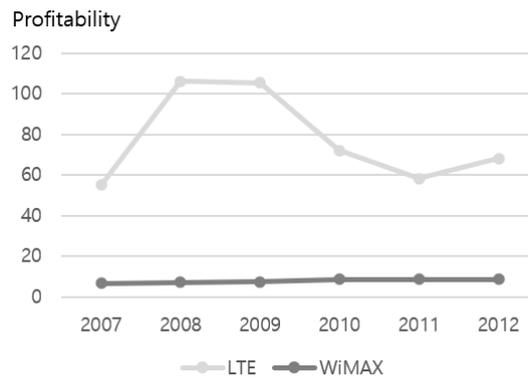
4.3 Profitability

Table 3. shows the profitability by year of LTE technology standard and WiMAX technology standard, from 2004 to 2007, the early stage of competition. The profitability of LTE technology standard indicates 55.1 and that of WiMAX technology standard indicates 6.7, respectively. It can be seen that there are significant differences in variables for each technology standard.

Further, it can be seen that the profitability of LTE technology standard is relatively high, and it is maintaining its superiority as shown in Figure 6. This means that LTE's family patents have been filed in more countries than WiMAX's, which implies that LTE technology standard is a standard with relatively high commercial value. This is because the high number of family patents shows that the applicant has a strong will to protect rights even at the cost of filing and maintaining patents.

Table 3. Comparison of scope between WiMAX technology standard and LTE technology standard

Year	Technology standard	M	SD	t
2007	LTE	55.1	153.4	6.362**
	WiMAX	6.7	11.1	
2008	LTE	106.1	392.2	7.713**
	WiMAX	7.3	16.6	
2009	LTE	105.4	409.1	10.491**
	WiMAX	7.6	15.4	
2010	LTE	72.19	325.8	2.924**
	WiMAX	8.84	23.8	
2011	LTE	58.31	293.3	11.318**
	WiMAX	8.84	23.5	
2012	LTE	68.30	354.0	12.972**
	WiMAX	8.80	23.3	

* $p<0.05$, ** $p<0.01$

Fig. 6. The profitability of WiMAX and LTE technology standards by year

4.4 Comparison by Condorcet method

Table 4. and Table 5. summarize the technical differences in diffusion, scope, and profitability between LTE technology standard and WiMAX technology standard by the Condorcet method. According to the summary of the results, it can be considered that LTE technology standard has higher payoffs than WiMAX technology standard in all aspects of diffusion, scope, and profitability.

Table 4. Comparison of WiMAX and LTE technology standards by measurement indicators

Criteria	Rank
Diffusion	LTE >WiMAX
Scope	LTE >WiMAX
Profitability	LTE >WiMAX

Table 5. Advantages of LTE technology standard

	Win	Lose
LTE strategy	3	0
WiMAX strategy	0	3

5. Conclusions

Technology standard competition (standard war) is a competition among competing technologies to become a de facto standard (dominant design) (Kang, 2009). In the 4th telecommunication market, LTE technology standard and WiMAX technology standard, which are each adopted as public technology standards, competed to become de facto standard. In the early stage of competition, the WiMAX technology were adopted in many countries such as US, Korea, Russia, Japan and other major developing countries (Kwak et al., 2014).

As a result, the number of patent registrations related to WiMAX technology standard was higher than that of LTE technology standard. However, as the time-sharing version of LTE technology appeared (Ismat, 2013), many Mobile WiMAX service providers decided to change to LTE technology (Kwak et al., 2014). As a result, LTE technology standard gets ahead of WiMAX technology standard in the number of registered patents as well as participating companies.

In this study, it is founded that LTE technology standard has an advantage over WiMAX in all technology-related indicators such as diffusion, scope and profitability based on the quantitative data of patents. Based on the process of natural selection, strategies to get higher payoffs spread to the group through generation by diffusion.

The main academic contribution of this study is to compare technology-related indicators such as diffusion, scope and profitability to figure out strategies to get higher payoffs between WiMAX technology standard and LTE technology standard based on evolutionary perspective.

However, this study only deals with technical trait of patent data such as diffusion, scope and profitability to compare LTE technology and WiMAX technology. Further research are required to deal with diverse trait of each individual to derive payoffs that explain evolutionary process.

Conflicts of Interest

The authors declare no conflict of interest.

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