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Assessing a relative technological competitiveness using patent and paper information at the country level: Model and application in mobile communications

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**Assessing a relative technological competitiveness using patent and paper  
information at the country level: model and application in mobile  
communications**

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**Abstract**

Science and technology have been the driving force of development for knowledge-based economies. In particular, as competition in mobile communications technology innovation among countries become more intense, there are growing needs for enhanced judgment, evaluation, and prediction of technological capabilities in order to improve a national competitiveness. Over the past decade, the mobile communications can be considered as the fastest growing industry. The world-wide mobile subscribers were 5.28 billion in 2010 and are expected to 7.3 billion in 2016. Until now, several models of a national technology level evaluation have been evaluated on only expert surveys or restricted patent and paper information respectively. However, the different methodologies are a result of a certain theoretical and empirical consensus and they generally lead to identify different results depending on the methodologies. In this paper, we evaluate the technological capabilities using patent synthetic indicators, paper synthetic indicators, and composite technology level evaluation of patent and paper synthetic indicators in mobile communications technology (3G, 3G transitional, and 4G) among countries (US, EU, Japan, China, and Korea). We also conduct an empirical study to validate the technology level evaluation measures. This research will offer more objective technology level evaluation than a subjective expert or peer surveys.

**Keywords:** Patent; Paper; Technological competitiveness; Technology level evaluation; Mobile communications

## 1. Introduction

Science and technology have been the driving force of development for knowledge-based economies. Knowledge-based economy is a kind of economy based solely on the production, distribution, and the use of knowledge. Therefore, it means that the most important things in the economy model are knowledge, skills, not the material products. As competition in science and technology innovation among countries become more intense in the theoretical and social paradigm called the NIS (National Innovation System), there are growing needs for improved judgment, evaluation, and prediction of science and technological capacities in order to improve country's competitiveness (Watts & Porter, 1997; MERIT, 1988; Ryu & Byeon, 2011).

Science and technological capabilities are important to national economic performance – all the more due to the national introduction of stronger IPRs (Intellectual Property Rights), regulatory harmonization and standardization, and the world-wide spread of emerging science and technologies (UNIDO, 2005). Science and technological capabilities are the conceptual level elements that capture what science and technology does. The science and technology level can be defined as the relative technological capabilities to use technological knowledge efficiently and to the extent to which technological knowledge is accumulated, invested in, produced, and innovated. The science and technology level refers to the current level of science and technology accumulation or accomplishment based on past science and technological activities. We just call the technology level replacing by the science and technology level from now on. Therefore, technology level evaluation refers to statistically measuring the extent of technology performance and capacity at an evaluation point (Ryu & Byeon, 2011). Also, the technology level is used when we want to compare one with other technological capacities relatively.

Several new models of national technology level have recently been developed. These researches are a result of a certain theoretical and empirical consensus about the nature of science and technology. Some significant researches to constitute composite indicators of technology level evaluation at the country level have recently been made (Archibugi & Coco, 2005). Both policy analysts and academy researchers need new and improved measures of technology level on the performance of nations to understand economic and social transformations. In particular, governments constantly require information about the performance of their countries, and this is often better understood in comparisons to the performance of their partners and competitors.

Patent and paper information have been used by economists and researchers in the fields of innovation to analyze current and forecast future science and technological directions. Patents are regarded as an essential source and commercial knowledge (Park, Yoon & Lee, 2005). Almost 80% of

all technological information can be found in patent applications (M. Blackman, 1995). According to the statistics of the WIPO (World Intellectual Property Organization), 90%-95% of economically valuable human innovation results are retained in patent databases (Yu & Le, 2009). In an increasing amount and variety of studies, bibliometric data have been also used to evaluate scientific research performance and production. Bibliometrics is a useful tool to analyze scientific production and bibliometric indicators are increasingly being used as a tool for research performance evaluation (Alfaraz & Calvino, 2004; Bibliometric methods, 2005).

Over the past decade, the mobile communications can be considered as the fastest growing industry. In fact, the mobile telephones have become daily necessities for thousands of million people, and they are increasingly being used in the most developed and developing countries in the world. Also, the world-wide mobile subscribers were 5.28 billion in 2010 and are expected to 7.3 billion in 2016. In 2001, the launch of 3G was in Japan by NTT DoCoMo on the WCDMA (Wideband Code Division Multiple Access) standard. One of the newest 3G technologies to be implemented is HSDPA (High Speed Downlink Packet Access). It is an enhanced 3G mobile telephony communications protocol in HSDPA family, also coined 3.5G, 3G+, or turbo 3G, which allows networks based on UMTS (Universal Mobile Telecommunications System) to have higher data transfer speeds and capacity. The recently released 4G, aims to provide broadband wireless access with nominal data rates of 100Mbits/s to fast moving devices, and 1Gbit/s to stationary devices. 4G systems may be based on the 3GPP LTE (Long Term Evolution), WiMax or Flash OFDM (Orthogonal Frequency Division Multiplexing), etc.

In this paper, we evaluate the technology level of mobile communications using patent and paper analyses at the country level. More specifically, we identify the technology level evaluation of 3G, 3G transitional, and 4G mobile communications among US, EU, Japan, China, and Korea. First, we develop the model of the technology level evaluation based on patent synthetic indicators and evaluate the technology level in the mobile communications. Second, we also develop the model of the technology level evaluation based on bibliometric synthetic indicators and evaluate the technology level in the mobile communications. Finally, we develop the model of the technology level evaluation based on the composite synthetic indicators of patent and bibliometric indicators and evaluate the technology level in the mobile communications.

## **2. Research approach and literature review**

### **2.1. The needs for a science and technological data-based technology level evaluation**

The IMD (International Institute of Management Development), RAND (Research And

Development Corporation), UNDP (United Nations Development Program), UNIDO (United Nations Industrial Development Organization), and WEF (World Economic Forum) periodically release national competitiveness indexes that measure the national capacities to improve economic development and the standard living. These indexes are included the science and technological competitiveness and all of these use patent or paper information as a solid indicator of the national innovative capacity (Furman et al., 2002). In addition, major developed or developing countries undertake technology level evaluation as a part of establishing strategies for mid-term science and technology R&D programs and seizing trends in science and technology. Examples are the 'National Core Technology Report' (U.S., 2005), the 'Survey on Research and Development Levels' (Japan, 2011), and the 'Survey on 20-year Technology Predictions for the Future' (China, 2008).

In Korea, government agencies or institutes carry out technology level evaluation, as shown in (Table 1). These surveys fundamentally evaluate the technology level by peer reviews or expert surveys. It is generally recognized that peer or expert surveys have various limitations and shortcomings (Chubin and Hackett, 1990). In particular, according to Nederhof(1998), the outcomes of peer review may be more than 50% due to chance and randomness. Therefore, several new measures of national technology level evaluation have recently been developed as like to Arco (Archibugi & Alerto, 2005), the Patent Asset Index (Ernst & Omland, 2011), etc.

Table 1  
Recent Korean cases of technology level evaluation. <sup>a</sup>

	KISTEP	KEIT	DTaQ
Title	Future potential technology level evaluation (2008)	Research report on ICT level evaluation (2010)	Survey report on defense technology level evaluation (2008)
Purpose	Analysis of the current status for effective R&D establishment	Preliminary research for technology planning	Identification of future potential defense technology
Evaluation Subject	90 core technologies of the nation	713 ICT core technologies	3,899 core technologies
Subject nations	Korea, US, Japan, EU, China	Korea, US, Japan, EU, China	US, France, Russia, Germany, UK, Japan, Israel, Korea, China, Italy, Canada, India, Spain, South Africa, Turkey
Methodology	Poll of organizations, groups, and corporations	Expert Delphi survey	Expert Delphi survey

<sup>a</sup> KISTEP is an institute for evaluating and planning science and technology on a national level under the Ministry of Educational Science and Technology (MEST). The KEIT is an agency for planning and evaluating industrial technology on a national level under the Ministry of Knowledge and Economy (MKE). The DTaQ is an agency for evaluating defense technology and managing quality assurance of military supplies under the Defense Acquisition Program Administration

(DAPA).

## 2.2. Patent data as technology level evaluation

The patent databases offer valuable information for technological strategy planning. It is drawn from literature that patent analysis has been successfully applied in high-tech industries, such as ICT (Information & Communication Technology) industry and BT (Bio Technology), for technological strategy planning. The patent analysis techniques have also used to reflect the technological innovation levels for a country, an industry, and a firm (H. Ernst, 2003). Within many economics and management disciplines, patent has become well established as a proxy factor for the measure of technological competence, although it is not perfect one (Felicia M. Fai, 2005). Many literatures show a positive relationship between patenting and company performance if patent applications are weighted according to their quantity and quality. The indicators of patents used in these literatures are numbers, citations, granted patents, and the technological and international scope of patent applications.

(Table 2) summarizes an important set of indicators which was used to analyze the technological strategy. The indicators were proposed for the evaluation of competitive position: number of patent applications (NP, PGPA, PCPA), patent citation indicators (CI, CII, TS, TCT), number of family (NF), number of citations (NC), technology independence (TI), and revealed patent advantage (RPA).

Table 2  
Literature on patent indicators.

Scholar	Indicator										
	NP	PGPA	PCPA	NF	CI	CII	TS	TCT	NC	TI	RPA
Huang et al. (2003)	*				*	*		*		*	
CHI Research (2010)	*	*	*		*	*	*	*			
Trajtenberg (1990)									*		
Griliches, Z. (1990)	*				*	*		*		*	
Ernst (2003)	*	*	*	*	*						
Breitzman and Thomas (2002)	*								*		
Harhoff et al. (2003)									*		
Narin (1995)	*					*		*			
Chia (2004)	*	*			*	*		*	*		
Kung and Lin (2004)	*					*			*		
Hsu (2005)	*		*		*	*	*	*			
Schmoch (1995)											*
Lai and Wu (1995)											*
Gellec and Bruno	*			*							

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(2000)

Number of patents(NP), Patent growth percent in area(PGPA), Percentage of company patents in the area(PCPA), Number of family(NF), CI(Cites per patent), Current impact index(CII), Technology Strength(TS), Technology Cycle Time(TCT), Technology independence(TI), Revealed patent advantage(RPA)

\*Source: F.-M. Tseng et al. revised

### 2.3. Paper data as technology level evaluation

Bibliometric studies are increasingly requested by science and technology managers and policy makers to support research performance evaluation. Bibliometric indicators have been proved useful in a wide range of research performance evaluation [20]. In general, there are two types of bibliometric indicators which indicate the quantity (research production) and quality (research impact) individually. Different indicators are frequently developed at the macro or micro levels, based on the production of scientists as well as the impact of their papers, such as the number of citations, number of citations per paper, or relative citation rate, etc. The combined use of several indicators that present information on different sides of scientific production is generally recommended (Leewen et al., 2003).

Recently, it seems to be more generally assumed that suitable bibliometric methods can offer crucial information about research performance that can be seen as complementary to expert reviews. As a basis for the comparative analyses we summarize the bibliometric indicators calculated in the various studies as shown in (Table 3).

Table 3  
Bibliometric indicators of paper output and impact.

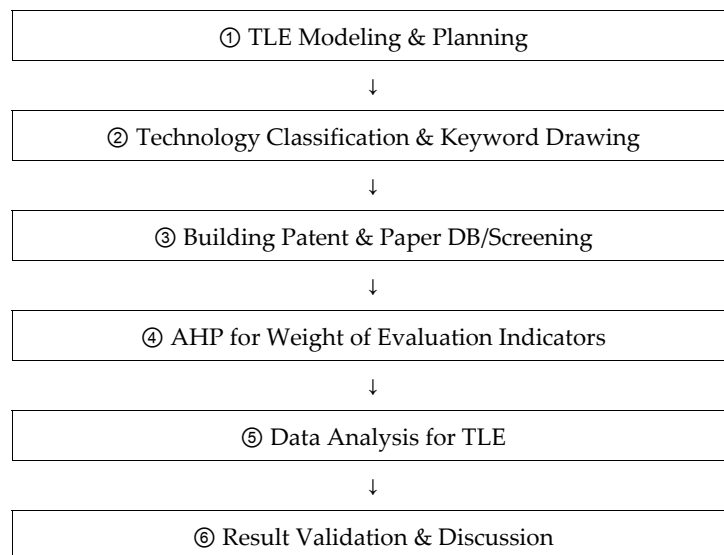
Indicator	Notation
Number of papers published	<i>P</i>
Total number of citations received	<i>C</i>
Citations per paper	<i>CPP</i>
Hirsch index (Number of papers ( <i>P</i> ) in the list that have <i>P</i> or more citations)	<i>H</i>
Percentage of papers not cited	<i>%Pnc</i>
Mean citation rate of journal packet	<i>JCSm</i>
Mean citation rate subfield(s)	<i>FCSm</i>
Citations per paper, compared to citation rate of journal packet	<i>CPP/JCSm</i>
Citation rate journal packet, compared to citation rate of subfield(s)	<i>JCSm/FCSm</i>
Percentage self-citations	<i>%SELCIT</i>

\*Source: H.F. MOED et al. revised

### 3. Research method

### 3-1. Research process

As shown in (Fig. 1), we perform 6 steps to research a technology level evaluation based on patent and paper information in mobile communications. Firstly, we develop a model for technology level evaluation and make an overall plan in order to analyze technology level evaluation. Secondly, we build a technology classification for mobile communications, and make keywords from the technology classification to draw target patent and paper information. Thirdly, we build patent and paper database to analyze TLE (Technology Level Evaluation) after noise screening by some experts. Fourthly, we identify the weights of patent and paper evaluation indicators from AHP (Analytic Hierarchy Process) expert survey. Fifthly, we analyze the real technology level evaluation by using patent and paper indicators with weights. Finally, we check how to validate the TLE model and discuss the results, and suggest how to use the results in order to create a R&D policy strategy.



**Fig. 1.** A research process for TLE.

### 3-2. The TLE based on the patent analysis

We develop the AIMC model of the TLE (Technology Level Evaluation) based on the quantitative and qualitative patent indicators. The patent indicators used in patent AIMC model are PAI (Patent Activity Index), PII (Patent Intensity Index), PMI (Patent Market-power Index), and PCI (Patent Citation Index).

The TLE based on the patent indicators (patent AIMC) can be identified by the following formulation.



$Patent AIMC = \underline{W} \times \underline{P}' = (w_1 \times PAI) + (w_2 \times PII) + (w_3 \times PMI) + (w_4 \times PSI) + (w_5 \times PCI)$ , where  $\underline{W} = (w_1, w_2, w_3, w_4)$ ,  $\underline{P} = (PAI, PII, PMI, PSI)$ .  $\underline{W}$  is weight vector and  $\underline{P}$  is patent indicator vector.

Table 4  
Critical patent indicators for technology level evaluation.

Symbol	Indicator	Definition	Meaning
PAI	Patent Activity Index	Patent application (PA) of a country i in technological field (TF) F ⇒ PA <sub>iF</sub> /PA of all competitors in TF F (Technology Share based on PA)	Extent of R&D expenditures of country i in TF F (interest of country i in TF F) ⇒ Competitive technological position of a country i in TF F (quantitative)
PII	Patent Intensity Index	PA <sub>iF</sub> /Number of a country's(i) total patent Applications	Importance of technological field F for a country i (R&D emphasis or intensity, quantitative)
PMI	Patent Market-power Index	Size of Patent family (PF) and share of triad (US, JP, EPO) patents of PA <sub>ik</sub>	Economic quality of a country's(i) patent applications (International scope of protection)
PCI	Patent Citation Index	Average citation frequency of PA <sub>ik</sub> : PC <sub>iF</sub>	Economic quality of a country's(i) patent applications (Competitive technological strength of a country i in TF F)

### 3-3. The TLE based on the paper analysis

We develop the AIC model of the TLE (Technology Level Evaluation) based on the quantitative and qualitative bibliometric indicators. The bibliometric indicators used in bibliometric AIC model are BAI (Bibliometric Activity Index), BII (Bibliometric Intensity Index), and BCI (Bibliometric Citation Index).

The TLE based on the bibliometric indicators (Bibliometric AIC) can be identified by the following formulation.

$Paper AIC = \underline{T} \times \underline{B}' = (t_1 \times BAI) + (t_2 \times BII) + (t_3 \times BCI)$ , where  $\underline{T} = (t_1, t_2, t_3)$   $\underline{B} = (BAI, BII, BCI)$ .  $\underline{T}$  is weight vector and  $\underline{B}$  is patent indicator vector.

Table 5  
Critical bibliometric indicators for technology level evaluation.

Symbol	Indicator	Definition	Meaning
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BAI	Bibliometric Activity Index	Paper publication(PP) of a country i in scientific & technological field (TF) F ⇒ PP <sub>iF</sub> /PP of all competitors in TF F (Science & Technology Share based on PP)	Extent of R&D expenditures of country i in TF F (interest of country i in TF F) ⇒ Competitive scientific & technological position of a country i in TF F (quantitative)
BII	Bibliometric Intensity Index	PP <sub>iF</sub> /Number of a country's(i) total paper Publications	Importance of scientific & technological field F for a country i (R&D emphasis or intensity, quantitative)
BCI	Bibliometric Citation Index	Paper citation(PC) of a country i in scientific & technological field (TF) F ⇒ Average citation frequency of PP <sub>iF</sub> : PC <sub>iF</sub>	Knowledge quality of a country's(i) Paper publications (Competitive scientific & technological strength of a country i in TF F)

### 3-4. The Composite TLE based on patent and paper indicators

We finally develop the composite model of the TLE (Technology Level Evaluation) based on the synthetic indicators of patent and bibliometric indicators.

The composite TLE based on the patent and bibliometric indicators (Patent AIMC & Paper AIC) can be identified by the following formulation.

*Composite TLE =  $\underline{Z} \times \underline{U}' = (z_1 \times Patent\ AIMC) + (z_2 \times Paper\ AIC)$ , where  $\underline{Z} = (z_1, z_2)$ ,  $\underline{U} = (Patent\ AIMC, Bibliometric\ AIC)$ .  $\underline{Z}$  is weight vector and  $\underline{U}$  is patent and bibliometric indicators vector.*

### 3-5. Determination of weights for evaluation indicators

Based on the non-linear weighted composite evaluation method, in addition to dimensionless process of the evaluation indicator's original value, the weight of each indicator also need to be determined and the purpose is to reflect the function and importance of evaluation indicator in the evaluation model. The method for the determination of weight can be grouped into two categories: one is the method to identify weight by data analysis. That is to determine the weight on the basis of the interrelation or the weight variation between the indicators, for example, mean square method, entropy method, factor analysis, average mean/equal mean, etc. and it avoids some deviation may caused by human factors, but fluctuates values depending on the data. The other is the method to identify weight by expert survey, and they mostly determine the weight through the way of comprehensive consultation ratings, which has some subjectivity, but has been used a wide variety of fields and given rational solutions, for example, AHP (Analytic Hierarchy Process), Delphi survey, etc. Therefore, in order to gain generality and avoid fluctuations caused by the method to give weight

depending on the specific data, we select the AHP method of rational weight to distribute the indicators' weights.

Satty(1980) developed a pairwise comparison approach based on the hierarchical structure of the problem. A reciprocal pairwise comparison matrix is constructed based on a subjective scale of 1-9. Criteria weights are obtained by synthesizing various assessments in a systematic manner.

#### 4. Results and empirical analysis

##### 4-1. Target data for TLE

We evaluate the technology level among US, EU, Japan, China, and Korea using the patent and paper information in 3G, 3G transitional, and 4G mobile communications over the last decade. The analysis patent data of public, notified or granted patent applications have been filed with the national patent offices in US, EU, Japan, China, and Korea during January 1<sup>st</sup>, 1999 – December 31<sup>st</sup>, 2010 with regards to inventors' nationalities. The analysis paper data have been published in SCI (Science Citation Index) & SCIE (Science Citation Index Expanded) classification journals during January 1<sup>st</sup>, 1999 – December 31<sup>st</sup>, 2010 with regards to authors' nationalities. (Table 5) shows the overview of patent and paper data analysis to evaluate the technology level evaluation among the countries.

Table 5  
Overview of data analysis.

	Patent TLE	Paper TLE
Target	Mobile communication technologies (3G, 3G transitional, and 4G)	
Country	US, EU, Japan, China, and Korea	
Data	Patent applications (18,350) - DB: public, notified/granted patents : KPO, USPTO, JPO, EPO, SIPO - Inventor's nationality: KR, US, JP, EU, CN - Period: Jan 1, 1999 - Dec 31, 2010	SCI/SCIE publications (4,250) - DB: Thomson Scientific Publications: former ISI(Institute for Scientific Information) - Authors' nationality: KR, US, JP, EU, CN - Period: Jan 1, 1999 - Dec 31, 2010
Analysis time point	Dec 1, 2011 – Dec 5, 2011	
Evaluation indicator	- Patent numbers, Patent citations: Patent Activity, Patent Intensity, Patent Market-power, Patent Citation	- Pater numbers, Paper citations: Bibliometric Activity, Bibliometric Intensity, Bibliometric Citation

The technology classifications of mobile communications are 3G, 3G transitional, and 4G. 3G mobile communications is a generation of standards for mobile phones and mobile communications

services fulfilling the IMT-2000 (International Mobile Telecommunications-2000) specifications by the ITU (International Telecommunication Union). To meet the IMT-2000 standards, a system is required to provide peak data rates of at least 200kbit/s (about 0.2Mbit/s). However, many services advertised as 3G provide higher speed than the minimum technical requirements for a 3G service. Recent 3G transitional releases, often denoted 3.5G, 3.75G, and 3.9G also provide mobile broadband access of several Mbit/s to smart phones and mobile modems in laptop computers. 4G is the fourth generation of cellular phone mobile communications standards and a successor of the 3G standards. A 4G system provides mobile ultra-broadband Internet access, for example to laptops with USB wireless modems, to smart phones, and to other mobile devices. Recently, two 4G systems are commercially deployed: the Mobile WiMax standard (at first in Korea in 2006), and the first-release LTE standard (in Scandinavia since 2009). In the U.S. Sprint Nextel has deployed Mobile WiMAX networks since 2008, and MetroPCS was the first operator to offer LTE service in 2010. USB (Universal Serial Bus) wireless modems have been available since the start, while WiMAX smart phones have been available since 2010 and LTE smart phones since 2011. Equipment made for different continents are not always compatible, because of different frequency bands. Mobile WiMAX and LTE smart phones are currently (April 2012) not available for the European market.

(Table 6) shows the technology classifications of mobile communications standards to evaluate the technology level among the countries.

Table 6  
The technology classifications of mobile communications standards.

Generation	Family	Mobile Communications standards
3G (IMT-2000)	3GPP	UMTS(UTRAN), WCDMA-FDD, WCDMA-TDD, UTRA-TDD(TD-SCDMA)
	3GPP2	CAMA2000 1xEV-DO Release(TIA/IS-856)
	3GPP	HSDPA, HSUPA, HSPA+, LTE(E-UTRA)
3G transitional (3.5G, 3.75G, 3.9G)	3GPP2	CDMA2000 1xEV-DO Revision A(TIA/EIA/IS-856-A), CDMA2000 1xEV-DO Revision B(TIA/EIA/IS-856-B), DO Advanced
	IEEE	Mobile WiMax(IEEE 802.16e), WiBro, Flash-OFDM, IEEE 802.20
4G (IMT-Advanced)	3GPP	LTE advanced(E-UTRA), TD-LTE advanced
	IEEE	WiMax advanced(IEEE 802.16m), WiMax2, WiBro evolution

#### 4-1-2.The weights of evaluation indicators

We conduct a survey of experts selected and the calculate weights per evaluation indicator based on the AHP method with the survey results by Expert Choice 2000 program. Subjects of the AHP survey are a total of 48 experts from professional companies, research institutes, patent agencies, and universities during November 22<sup>nd</sup>, 2011 – November 24<sup>th</sup>, 2011 by online survey system. (Table 7) shows the weight of patent and paper indicators for technology level evaluation.

Table 7  
The weights of evaluation indicators.

Patent AIMC	0.711	Patent AIC	0.289
Patent indicator	Weight	Paper indicator	Weight
PAI	0.128	BAI	0.276
PII	0.139	BII	0.223
PMI	0.368	BCI	0.501
PCI	0.365		
Sum	1.000	Sum	1.000

## 4-2. Empirical results of the technology level evaluation

### 4-2-1. Results of Patent AIMC for TLE

The public, notified and granted patents whose 18,350 applications have been filed with the patent offices in the US, Europe, Japan, China, and Korea from January 1<sup>st</sup>, 1999 to December 31<sup>st</sup>, 2010 with regards to technology classifications of mobile communications. We analyze and evaluate the four patent indicators including Patent Activity Index (PAI), Patent Intensity Index (PII), Patent Market-power Index (PMI), and Patent Citation Index (PCI) with regards to inventors' nationalities.

As a result of evaluating Patent AIMC in overall mobile communications technology as shown in (Table 8), EU is a leader (100.0%), US is second (92.3%), Korea is third (87.9%), China is fourth (51.0%), Japan is fifth (49.4%). Specifically, US is stronger than other countries in patent activities, EU is stronger than other countries in patent citations, Korea is stronger than other countries in patent intensities and market-powers. In 3G mobile communications technology, EU is a leader, but Korea is a 3G transitional leader, and US is a 4G leader.

Table 8  
A technology level evaluation based on patent indicators among countries in mobile communications, 1999-2010.

	Indicator	US	EU	Japan	China	Korea	Total
Mobile communications	PAI (Patent Activity Index)	0.306	0.166	0.116	0.212	0.200	1.000
	PII (Patent Intensity Index)	0.202	0.184	0.197	0.189	0.228	1.000
	PMI (Patent Market-power Index)	0.236	0.272	0.064	0.113	0.316	1.000
	PCI (Patent Citation Index)	0.219	0.418	0.172	0.033	0.159	1.000
	Patent AIMC	0.243	0.263	0.130	0.134	0.231	1.000
	Patent AIMC (Transform to 100%)	92.3	100.0	49.4	51.0	87.9	%
3G	PAI (Patent Activity Index)	0.314	0.189	0.120	0.234	0.144	1.000
	PII (Patent Intensity Index)	0.205	0.227	0.205	0.219	0.144	1.000
	PMI (Patent Market-power Index)	0.240	0.317	0.108	0.163	0.172	1.000
	PCI (Patent Citation Index)	0.235	0.369	0.197	0.021	0.178	1.000
	Patent AIMC	0.250	0.279	0.152	0.158	0.161	1.000
	Patent AIMC (Transform to 100%)	89.8	100.0	54.5	56.6	57.7	%
3G transitional	PAI (Patent Activity Index)	0.253	0.115	0.112	0.162	0.358	1.000
	PII (Patent Intensity Index)	0.164	0.138	0.191	0.151	0.356	1.000
	PMI (Patent Market-power Index)	0.240	0.317	0.108	0.163	0.172	1.000
	PCI (Patent Citation Index)	0.178	0.184	0.199	0.185	0.254	1.000
	Patent AIMC	0.213	0.197	0.148	0.166	0.276	1.000
	Patent AIMC (Transform to 100%)	77.3	71.6	53.6	60.0	100.0	%
4G	PAI (Patent Activity Index)	0.353	0.153	0.110	0.205	0.179	1.000
	PII (Patent Intensity Index)	0.236	0.189	0.194	0.198	0.183	1.000
	PMI (Patent Market-power Index)	0.193	0.304	0.019	0.097	0.387	1.000
	PCI (Patent Citation Index)	0.525	0.475	-	-	-	1.000
	Patent AIMC	0.322	0.284	0.073	0.121	0.200	1.000
	Patent AIMC (Transform to 100%)	100.0	88.1	22.5	37.6	62.0	%

#### 4-2-2. Results of Paper AIC for TLE

The 4,250 papers which have been published in Thomson Scientific Publications from January 1<sup>st</sup>, 1999 to December 31<sup>st</sup>, 2010 with regards to technology classification of mobile communications. We analyze and evaluate the three bibliometric indicators including Bibliometric Activity Index (BAI), Bibliometric Intensity Index (BII), and Bibliometric Citation Index (BCI) with regards to authors' nationalities.

As a result of evaluating Paper AIC in overall mobile communications technology as shown in (Table 9), EU is also a leader (100.0%), US is second (95.7%), Japan is third (52.3%), China is fourth (44.4%), Korea is fifth (40.8%). Specifically, US is stronger than other countries in paper citations, EU is stronger than other countries in paper activities, China is stronger than other countries in paper intensities. In 3G mobile communications technology, US is a leader and EU (99.7%) is very closely second position next to US, but EU is a leader in both 3G transitional and 4G mobile communications

technology.

Table 9

A technology level evaluation based on bibliometric indicators among countries in mobile communications, 1999-2010.

	Indicator	US	EU	Japan	China	Korea	Total
Mobile communications	BAI (Bibliometric Activity Index)	0.170	0.530	0.053	0.136	0.110	1.000
	BII (Bibliometric Intensity Index)	0.132	0.123	0.210	0.343	0.191	1.000
	BCI (Bibliometric Citation Index)	0.421	0.253	0.190	0.038	0.098	1.000
	Paper AIC	0.287	0.300	0.157	0.133	0.122	1.000
	Paper AIMC (Transform to 100%)	95.7	100.0	52.3	44.4	40.8	%
3G	BAI (Bibliometric Activity Index)	0.112	0.582	0.026	0.172	0.109	1.000
	BII (Bibliometric Intensity Index)	0.147	0.245	0.107	0.282	0.220	1.000
	BCI (Bibliometric Citation Index)	0.529	0.224	0.081	0.032	0.133	1.000
	Paper AIC	0.329	0.328	0.071	0.126	0.146	1.000
	Paper AIMC (Transform to 100%)	100.0	99.7	21.8	38.5	44.4	%
3G transitional	BAI (Bibliometric Activity Index)	0.215	0.492	0.074	0.106	0.113	1.000
	BII (Bibliometric Intensity Index)	0.067	0.082	0.163	0.455	0.232	1.000
	BCI (Bibliometric Citation Index)	0.380	0.290	0.200	0.045	0.084	1.000
	Paper AIC	0.265	0.300	0.157	0.153	0.125	1.000
	Paper AIMC (Transform to 100%)	88.4	100.0	52.5	51.2	41.8	%
4G	BAI (Bibliometric Activity Index)	0.250	0.359	0.125	0.188	0.078	1.000
	BII (Bibliometric Intensity Index)	0.224	0.103	0.356	0.209	0.108	1.000
	BCI (Bibliometric Citation Index)	0.258	0.302	0.093	0.224	0.124	1.000
	Paper AIC	0.248	0.273	0.160	0.210	0.108	1.000
	Paper AIMC (Transform to 100%)	90.8	100.0	58.7	77.0	39.4	%

#### 4-2-3. Results of Composite TLE

There is a composite technology level evaluation based on Patent AIMC and Paper AIC among countries in mobile communications technology as shown in (Table 10). In overall mobile communications technology, EU is a leader, US is second (93.3%), Korea is third (74.3%), Japan is fourth (50.2%), and China is fifth (49.1%). In 3G mobile communications technology, EU is a leader, but Korea is a 3G transitional leader, and US is a 4G leader. In particular, Korea is strong in patent indicators, but weak in paper indicators unlike other countries.

Table 10

A composite technology level evaluation based on patent AIMC and paper AIC among countries in mobile communications, 1999-2010.

	Indicator	US	EU	Japan	China	Korea
Mobile communications	Patent AIMC	92.3	100.0	49.4	51.0	87.9
	Paper AIC	95.7	100.0	52.3	44.4	40.8
	Composite TLE	93.3	100.0	50.2	49.1	74.3
3G	Patent AIMC	89.8	100.0	54.5	56.6	57.7
	Paper AIC	100.0	99.7	21.8	38.5	44.4
	Composite TLE	92.8	100.0	45.1	51.4	53.9
3G transitional	Patent AIMC	77.3	71.6	53.6	60.0	100.0
	Paper AIC	88.4	100.0	52.5	51.2	41.8
	Composite TLE	96.7	95.9	64.0	69.1	100.0
4G	Patent AIMC	100.0	88.1	22.5	37.6	62.0
	Paper AIC	90.8	100.0	58.7	77.0	39.4
	Composite TLE	100.0	94.0	33.9	50.3	57.0

#### 4-3. Comparison and validation

We now move on to check the consistency of the TLE measures. In order to validate our measures, we conduct an empirical study. We compare Patent AIMC, Paper AIC, Composite TLE, and expert Delphi survey among countries. The expert Delphi survey is the re-calculated results for the selected technology items from KEIT's Research report on ICT (Information and Communication Technology) level evaluation (2010) and the strategic domain of next generation mobile communications was surveyed by 495 researcher, professors, and industrial technicians in Korea. Though we deal with typical cardinal values, the small sample is not justified a normal distribution. Therefore, the method of construction of the indicators only allows comparison between the rankings, and not the absolute values. So, the issue is to check similar the rankings of countries are for the other studies; for this purpose, a rank correlation (Spearman statistic) is employed because it is not required normal distribution of data.

(Table 11) shows the correlations among the rankings for the countries available for each couple of indicators. This allows consideration of 5 all countries for Patent AIMC-Paper AIC, Patent AIMC-Composite TLE, Patent AIMC-Expert Delphi Survey, Paper AIC-Composite TLE, Paper AIC-Expert Delphi Survey, Composite TLE-Expert Delphi Survey. As shown in (Table 11), most of the indicators are mutually inter-dependent, therefore show strong correlations (e.g., between Patent AIMC, Paper AIC, Composite TLE and Expert Delphi Survey). However, an indicator appears to be somewhat



independent, whose correlation is weak, e.g., Patent AIMC versus Paper AIC. Therefore, we confirm that Composite TLE is needed to consider patent and paper information simultaneously. Also, though different TLE methodologies lead to somewhat different results in general, we find out that Expert Delphi Survey can be replaced by Patent AIMC, Paper AIC, and Composite TLE.

Table 11

Spearman rank correlations: rank correlations based on scores on patent, paper, and expert survey TLE for mobile communications among countries.

	Patent AIMC	Paper AIC	Composite TLE	Expert Delphi Survey
Patent AIMC	1.000			
Paper AIC	0.432	1.000		
Composite TLE	0.921**	0.561*	1.000	
Expert Delphi Survey	0.731**	0.602**	0.673**	1.000

\* Correlation is significant at the 0.05 level (2-tailed), \*\* significant at the 0.01 level (2-tailed)

## 5. Discussions

### 5.1. Conclusion

Technology level evaluation based on patent and paper information leads to a consistent relative evaluation of the relative level of science and technology, and this evaluation can be used to identify the technological status among countries. Furthermore, these methodologies can be more objective technology level evaluation than the subjective expert Delphi, or peer review surveys. The new development of the composite synthetic technological level indicators using patent and bibliometric information at the country level can be also applied to researchers, institutions, companies, technological domains, etc.

The empirical research results give a quite faithful and uniform picture on the national positions of innovative activities and performance in the mobile communications among countries. In overall mobile communications technology, EU is a leader, US is second (93.3%), Korea is third (74.3%), but Japan is fourth (50.2%), and China is last (49.1%). In 3G mobile communications technology, EU is a leader, but Korea is a 3G transitional leader, and US is a 4G leader. In particular, Korea is strong in patent indicators, but weak in patent indicators unlike other countries.

### 5.2. Limitation

Patent and bibliometric metrics are increasingly used to assess the competitive position of technology and science across nations, universities, firms, institutions, regions, etc. But the technology level evaluation methodologies based on patent and paper information applied in this paper have some limitations. First, we do not thoroughly justify the patent indicators (Patent AIMC), bibliometric indicators (Paper AIC), and the Composite TLE methodologies. But we consider both the quantitative and qualitative patent and paper indicators which have simple, specific, distributed, and relative features from literatures (P. Vinkler, 1988).

Second, we identify subjectively the weights of patent and paper indicators by AHP (Analytic Hierarchy Process) method with expert survey. The data-oriented methods such as mean square method, factor analysis, etc avoid some variation caused by human factors, but they also fluctuate values depending on the data.

Third, the patent and paper data in mobile communications are not complete sets. The patent announcements and paper publications are generally 1~2 year gaps, and are gathered by keywords under technology classifications in mobile communications.

### **5.3. Further study**

The proposed technology level evaluation methodologies and weights are not sufficiently checked the validity and compared other studies. Hence, we plan to establish a consolidated patent and paper indicators to measure national technology innovation and science activity by literature reviews and statistical data analyses.

We just study to identify technology level evaluation based on patent and paper information in mobile communications. We are eager to more review and compare with statistical data on levels of production, sales, market shares, trades, domain sites, etc in mobile communications industry.

Each country follows a different path of science research and technology development because of such as professional human resources, R&D funding amounts, and infrastructures, differ across countries. Hence, one must develop a technology level evaluation considering the characteristics of each country's science and technology and develop strategies that are tailored to each country's science and technology development. The identification of technological and industrial features is a possible domain for the future research. Investing the relationship between technology and industry characteristics using the technology level evaluation would be a practical and interesting topic for future study. Establishing strategies for the science and technology development appropriate to each pattern is necessary.

## Appendix

Table 12

Aggregate patent statistics in mobile communications, 1999-2010.

	Data item	US	EU	Japan	China	Korea	Total
Mobile communication <sup>s</sup>	# of patent applications	5,606	3,046	2,134	3,898	3,666	18,350
	# of patent families	87,573	54,769	8,964	29,015	76,556	256,877
	# of triadic patents	1,666	1,083	410	523	1,133	4,815
	# of patent citations (USPTO)	1,677	2,817	209	23	365	5,091
	# of patent applications (USPTO)	2,121	1,866	337	191	635	5,150
3G	# of patent applications	3,514	2,116	1,339	2,619	1,615	11,203
	# of patent families	56,303	34,215	6,384	18,501	44,757	160,160
	# of triadic patents	1,156	730	272	344	721	3,223
	# of patent citations (USPTO)	1,531	2,748	165	13	245	4,702
	# of patent applications (USPTO)	1,241	1,422	160	119	262	3,204
3G transitional	# of patent applications	1,092	496	483	698	1,544	4,313
	# of patent families	9,600	5,745	1,917	4,153	9,730	31,145
	# of triadic patents	321	236	103	125	236	1,021
	# of patent citations (USPTO)	144	68	44	10	120	386
	# of patent applications (USPTO)	436	199	119	29	254	1,037
4G	# of patent applications	1,000	434	312	581	507	2,834
	# of patent families	21,670	14,809	663	6,361	22,069	65,572
	# of triadic patents	189	117	35	54	176	571
	# of patent citations (USPTO)	2	1	-	-	-	3
	# of patent applications (USPTO)	444	245	58	43	119	909

Table 13

Aggregate paper statistics in mobile communications, 1999-2010.

	Data item	US	EU	Japan	China	Korea	Total
Mobile communication <sup>s</sup>	# of paper publications	722	2,253	227	579	469	4,250
	# of paper citations	12,991	24,321	1,847	943	1,969	42,071
3G	# of paper publications	210	1,094	48	323	204	1,879
	# of paper citations	3,511	7,755	123	331	861	12,581
3G transitional	# of paper publications	496	1,136	171	244	260	2,307
	# of paper citations	9,380	16,398	1,706	547	1,093	29,124
4G	# of paper publications	16	23	8	12	5	64
	# of paper citations	100	168	18	65	15	366

Table 14

Scores summary of patent, paper, and expert survey TLE among countries in mobile communications, 1999-2010.

Technology	Country	Patent AIMC	Paper AIC	Composite TLE	Expert Delphi Survey
Mobile communications	US	92.3	95.7	93.3	100.0
	EU	100.0	100.0	100.0	96.9
	Japan	49.4	52.3	50.2	83.0
	China	51.0	44.4	49.1	70.3
	Korea	87.9	40.8	74.3	85.6
3G	US	89.8	100.0	92.8	100.0
	EU	100.0	99.7	100.0	98.8
	Japan	54.5	21.8	45.1	90.5
	China	56.6	38.5	51.4	68.0
	Korea	57.7	44.4	53.9	83.0
3G transitional	US	77.3	88.4	96.7	100.0
	EU	71.6	100.0	95.9	96.3
	Japan	53.6	52.5	64.0	78.5
	China	60.0	51.2	69.1	70.2
	Korea	100.0	41.8	100.0	85.9
4G	US	100.0	90.8	100.0	100.0
	EU	88.1	100.0	94.0	95.6
	Japan	22.5	58.7	33.9	80.1
	China	37.6	77.0	50.3	72.6
	Korea	62.0	39.4	57.0	87.8

a Expert Delphi Survey is the re-calculated results for selected technology items from KEIT's Research report on ICT level evaluation(2010), the strategic domain of next generation mobile communications was surveyed by 495 researchers, professors, and industrial technicians in Korea

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