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Identifying emerging core technologies for the future: Case study of patents published by leading telecommunication organizations ☆

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ABSTRACT

In recent years, the volume of mobile traffic has increased at an unprecedented rate and the mobile paradigm has changed. These dynamics have driven the next-generation telecommunications technologies, and the existing fourth-generation technology is reaching maturity. The pre-acquisition of promising future technologies enables firms to achieve and sustain their business growth; thus, numerous organizations in the telecommunications sector have made a huge amount of effort to develop fifth-generation (5G) technologies. Although understanding these emerging and promising 5G technologies is essential, they still remain poorly investigated. To fill this research gap, we first define the characteristics of promising technologies in the telecommunications sector, then develop a framework for identifying them based on patents. Specifically, we design three patent indices for deriving the core patents published by leading organizations in the sector. We then apply bibliographic coupling and text mining to the patents and identify their major innovation trends. We identify 21 technology fields as promising areas emphasized by the leading organizations. Theoretically, this study is one of the few attempts to examine various approaches to identify promising technologies and to suggest the most appropriate one considering the research purpose as well as the characteristics of telecommunications sector. In practice, this study can provide information about patent activities of key incumbent actors and thus offer some insights into recent technological developments towards 5G.

1. Introduction

Considering the proliferation of smart devices and the increasing demand for multimedia streaming services, mobile data traffic volume will certainly accelerate (Fehske, Fettweis, Malmodin & Biczók, 2011). Recently, indoor traffic has received considerable attention because approximately 80% of data traffic has been generated within houses or office buildings since 2010 (Laya et al., 2014). These unexpected increases in mobile traffic volume and the changing mobile

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paradigm have driven the next-generation telecommunications technologies. Long-term evolution (LTE) systems embodying fourth-generation (4G) technology are now reaching maturity, indicating that one can only expect incremental improvements and small amounts of new spectrum (Andrews et al., 2014). Therefore, numerous organizations across the world, both public institutions and private enterprises, have been inspired to develop beyond-4G (B4G) technologies. Furthermore, the future 5G technologies are expected to evolve from locally focused technologies, while macro-based technology has occupied the mainstream of technology evolution in the telecommunications industry before release 12 (Rel-12) (Chen & Zhao, 2014). These trends indicate an opportunity to enhance market competitiveness by developing promising telecommunications technologies. For this reason, numerous organizations have redoubled their efforts to develop 5G.

To capture successful technological opportunities, particularly in the telecommunications industry, logical forecasting or prediction is necessary. Investing in a promising technology without understanding future technological directions can be very risky, as technological and market standards largely drive the technological and product/service markets in the telecommunications sector. Bekkers, Duysters, and Verspagen (2002) compared the strategies of Motorola and Philips and showed that the direction of market competition and network centrality significantly affects share or structure of a technology-intensive market. In this context, patent information might easily indicate the technological opportunity of the telecommunications sector by identifying both technological directions and relationships. In addition to providing bibliographical information, such as inventor, assignee, application date, and citations, a patent document provides detailed technological descriptions, including functional principles, technical components, and cause-effect relationships. From patent information, researchers have derived various factors such as technological strengths, weaknesses, corporate R&D efforts, technology trends, prediction of emerging technologies, and technological capabilities at individual, firm, sector, and national levels (Noh, Jo & Lee, 2015). Hence, patent analysis approaches have been widespread in studies of telecommunications (Duysters & Hagedoorn, 1998; Mu & Lee, 2005; Lee, Kim, Cho & Park, 2009a; Kang, Huo & Motohashi, 2014).

Although previous attempts to discover or forecast promising technologies have yielded valuable insight, two critical limitations remain: (1) the concepts of promising technology vary among the studies and (2) the industrial movement for developing B4G or 5G technologies has been little investigated.

Regarding the first limitation, perspectives on the promising technology depend on the characteristics of the sector or technology and the research objectives. Such variation is quite natural. However, as researchers commonly focus on only a single perspective, an in-depth understanding of the concepts of a promising technology is urgent. Regarding the second limitation, although recent literature has addressed the visions or technological specifications expected to meet the future needs of the telecommunications market (Pierucci, 2015; Osseiran et al., 2014; Rappaport et al., 2013), practical technology developmental states or technological directions towards 5G technology remain unclarified. In addition, because 5G standards are not yet officially defined, future technical standards can be better predicted by observing real technology trends than identifying target specifications. To resolve these limitations, we first attempted to organize the various concepts of promising technology through a literature review. Then, based on a concrete concept of promising technology for the future telecommunications sector, we began forecasting the directions of 5G.

Specifically, this study proposes a framework for identifying promising telecommunications technologies from patent information. The framework is then applied to understanding current technological movements towards 5G. For this purpose, we selected top organizations related to the telecommunications industry from the standard essential patent (SEP) database of the European Telecommunications Standards Institute (ETSI), and collected the latest telecommunications patents of the 30 organizations leading in the development of 4G technologies from the United States Patent and Trademark Office (USPTO). Next, we designed patent indices based on the recency, frequency, and monetary (RFM) concept and extracted the most significant patents by the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a multi-criteria decision-making method. Then, we derived clusters of promising technologies using a bibliographic coupling and network analysis. Finally, to clarify the technological directions towards 5G, we extracted the technological keywords of each cluster by text mining.

The remainder of this paper is structured as follows. Section 2 describes the extant perspectives on what constitutes a promising technology and outlines the technological evolution of the telecommunications sector. This information was compiled through a literature review. Based on the literature review, Section 3 presents the basic approach of this study and details the processes of the research framework. Section 4 presents the study results; Section 5 discusses them. Concluding remarks, with implications and limitations, appear in Section 6.

2. Literature review

2.1. Existing approaches for identifying promising technology

The literature has used the term *promising technology* frequently and widely, but has not clearly defined it. Given that even *technology* is difficult to define in a single context, this lack of understanding is understandable. Rooney (1997), who reviewed historical definitions of technology, reported that the term *technology* must cover a wide and diffuse set of intersecting and heterogeneous contingencies. However, to support decision-making, the forecasts of a promising technology require careful consideration of its relevant aspects. To understand these aspects, we should first explore extant studies related to promising technologies.

Accordingly, we reviewed the recent literature on technological forecasting, prediction, and foresight and promising technologies, and then summarized perspectives on what constitutes a promising technology. We identified four popular perspectives and other opinions argued in only one or a few studies.

The first type of promising technology is *technological vacancy*. Researchers adopting this perspective have focused on novel advantages in technological competition, indicating opportunities with high potential for opening a new market that have received little attention (Lee, Yoon & Park, 2009b; Jun, Sung Park & Sik Jang, 2012; Choi & Jun, 2014; Lee, Kang & Shin, 2015a). To discover vacant technologies, researchers use visualizations such as patent maps and patent matrixes, compiled by clustering, text mining, and similar techniques. However, although technological vacancies easily identify various opportunities, evaluating the feasibility or marketability of each vacancy presents another challenge.

The second type of promising technology is *convergent technology*, which has been recently investigated as a leading technology for the future. In particular, both information and communications technologies have merged in numerous technologies related to vehicles, medical instruments, and other products. Due to those various cases of technology convergence, researchers have also focused on promising convergences (Curran & Leker, 2011; Geum, Kim, Lee & Kim, 2012; Kim & Hwang, 2012; Karvonen & Kässi, 2013; Lee & Yoo, 2014; Lee, Han & Sohn, 2015b). To forecast convergence, relationships among patents, such as citation or co-occurrence of an International Patent Classification (IPC), have been used.

A third approach is the examination of the recent appearance and rapid growth of a technological field with respect to *emerging technology*. In addition, because studies have investigated emerging technologies for quite some time, definitions of them in earlier studies are relatively easy to find. Cozzens et al. (2010) reviewed the literature and summarized four major concepts in definitions of emerging technologies: (1) fast recent growth, (2) transition to something new, (3) untapped market or economic potential, and (4) science-based nature. Similarly, Rotolo, Hicks, and Martin (2015) defined emerging technologies with four aspects: (1) radical novelty, (2) relatively fast growth, (3) coherence, and (4) uncertainty and ambiguity. Thus, comparison of time-series patent and literature networks constructed from citation analyses has commonly been used as a quantitative approach, and an expert survey or panel discussion has been a qualitative approach to identifying an emerging technology.

Forecasting and foresight for a *customer-based technology* is the fourth major way to identify promising technology, and market acceptance (or market-pull) is the most important aspect to satisfy. Even if it innovates, we cannot call a technology promising if its use or diffusion is limited because of market failure. Involving customers or end users in forecasting or foresight for promising technology has been discussed (Tuominen & Ahlqvist, 2010; Geum, Lee, Kang & Park, 2011; Reinhardt & Gurtner, 2011; Pichyangkul, Nuttavuthisit & Israsena, 2012; Ju & Sohn, 2015). However, customers generally find it difficult to express their future needs because they lack technological knowledge, so customer-centric approaches should be designed carefully (Reinhardt & Gurtner, 2011).

Beyond these major concepts, a promising technology can be defined in other ways. Some argue that technology-push and market-pull should be examined together, although the factors or criteria of these two aspects are dissimilar, depending on the study (Lee & Hwang, 2010; Cagnin, Havas & Saritas, 2013; Ma et al., 2014). In this case, the term “promising” is considered to have complex and multidimensional characteristics. On the other hand, some researchers have focused on the concept of the technology life cycle (Ernst, 1997; Gao et al., 2013). When a technology has reached the end of its growth stage, it is described as having a high competitive impact not yet integrated into new products.

The perspectives on promising technology discussed above are not mutually exclusive and clearly not exhaustive; they are affected by the purpose of the research and the characteristics of target technologies. These perspectives should be taken into account before a framework to identify promising technologies is developed, which the existing studies lack. Among the four perspectives, this study adopted the emergence perspective of promising technology as the development of telecommunications technology has been relatively path-dependent and driven by leading telecommunication organizations as is discussed in Section 3.1.

2.2. Technology evolution of telecommunications

Telecommunications technology has undergone several generations of development, with each generation resulting in new products (Kano, 2000). The performance of this technology in such areas as peak data rate, peak spectrum efficiency, capacity, and cell-edge user throughput has increased constantly over technological generations to meet market needs. LTE-advanced (LTE-A) was the first 4G system, the standardization of which was initiated by Rel-10 of the Third Generation Partnership Project (3GPP) (Parkvall & Astely, 2009; Ghosh, Ratasuk, Mondal, Mangalvedhe & Thomas, 2010). However, data traffic has grown significantly, owing to increasing demands for mobile data along with new services and applications, far beyond what the International Telecommunications Union initially established for 4G. Therefore, a future telecommunications technology is expected to provide not only very high broadband capacity, but also efficient support for a variety of traffic types, flexible and cost-efficient deployments, energy-efficient communications strategies, robust systems against emergencies, and a balance between backward compatibility and future enhancements (Akyildiz, Gutierrez-Estevez, Balakrishnan & Chavarria-Reyes, 2014). 5G is considered a set of new and different technologies, because it requires much higher aggregate data rates and much lower latencies that mere evolution of the status quo cannot achieve (Boccardi, Heath, Lozano, Marzetta & Popovski, 2014; Chen & Zhao, 2014).

Telecommunications has received much attention because of its tremendous growth and economic impact, reflected in the large number of studies conducted in the telecommunications field. One of research streams is the forecasting and identification of promising telecommunications technology (Anderson, Daim & Kim, 2008; Lee et al., 2009a; Kim, Daim & Anderson, 2010; Kishiyama, Benjebbour, Nakamura & Ishii, 2013; Rappaport et al., 2013; Osseiran et al., 2014; Pierucci, 2015). This research has focused greatly on the forecasting of technology diffusion, demand of technology-based services, or traffic volumes. Relatively little effort has been made to identify emerging telecommunications technologies, especially in the era of 5G. Of course, more and more recent studies have started to suggest a specific technology as a candidate for 5G telecommunications (Pachauri & Singh, 2012; Rappaport et al., 2013; Osseiran et al., 2014; Pierucci, 2015). However, most limit their attention to one technology. Further analysis is needed to investigate overall trends of technologies and identify promising technologies based on the trends.

5G technology is expected to have two distinguishing characteristics: a user-centric instead of an operator-centric concept as in 3G, a service-centric concept as in 4G (Janevski, 2009; Khan, Bojkovic & Marwat, 2012), and a new type of carrier for local areas in Rel-12 and beyond (Chen & Zhao, 2014). The characteristics of telecommunications technology and those of 5G should be considered in predicting promising technologies.

3. Research framework

3.1. Basic approach to identifying emerging core telecommunications technologies for the future

As discussed in Section 2, to identify future promising telecommunications technologies requires understanding the telco sector. Earlier studies have found three representative characteristics. First, telecommunications technologies have a high level of volatility and uncertainty (Du Preez & Pistorius, 2003), so their lifetime is shorter than that of other industrial technologies. R&D of telecommunications organizations is quite active. Second, the telecommunications sector requires a large investment in infrastructure to establish service (Bauer, 2010). That investment and the lack of attractive applications explains why 3G licenses worldwide have lagged, even though 3G began in 2001 (Kim et al., 2010). Third, technical or market standards play a pivotal role in the technological and products and services markets of telecommunications (Bekkers et al., 2002). This means that leading firms would attempt to impose their technologies on industry standards by collaborating with other standard-setters to form a consensus and thus establish various technological specifications in consortia (Shiu & Yasumoto, 2015).

The three above-mentioned characteristics give clues to identify future core technologies in the telecommunications sector. First, the emergence perspective, one of the four major contexts to define a promising technology as described in Section 2, is suitable for identifying a future technological development direction towards 5G. The volatility and uncertainty of telecommunications technology are connected with the attributes of emerging technology suggested by Rotolo et al. (2015). Second, a key player-centric approach might be the most effective and efficient way to execute practical telecommunications technology trends. The ability and experience of R&D to construct required infrastructures are not easy to obtain in a short period. Telecommunications technologies are systemic in nature. Thus, capital investments and the reaping of network externalities make those technologies strongly “path-dependent” (Rosenberg, 1994; Bowden, Clayton & Pereira, 2012). This also can be explained under the standards-based technology context that standardization typically proceeds in an evolutionary manner, in lockstep with the evolution of both embodied and disembodied technologies in complicated system technologies, such as distributed data processing, telecommunications, or factory automation (Tassey, 2000). Therefore, incumbent players can be more significant than a technology performance as a determinant of future technology advances in the telecommunications market. On the one hand, several economic factors should also be considered in understanding the key player-centric approach in the unique context of standards-based market; specifically, researchers agreed that economies of scale are essential at some point to achieve successful technology standardizations (Yoffie, 1997; Schilling, 2002). To gain economies of scale, a technology needs to reach a certain level of installed base, which refers to the number of installations of the technology and the number of users (Farrell & Saloner, 1986; Schilling, 2002). Standards-based compatibility is also crucial to enabling interoperability and unlocking innovation in complex technologies based on various components provided by different suppliers (Chiesa, Manzini & Toletti, 2002). As these two factors—installed base and compatibility—can be actual barriers to newcomers in the standards-based telecommunications market, standard-setters in a previous generation is likely to maintain a market position as standard-setters again in the next standard generations. Third, using patents information is suitable to identify promising technologies, even for the standards-based telecommunications market. Patent documents have been used to gradually derive technological trends in numerous extant studies because patents include valuable technological information (Noh et al., 2015). For the same reason, participants in standards-setting usually must disclose relevant patents (Rysman & Simcoe, 2008). Hence, the basic approach of this study focuses on key players to identify emerging telecommunications technologies based on the patent information.

Based on the basic approach, now we should deliberate that which patent more fits to the emergence perspective. Organized definitions on emerging technologies from the works of Cozzens et al. (2010) and Rotolo et al. (2015), as mentioned above, can help locate patents that are close to the emergence concept. However, the definitions from those studies did not suggest quantitatively measurable indices. This study employs the RFM concept as a bridge to connect theoretical definitions on the emergence technology and practical indices to select proper patents. The RFM concept initially introduced by Bult & Wansbeek (1995) is composed of three indices: (1) recency (R), (2) frequency (F), and (3) monetary (M). This

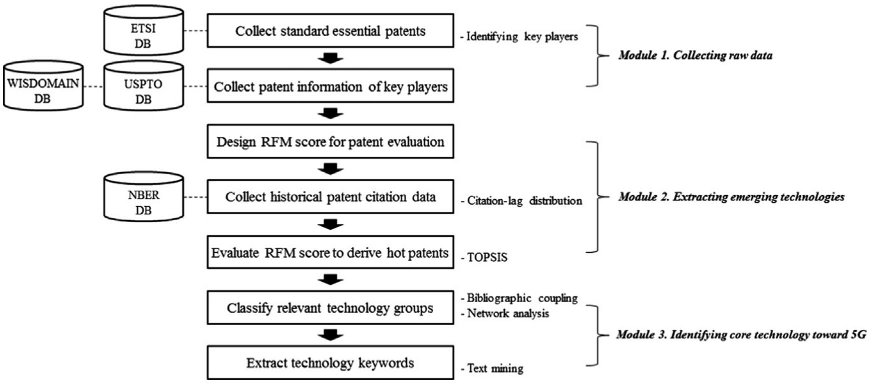

Fig. 1. Overall research framework.

concept has seen general use in marketing to identify core customers strongly expected to purchase goods against required costs to advertise. These indices can go far towards defining what the emerging technology is. First, recently issued patents can be considered new technologies, corresponding to the attributes of "fast recent growth" by Cozzens et al. (2010) and "radical novelty" by Rotolo et al. (2015). Second, frequently cited new patents can be interpreted as growing technologies, directly related to the attribute of "fast recent growth" by Cozzens et al. (2010) and "relatively fast growth" by Rotolo et al. (2015). Third, as a large number of family patents signify a larger amount of effort or investments, they might indicate high economic potential or impacts of untapped market by patent holding organizations, being connected with the attribute of "untapped market or economic potential" by Cozzens et al. (2010). Regarding the other attributes for an emerging technology, "science-based" by Cozzens et al. (2010) and "uncertainty and ambiguity" by Rotolo et al. (2015) are concerned with the nature of patented inventions; considering that our approach is based on patents, those conditions are basically satisfied. The final attribute is "coherence" suggested by Rotolo et al. (2015). If a patent with high RFM scores can be clearly grouped with other patents where this group is distinguished by a certain identity and momentum, there might be a coherence. Consequently, we expect that emerging core telecommunications technologies can be expected by applying the RFM concept and analytical grouping to the recent patents published by key players.

3.2. Research framework

The research framework used to identify emerging core technologies is shown in Fig. 1. It comprises three modules, each with a set of processes to achieve a respective purpose. The first focuses on identifying technological key players and collecting their patent information. Because technological standard-setters make large investments in R&D to maintain their positions, searching for SEP information from the ETSI database is an effective way to do so. After identifying key players, the module collects bibliographical data and text data about their patents sequentially using the USPTO and WISDOMAIN, a private data service provider, databases. The second module designs RFM concepts and evaluates RFM scores, using the patent information obtained in the first module. Then, patents with similar contents are clustered to identify emerging technology areas. For this purpose, bibliographic coupling and network analysis are employed in the third module. Then, text mining is applied to the patents in each group to extract technological details of each group.

Table 1
Search criteria to identify technological key players in telecommunications.

Category	Declared state	Patent scope	Project	Explanation
LTE	Essential	Basis only Basis + Family	3GPP LTE 3GPP-EUTRAN 3GPP release 8 3GPP release 9 LTE LTE/EPS release 9	3GPP LTE (un-normalized) LTE GSM phase 2+and UMTS/LTE release 8 GSM phase 2+and UMTS/LTE release 9 LTE (un-normalized) LTE/EPS release 9 (un-normalized)
LTE-A	Essential	Basis only Basis + Family	3GPP release 10 3GPP release 11 3GPP release 12	GSM phase 2+and UMTS/LTE release 10 GSM phase 2+and UMTS/LTE release 11 GSM phase 2+and UMTS/LTE release 12

3.3. Detailed process

3.3.1. Module 1: collecting raw data

Because LTE and LTE-A patents are not separated clearly in the standard projects of 3GPP, LTE/LTE-A SEPs should be considered to identify technological key players. Thus, the criteria used to search the ETSI database in this study are given in Table 1. There are two types of SEPs with respect to priority right: a basis patent and a family patent. A basis patent is an original patent in a set of family patents whose application can have prior approval. Therefore, the number of basis patents is an indication of practical technological capabilities. On the other hand, a family patent indicates multiple applications for an original patent to acquire global legal rights, and so indicates efforts to enter markets. Basis patents and family patents together represent the scope of patents and are used to identify key players.

After identifying the key players, the next step was to collect their recent telecommunications patents. We searched for IPC classes G08C, H01P, H01Q, H03B, H03C, H03C, H03D, H03H, H03K, H03L, H03M, H04B, H04H, H04J, H04K, H04L, H04M, and H-4N-001 as telecommunications patents (Schmoch, 2008). Then we collected the USPTO patents issued to the key players because most of the basis SEPs are included in the USPTO database. We also used the commercial database WIS-DOMAIN (www.wisdomain.com) to collect bibliographical and family patent information from the International Patent Documentation Center (INPADOC).

3.3.2. Module 2: extracting emerging technologies

In the second module, the RFM concept is defined as criteria for selecting patents close to the emergence concept. Thus, operational definitions of the RFM concept are designed within the context of patent information. First, recency (R) was designed to focus on the most recent R&D activities. If a patent has been referenced by other recent patents frequently, it is regarded as a recently available technology. Therefore, the average of the application dates of the forward citation patents in the focal patents is used as a proxy measure of R. Second, frequency (F) was designed to address the innovativeness or originality of a technology. In general, evaluating the technological advance of a patent has used its number of forward citations. However, because that number increases with time, it should be adjusted using a citation-lag distribution constructed from historical patent citation data. Therefore, we established a citation-lag distribution for the telecommunications sector based on the NBER database, on the assumption that the distribution is dynamically stable, considering that the database contains patent citation information only from 1976 to 2006, and used the adjusted number of forward citations for F. Despite the limitations that the database might be outdated, it has been used to adjust citation-related index values in the previous studies (Park, Park, Yoon, & Ko, 2016). Third, monetary (M) was interpreted as investments of resources such as finance, time, or the human workforce. An organization might put forth extra effort to apply for a patent globally when it believes it needs one in the global market, so M can be defined as the number of family patents for a focal patent.

After designing the operational definitions of the RFM concept, as shown in Table 2, we easily determined core patents, here called hot patents, as those with a high RFM score. In this study, we used TOPSIS to prioritize the hot patents, where priority increased with increasing R, F, and M values.

Table 2
Operational definitions of RFM concepts with respect to patents.

RFM concept	Operational definition	Description
Recency	$\boldsymbol{R_i}=\sum_{j=1}^{N}\frac{\boldsymbol{AD_j}}{\boldsymbol{N}}$ where $\boldsymbol{R_i}$ is the calculated recency of the $\boldsymbol{i}$th focal patent $\boldsymbol{AD_j}$ is application date of $\boldsymbol{j}$th forward citation patent of the $\boldsymbol{i}$th focal patent $\boldsymbol{N}$ is the total number of forward citation patents of the $\boldsymbol{i}$th focal patent If there are no forward patents, then $\boldsymbol{R_i}=0$	Average value among application dates of forward citation patents
Frequency	$\boldsymbol{F_i}=\frac{\boldsymbol{FC_i}}{\boldsymbol{CD_{i,t}}}$ where $\boldsymbol{F_i}$ is the frequency of the $\boldsymbol{i}$th focal patent $\boldsymbol{FC_i}$ is the total number of forward citations of the $\boldsymbol{i}$th focal patent $\boldsymbol{t}$ is the time lag between present year and issued year of the $\boldsymbol{i}$th focal patent $\boldsymbol{CD_{i,t}}$ is the cumulative distribution value of all $\boldsymbol{t}$ (citation-lag distribution)	Adjusted number of forward citations by citation-lag distribution
Monetary	$\boldsymbol{M_i}=\boldsymbol{FP_i}$ where $\boldsymbol{M_i}$ is the monetary of the $\boldsymbol{i}$th focal patent $\boldsymbol{FP_i}$ is the total number of INPADOC family patents of the $\boldsymbol{i}$th focal patent	Number of INPADOC family patents

Table 3
Scores of key players and USPTO-issued patents.

Rank	Key players	Weighted score	Total SEP sum of the four settings	USPTO patents in telecommunications
1	KP1	2,940	7,340	2,944
2	KP2	2,840	8,177	4,231
3	KP3	2,440	2,826	34
4	KP4	2,440	2,386	630
5	KP5	2,380	1,824	1,250
6	KP6	(2,280, 1,940)	(1,946, 1,779)	1,858
7	KP7	2,160	1,021	579
8	KP8	2,100	1,485	865
9	KP9	1,940	1,039	1,517
10	KP10	1,900	2,046	1,636
11	KP11	1,700	1,511	28
12	KP12	1,600	1,450	2,286
13	KP13	1,600	1,026	241
14	KP14	1,420	950	2,071
15	KP15	1,400	505	1,876
16	KP16	1,360	430	1,104
17	KP17	1,200	7,830	4,963
18	KP18	1,160	1,476	2,082
19	KP19	1,080	322	93
20	KP20	1,060	301	1,577
21	KP21	1,020	2,372	467
22	KP22	660	223	51
23	KP23	660	175	64
24	KP24	480	222	2,244
25	KP25	460	341	50
26	KP26	460	167	4
27	KP27	440	80	48
28	KP28	420	239	48
29	KP29	420	161	238
Total			**51,650**	35,079

3.3.3. Module 3: identifying core technology towards 5G

The second module prioritized hot patents based on RFM concepts, but the ranking of hot patents is not enough to explain technological trends. Therefore, construction of technology groups composed of similar or associated patents is the main purpose of the third module. Bibliographic coupling and network analysis based on cosine similarity were used to this end, and text mining to understand the technological statement of each technology group.

4. Results

4.1. Module 1: collecting raw data

Table 3 presents the standard organizations and the number of SEPs they hold, found using the search criteria, shown in Table 1, with the ETSI database. To identify key players, first we assigned points according to rank and then multiplied the scores by the weights. There are four settings comprising two technical categories (LTE and LTE-A) and two patent scopes (Basis only and Basis with Family). We assigned 30 points to the organization ranked first and 1 point to the organization ranked last for each setting. In addition, we double-weighted the Basis-only scope of the LTE-A category because practical and recent R&D activities might be a better way to identify key players. Using the aforementioned scoring and weighting calculations, we extracted the top 30 key players (see Appendix A). Chronologically, the Finnish Nokia and the German Siemens jointly founded Nokia Siemens Network (2007), which then changed its name to Nokia Networks because all the shares held by Siemens were Nokia (2011). Moreover, Microsoft took over all the businesses of Nokia, excluding Nokia Networks (2013). However, although the firms related to Nokia have complicated backgrounds, both Nokia Networks and Nokia are still leading firms in telecommunications. Thus, the patent documents of Nokia and Nokia Networks were collected using the same patent search formula and finally we had 29 key players. We represented their name by index (from KP1 to KP29) instead of actual name for confidentiality.

After extracting the key telecommunications players, we collected their 35,079 patents, issued between March 1, 2010 and March 1, 2015, from the USPTO, and bibliographical information such as updated forward patents and INPADOC family patents on the given patents using WISDOMAIN. We collected patents for a 5-year period because it might take at least

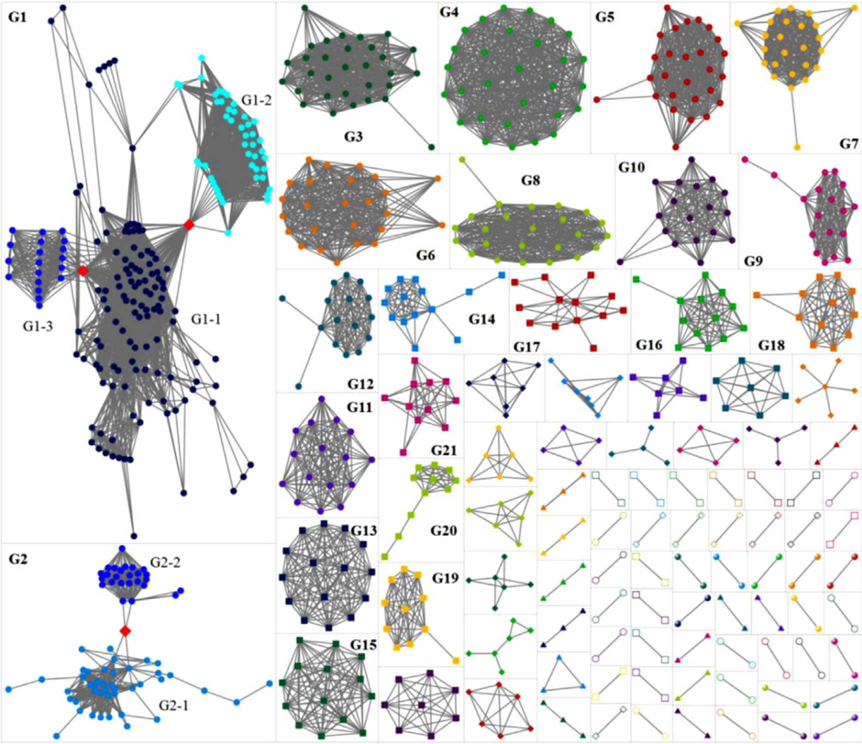

Fig. 2. Result of the bibliographic coupling and network analysis of associated hot patents.

5 years for a technological development trend towards 5G to appear. Rel-11 (January 2010–March 2013), Rel-12 (June 2011–March 2015), Rel-13 (September 2012–March 2016), and Rel-14 (September 2014–) correspond to pre-to-post 4G standards.

4.2. Module 2: extracting emerging technologies

Because of the increase in citations over time, the RFM index frequency should be adjusted by a citation-lag distribution, constructed before using the RFM concept. This study used the NBER database, which is easily collected and generally used as historical citation data. A citation-lag distribution is constructed as follows. Patent rights last 20 years and so the time lag ranges from 0 to 20. Since the NBER database has data from 1976 to 2006, the maximum year at which to observe a time lag of 20 is 1986. Then cumulative forward citations are calculated for a specific period, adjusted by a distribution identified from the NBER database. This study collected patent documents issued from 2010 up to 2015 as raw data and historical citation data from 1982 through 1986 with United States Patent Classification numbers (USPCs) corresponding to the IPCs on telecommunications technology were considered. The USPCs include 29, 52, 73, 74, 84, 174, 178, 191, 200, 235, 236, 246, 248, 250, 307, 315, 318, 323, 324, 326, 327, 329, 330, 331, 332, 333, 334, 338, 340, 341, 342, 343, 348, 358, 359, 361, 362, 365, 367, 369, 370, 375, 377, 379, 380, 381, 388, 398, 455, 505, 702, 705, 708, 713, 714, 725, and 726. As a result, the 5-year citation-lag distribution for the telecommunications sector was derived as shown in Appendix B.

The prioritization of 35,079 patents using TOPSIS was based on the citation-lag distribution and collected bibliographical information for the RFM concept. Consequently, 1757 hot patents, relevant to 95th percentile, were regarded as emerging technologies in this study.

4.3. Module 3: identifying core technology directed towards 5G

Identifying core technological directions is not easy using only prioritized hot patents, so associated or similar patents can help establish what core technologies are the key players' focus. Therefore, we grouped the associated hot patents using bibliographic coupling and network analysis. We considered two patents associated when the cosine similarity between them was ≥ 0.8, grouping 802 of 1757 patents as a result. Among them, 21 that comprised at least ten patents appeared to be core technologies, as shown in Fig. 2.

Interestingly, a group has subgroups when a patent with the highest betweenness centrality is regarded as a technological bridge. In this study, we observed subgroups in groups 1 and 2 (G1 and G2). Red square vertices in G1 and G2 indicate patents of highest betweenness centrality. Differently colored vertices indicate subgroups.

Table 4
Keywords of core technologies.

Group		Derived keywords
G1	G1-1	notification message, dual transport, DTV signal, data stream, decoded notification, virtual channel, stream data, broadcast transmitting, mobile service, trellis encoder, traffic information, FEC (Forward Error Correction), data sequence, data blocks multimedia signal, RS (Reed-Solomon) frame, FIC (Fast Information Channel) data, data packet, protocol transport
	G1-2	NRT (Non-Real Time) service, SDP (Session Description Protocol) message, program table information, IP (Internet protocol) signaling, channel configuration, MPH (Mobile/Pedestration/Handheld) service, RS (Reed-Solomon) frame, FIC (Fast Information Channel) signal, digital broadcast, GSE (Generic Stream Encapsulation) packet, mobile service data, demodulate, message descriptor, ensemble level, reference time, broadcast receiver, processor decode, IP access, SMT (Service Map Table) first descriptor, channel TPC (Two-Pore Channel)
	G1-3	second service, TCM (Trellis-Coded Modulation) encoder, DSM-CC (Digital Storage Media Command and Control) module, data packet, broadcast service, RS (Reed-Solomon) frame, signal receiving unit, mobile broadcast, text information, voice output, data detector, decoding unit, digital broadcast, frame decoder, location information, data transmit, receiving system, coding process, robustness, channel variation
G2	G2-1	transmission time interval, channel condition, communication device, mobile device, access terminal, non-handoff users, CQI (Channel Quality Indicator) feedback period, soft-handoff users, resource allocation, channel quality, scheduled channel, frequency block, base station, mobile station, ACK (Acknowledgment) TX (Transmission) pattern, subchannel, MCS (Modulation and Coding Scheme), MIMO (Multiple-Input Multiple-Output)
	G2-2	multiple data, OFDM symbol, parallel channel, spatial multiplexing, antenna mapping, multiple antennas, down link (or forward link), uplink (or reverse link), (non-)steered mode, different antenna pairs, user terminal, co-located, calibration, MIMO (Multiple-Input Multiple-Output), different frequency
G3		first data, radio resource, NACK (Negative Acknowledgment) signal, paging message, downlink burst, resource allocation, user equipment, plurality user equipment, point – multipoint control, RACH (Random Access Channel) preamble, broadband wireless access, E-UMTS (Enhanced Universal Mobile Telecommunication System)
G4		reference picture, parity macroblock, frame picture, motion vector information, different parity field, equal parity field, order embodiment, display order
G5		radio bearer, channel quality, user packet, polling procedure, PDCP (Packet Data Convergence Protocol) data, entity integrity check, security failure, plurality, radio communication service, random access, evolution LTE (Long-Term Evolution)
G6		sub b sub y, code bits, symbol bits, input data symbol, OFDM symbol, LDPC (Low-Density Parity Check) code, encoded data, interleaving process, subcarrier signal, parity check
G7		BCH (Broadcast Channel) common measurement gap, random access, time alignment, RRC (Radio Resource Control) connection, DRX (Discontinuous Reception) level, resolution timer, relay eNDB, mobile terminal, network node, PCH (Paging Channel) common measurement gap, user equipment, scheduling channel, monitoring
G8		authentication code, sink device, source device, message authentication code, advertisement information, error correction, ECC (Error Correction Code) bits, CRC (Cyclic Redundancy check) checker, DDR (Dual Date Rate) serial encoder, memory device, mobile device
G9		multiplexing rate, wireless node, cyclic delay diversity (CDD), feedback data structure, user data, phase shift-based precoding matrix, plurality matrix, diagonal matrix, multiplying matrix, orthogonality subcarriers
G10		quick paging, access sequence, reverse link, CQI (Channel Quality Indicator) reporting, pilot PN (Pseudo Noise) field, quick channel info block, data burst, pending communication, presence paging, delay
G11		MAC (Media Access Control) PDUs (Protocol Data Units), consolidated poll, physical layer feedback, chunk size, communication connection, hierarchical scheduling, QoS (Quality of Service) enhancement, remote station
G12		plurality tones, idle spectrum, quadrature imbalance, carrier plurality, OFDM (Orthogonal Frequency Division Multiplex), algorithm data, overlapping carrier signal, modulation scheme
G13		control information, ACK (Acknowledgment)/NACK (Negative Acknowledgment) information, OFDM symbol, spread ACK/NACK, transmitting multiplexed signal, plurality bit control, user equipment, signal via plurality neighboring, neighboring frequency resources, antenna set
G14		UL-SCH (Uplink Shared Channel), UL-DCH (Uplink Dedicated Channel), HT (High Throughput) devices, legacy devices, OTA (Over The Air), OSI (Open System Interconnection) report, intersector interference, intrasector interference, neighbor base station, interference estimate, channel target, station interference, transmit power
G15		antenna array, CMDA (Code Division Multiple Access) user, user device, plurality access identifier, orthogonal subchannel, data buffer, user device, directional transmission
G16		scrambling code, sequence root index, frequency-domain sequence, cell identify, Zadoff-Chu sequence, synchronization code, DC (Direct Current) subcarrier, subcarrier guard
G17		sleep mode, connection control, power saving, associated wireless terminal, non-zero modulation symbol, ZSR (Zero Symbol Rate) modulation, power consumption
G18		communication session, rate indicator channel, CDM (Code Division Multiplexing) signal, QoS (Quality of Service) resources, orthogonal spreading code, SNR (Signal-Noise Ratio), SPS (Semi-Persistent Scheduling) signal, plurality, flexibility
G19		frequency band, peer communication, air link, peer discovery, peripheral communication, device capability information, battery power, beacon symbol, peer-peer communication, beacon signal burst, signal burst
G20		contact location, ground contact, third ground, mobile device, handheld media player, data delivery electronic device, digital contact, host device, mobile device, remote recipient
G21		power amplifier, plurality tuning algorithm, matching network, switched capacitor, antenna branch, antenna matching, filter circuit, impedance matching, RF (Radio Frequency) transmitter

After identifying the core technologies, we applied text mining to each group in the core technologies to capture technological details. To achieve this, representative keywords for each group were extracted from the patent abstracts using Term Frequency and Inverse Document Frequency (TF-IDF) criteria, following the procedure of Noh et al. (2015) as shown in Table 4, and then each group was given a label based on the derived keywords. With the knowledge base of the telecommunications sector, the technological details can be understood using the differentiated keywords of each group: G1 addresses digital *broadcasting technology* and is clustered into three subgroups—digital mobile telecommunications (G1-1), mobile broadcasting (G1-2), and broadcasting channel control (G1-3). It focuses on reliable digital signal broadcasting, particularly of high-volume multimedia data. Moreover, most of the technologies work in the user plane, indicating user-centered broadcasting, is one of the most interesting topics in 5G telecommunications technologies. G2 is called *transmission control technology* and comprises two subgroups: transmission and antenna scheduling (G2-1) and transmission diversity processing (G2-2). These technologies aim to secure user plurality access and increase transmission capacity by the cost-efficient approach of optimizing limited communication resources. G3 is relevant to resource allocation, in particular, *burst reliever technology*. Telecommunications service based on G3 can provide user plurality access more effectively. G4 encompasses *multimedia file compression and efficient picture coding technology*. This technology attempts to satisfy user demand because multimedia streaming has increased tremendously in the past few years. G5 is *packet switch technology,* in which packets of signals are divided to secure capacity for simultaneous transmissions. G6 concerns *robust transmission technology*, which affects quality of service and reliability for users. G7 is *technology that deals with measurement gap monitoring*. In the future, this technology will provide smooth handover between vehicles at high speed. G8 is labeled *data flow error detection technology*. The necessity of this already important technology will increase because of the huge increase in transmission among multiple devices. G9 addresses *feedback precoding technology* (or algorithm) for enhancing signals. In particular, as data transmission speed is increased through feedback during multi-cell communications, this technology will become more significant in telecommunications. G10 is *quick paging management technology*, which is expected to increase communication capacity and decrease power consumption of user equipment. G11 encompasses *protocol control/management technology*, which is cost-efficient and enables more reliable handover. G12 includes *technology that detects and extracts an idle spectrum*. This technology enables cost-efficient service offerings by increasing communication speed and enhancing the performance of massive connectivity. G13 comprises *technology relevant to spread signal transmission*. Transmitting a spread signal to an antenna set has the effect of increasing communication capacity with limited resources. G14 is *technology for managing mixed-mode network devices to minimize signal interference*. High-throughput devices and legacy devices can communicate successfully in a mixed-mode network. In an environment of rapid technological change and multiple devices, mixed-mode network management will be significant for effective communication. G15 includes *technology that affects directional transmission based on the antenna array*. A signal steered using the technology not can only increase communication capacity, but decrease interference. G16 is *distinguishing signal identification technology,* which allows people to use frequency division or scrambling code to classify plural cells or devices. G17, *energy-efficient wireless transmission technology*, lengthens the sleep mode of a user device by enhancing transmission power, thus decreasing energy consumption of the device. G18 is *technology used for flexible resource assignment of user equipment*. Semi-persistent scheduling efficiently allocates communication resources after an orthogonal spreading code distinguishes user equipment, thus increasing network capacity and user satisfaction. G19 is composed of *peer communication technologies*. Improvement in mobile device performance will help decentralize mobile communication, which in turn can help decrease local data traffic. G20 involves *interface connection or device connection technologies*. G21 comprises *radio frequency power amplifier and antenna matching technologies*, cost-efficient ways to increase communication capacity.

4.4. Four R&D trends towards 5G

The analysis results show the clear R&D trends towards 5G of the key players. Of course, the trends may be overlapped to some extent, and each of the 21 core technologies can be associated with more than one trend. Nevertheless, when we classified the technologies based on their similarities in keywords, we could identify four major R&D trends and obtain their corresponding technologies.

The first is characterized by *increasing efficiency*, as the relevant technologies have mainly focused on the way to use the current communication resources efficiently by developing new transmission methods. Signal multiplexing algorithm, carrier spreading diversity, and new transmission concepts are included in these technologies. Representative keywords of each group are as follows: G9 (multiplexing rate, cyclic delay diversity, orthogonal subcarriers), G13 (spread ACK/NACK transmitting multiplexed signal, plurality bit control), and G15 (Antenna array, directional transmission), and G18 (orthogonal spreading code, CDM).

The second is towards *increasing capacities*. With the exponential growth of user devices and communication equipment, the data traffic has increased dramatically, which lead to the development of technologies to increase communication capacities. In this case, data burst, plurality, signal interference, and radio frequency power amplifier can be regarded as major issues, according to our keyword analysis. Seven core technologies are related to this trend: G2 (MIMO, multiple antennas), G3 (downlink burst, plurality user equipment), G5 (channel quality, plurality), G10 (data burst, CQI), G12 (plurality tones, carrier plurality), G14 (interference, transmit power), G16 (cell identify, synchronization code), and G21 (power amplifier, plurality-tuning algorithm, antenna matching).

The third is for *reliable data communication*, which has gained more significance recently. Such keywords as reliable handover for continuous connection relay, error correction, and parity check are mainly related to this trend. Core technologies in this category correspond to G6 (LDPC code, parity check), G7 (relay eNDB, measurement gap), G8 (authentication code, error correction code), and G11 (communication connection, QoS enhancement).

The final is *increasing user values* rather than operation efficiency. This focus on user-centered facet of the telecommunications technology is worthy of attention for the future. Five core technologies are associated with this trend. Among them, two core technologies can be examined under the user plane: G1 (digital broadcasting, RS frame) and G4

Table 5
Additional information to provide more details on core technologies.

Group	The number of patents	RFM value (average TOPSIS score)	Average issued year	Patent concentration (Hirschman-Herfindahl index)	Leading organizations
G1	188	0.091	2011.888	0.791	KP1
G1-1	121	0.097	2011.752	0.710	KP1
G1-2	47	0.080	2012.191	1.000	KP1
G1-3	19	0.108	2012.000	0.900	KP1
G2	69	0.045	2013.594	0.439	KP2
G2-1	44	0.039	2013.864	0.397	KP2
G2-2	25	0.055	2013.120	0.536	KP2
G3	31	0.127	2012.677	0.763	KP1
G4	29	0.022	2011.000	0.933	KP1
G5	27	0.125	2012.704	0.860	KP1
G6	25	0.055	2012.760	1.000	KP14
G7	25	0.126	2012.680	0.712	KP1
G8	24	0.038	2014.083	0.774	KP2
G9	18	0.020	2012.056	0.623	KP1
G10	18	0.068	2012.222	0.802	KP2
G11	16	0.033	2013.313	0.500	KP2
G12	16	0.038	2012.813	0.672	HTC
G13	15	0.023	2012.333	1.000	KP1
G14	14	0.068	2013.357	0.867	KP2
G15	14	0.040	2012.929	0.388	KP19
G16	13	0.019	2012.231	1.000	KP1
G17	13	0.027	2012.846	0.621	KP2
G18	12	0.025	2013.167	0.847	KP2
G19	11	0.036	2013.909	0.686	KP2
G20	11	0.152	2012.182	1.000	KP5
G21	11	0.049	2014.273	0.190	KP24

(reference picture, display order): both are closely related to multimedia coding and transmission technologies. Of the remaining technologies, G17 (sleep mode, connection control, power saving) can reduce power consumptions of a user device by enhancing transmission power. G19 (peer discovery, peer-peer communication) can help users to communicate with others located close to them. G20 (mobile device, data delivery electronic device, digital contact) is a technology regarding connections between various mobile devices, and device interfaces that can help users to control their equipment.

5. Discussion

5.1. Implications

In Section 4, we investigated the directions of technology development of key players in telecommunications. In this section, we discuss more of the relevant issues. First, it is worth addressing the value of text mining and its limitations as a way to identify technological contents from a collection of patent documents. Of course, text mining to extract keywords from a patent is one feasible way to help understand core technologies, but additional information is needed to obtain more details. Table 5 suggests the information that can show the characteristics of core technologies.

The number of patents shows the degree of relevant R&D activities of leading organizations. G1 is the technology mostly emphasized, with 188 patents, followed by G2 and G3. The average RFM scores for patents in each group helped us prioritize the core technologies. G3, G5, and G7 are the technologies frequently cited by recent patents and granted patent rights in multiple countries, indicating great values from both technological and market perspectives. Average issued year is another important variable to reveal the latest technological competition. Although the RFM concept is useful in identifying emerging core technologies, it fails to indicate “pioneering” technologies. For pioneering technology, the number of forward patent citations and the number of family patents can be low. Thus, average issued year is another important factor to help us get a sense of future technologies. In this study, G2-1, G8, G19, and G21 have low RFM scores and high average issued year, that is, very recently. Interestingly, these four groups include technologies relevant to massive connectivity and multiple device-to-device communication, both of which have been looked at as potential technologies for quite some time, but have not been the subject of intense R&D. A low patent concentration signifies higher market competition, so an organization can own the market where there is low patent concentration before a dominant design or technology is established. For this reason, G21 technology presents the greatest opportunity.

The second issue is the cutoff value of cosine similarity that distinguishes the boundary between technological groups. In this study, connections between vertices (or patents) are accepted only when the cosine similarity between two patents is greater than 0.8. Obvious group classification is the preferred way to identify the directions of technology development because RFM scores are used to screen patent samples before constructing technology groups. However, if researchers or managers want to identify loosely coupled relationships or strictly distinguish between specific technologies, they can reduce or increase this cutoff value.

The third issue for discussion is convergence technology, which is not easy to identify using this study's framework. This study emphasized only emerging technology as promising technology, but promising and innovative technologies have resulted from the convergence between the telecommunications sector and other sectors. That is, convergence technology can be another type of promising technologies in the telecommunications sector, which is worth investigating. Nevertheless, the framework of this study is not the best for discovering converging opportunities. Other, completely different approaches are needed to identify convergent technology. For example, the degree of knowledge flows between different fields (patent citation analysis) or the applicability of patents in different fields (patent co-classification analysis) are commonly examined to consider converging technologies. Thus, researchers or managers who want to employ the framework of this study should deliberately fit their analysis objectives to the advantages of the framework.

Fourth, an effective way to incorporate state-of-the-art patents when analyzing promising technologies needs to be discussed. The number of forward citations is one of the most frequently used criteria to evaluate patent value in previous studies. However, that number tends to increase faster over time. Old patents will have more opportunities than young patents. Accordingly, significant state-of-the-art patents may not be included as hot patents if we evaluate patent values based on citation frequencies. To solve this problem, we adjusted the forward citation frequency as "an expected frequency for a life of patents." Nevertheless, a patent may have no forward citation just because it is so new that it does not have enough time to be cited by other patents. In this case, recency and adjusted frequency for the patent cannot be calculated, the frequency values will be zero, and the patent will be ignored. Therefore, the proposed framework cannot be used to identify up-to-the-minute promising or pioneering technologies. Another approach is needed to select valuable up-to-the-minute patents to resolve this limitation, though designing the method is a challenge.

Finally, we found that using multiple patent databases could fill in missing information. The ETSI database contains essential standard patent information but little bibliographical information. The technological details or bibliographical information of a patent can be obtained from various patent office databases. However, because raw patent documents of patent offices are not updated often, commercially available patent databases in general have been used to find information that has changed. For instance, the application number of a reference patent may have been changed to the publication number or family patents may have been added over time. On the other hand, the NBER database is a useful source of historical citation data. Therefore, using multiple patent databases can increase the reliability and robustness of patent information.

5.2. Future research opportunities

While this research seems to have pursued rigorous analytical framework and could yield insightful results, some future research opportunities need to be discussed further, considering that 5G technology is still at a quite early stage of its development. In terms of the research method, this study is based on patent analysis, taking a quantitative approach. Industry experts were involved in the analysis to help verify the process and results, but a systemic qualitative approach (e.g., having an interview with technology firms) can help reveal new insight and methods of investigation and validate the theoretical model against industry practice. In terms of the level of analysis, this study was carried out at the macro level, but more in-depth analysis can be designed at other levels; *organizational level* to investigate organizational strategies; *sub-sector level* to examine technology competition in a particular technology field; and *individual patent level* to explore essential patent strategy or evaluate the probabilities of being a technology standard for a particular patent. The followings are the main future research topics identified.

First, the definition of promising technology can be elaborated to reflect the nature of standards-based markets in the telecommunications sector. This study employs the emergence perspective to identify promising technologies. Its results are expected to be useful by describing recent technological development trends of key players towards 5G when technological specifications or visions towards B4G have not yet clearly defined. However, some may argue that promising technology in the standard-based markets can be a technology that is likely to be selected as a standard, while not every patent derived as the core technology in this study will be standards in the future. Bekkers et al. (2002) also claimed that market or technical standards play a pivotal role in technology-intensive industries, and thus, identifying technologies with a high possibility to be future standards can be an interesting future study. Standardization typically evolves in lockstep with the evolution of both embodied and disembodied technologies in telecommunications (Tassey, 2000). However, when predicting potential standards, market agreements or a market position can be more significant than a technological performance. In such cases, other approaches than the RFM concept suggested in this study need to be developed.

Second, organizational efforts on strategic technology management in the standards-based market can be a meaningful topic to explore. This study mainly focuses on practical technology development activities of key players towards 5G in the telecommunications sector. However, not only their development activities but also their technology standardization activities are worth investigating. The needs of huge capital investments and the effects of network externalities can make telecommunications technologies strongly "path-dependent" (Rosenberg, 1994; Bowden et al., 2012). In addition, as the key players have already observed the strategy of their competitors from their experiences of 3G and 4 G technologies, the competition to have their own technology as a standard might be fierce even at the very early stage of standardization for 5G technologies. This organizational strategy regarding the development of path-dependent technologies may also be affected by the strategy to manage technology life cycle. It is generally recognized that telecommunications technologies have shorter life cycle than other technologies (Park, Yoon & Lee, 2005). Besides, according to the recent study by Jeong, Park, and Yoon (2016), B4G telecommunications technologies would need a longer time to enter the phase of "useful life" compared to 4G telecommunications technologies, while shorter time to enter the phase of "wear-out". These findings indicate that R&D risks in the telecommunications are relatively high and tend to increase. On the contrary, once a technology becomes a standard, it may extend its lifespan due to its path-dependent nature. Therefore, there might be some unique characteristics of organizational strategies on telecommunications technology management. An investigation of 3G and 4G technologies in their early stages of standardization process would be greatly useful to understand the organizational strategies for 5G technologies.

Third, this study adopted a quantitative approach to identify emerging core technologies. Such approach is based on objective observations; thus, results of this study can provide practical opportunities to look back on current R&D directions for organizations making huge efforts to develop B4G technologies. However, these data-driven results are limited in drawing detailed implications for technology strategy at the micro-level, which can provide more direct and insightful knowledge. Instead, a qualitative approach enables to discover technology alternatives with core functionalities related to the technological groups (G1–G21), identify main competing solutions and actors in these fields, and offer information about the efforts of such actors to have their technology as a standard. Therefore, it is expected that qualitative information collected from interviews or practical discussion with experts in the telecommunications sector can complement and validate the results of this research.

6. Conclusion

The purpose of this study was to propose a framework for identifying promising telecommunications technologies based on patent information. To define them, this research reviewed literature on promising technology and the characteristics of the telecommunications sector. We used the RFM concept to determine the hot patents and then bibliographic coupling and text mining to identify the technological developments that lead to 5G. The main findings of this study can be used in both theoretical and practical situations. With respect to the theoretical findings, we summarized the perspectives on promising technology in existing literature and then questioned the significance in defining a promising aspect according to analysis objectives or the characteristics of the technology. In addition, the RFM concepts defined in this study can be applied to other kinds of patent analysis studies to identify core technologies. With respect to the practical findings of our study, we identified the directions of technological developments of key telecommunications players by searching multiple patent databases. Our summary of the perspectives on promising technology can be a milestone for future studies. The emerging core technologies we derived can be used to establish R&D plans in the telecommunications sector. Thus, we expect the research findings to contribute to the field of patent analysis and inform the decisions of those who are in charge of R&D planning in the telecommunications sector.

Despite the theoretical and practical contributions of the main findings and results of this study, it has some limitations. First, the overall technological capabilities of the key players cannot be described sufficiently using information only from the USPTO database, because a corporation might not apply for a patent in the U.S. if the U.S. is not its target market. Thus, patents in European countries, Japan, Korea, and China, for example, need to be included to capture the overall technological directions of the key telecommunications players. Second, measuring M in the RFM concept can be elaborated. Patent family information has been frequently used as a proxy to measure the value of a technology (Ernst & Soll, 2003; Lanjouw & Schankerman, 2004; Dou, 2004; Reitzig, 2004; Harhoff & Hoisl, 2007; Zuniga et al., 2009). However, simply counting the number of family patents to obtain the index value may overlook the differences in markets. For example, a market size may vary and it may be correlated with the value of technology in the market (Ernst & Omland, 2011). Recognizing this limitation, Ernst and Omland (2011) suggested a new index, called market coverage, by considering a market size to calculate the index value. Despite its usability, the market coverage index was not used in this study due to the large size of data. A future study needs to adopt the newly suggested index, if focusing on detailed analysis using a limited set of data. In the similar vein, third, measuring F in the RFM concept can be improved. We developed a citation-lag distribution table using the NBER database, which is based on the US patents, published 1986 to 2006, and used it to adjust our index value. During the process, we assumed that the distribution of the citation-lag would have been stable in the telecommunications over the last years. Further analysis is required to justify the assumption or recent data needs to be used to develop the table. Finally, this study was conducted mostly at the macro-level, attempting to identify the sector-level trends in technology development. However, in order to offer more practical implications, it is necessary to pin down the analysis further to the micro-level, investigating the organization-level strategy concerning not only technology development but also technology standardization towards 5G. For example, it would be interesting to examine how firms have engaged in standard setting activities to have their technologies selected as a standard, and how they have established their technology roadmaps, considering that the telecommunication sector is characterized by a standard-based market. Future research needs to address this issue.

Appendix

See **Table A1** here

Table A1
Citation-lag distribution for the telecommunications sector.

Time lag	Year					Total	Cumulative sum	Distribution	Cumulative distribution
	1982	1983	1984	1985	1986				
0	280	298	526	676	585	2365	2365	0.177609	0.001776
1	4590	5337	7278	8924	12,088	38,217	40,582	2.870056	0.030477
2	10,401	11,501	14,150	21,861	20,516	78,429	119,011	5.889934	0.089376
3	12,687	12,788	19,917	19,107	26,961	91,460	210,471	6.868548	0.158062
4	13,264	15,873	16,514	23,544	22,262	91,457	301,928	6.868322	0.226745
5	15,221	12,503	18,480	18,315	21,850	86,369	388,297	6.486219	0.291607
6	11,911	14,102	14,346	17,823	19,555	77,737	466,034	5.837965	0.349987
7	13,253	10,863	13,844	15,783	17,471	71,214	537,248	5.348095	0.403468
8	10,236	10,206	12,728	14,460	16,996	64,626	601,874	4.853343	0.452001
9	9851	9601	10,934	13,654	16,905	60,945	662,819	4.576904	0.497770
10	9120	8793	11,589	13,701	17,860	61,063	723,882	4.585766	0.543628
11	8310	8545	11,261	14,928	16,059	59,103	782,985	4.438572	0.588013
12	8068	8664	12,096	13,344	19,911	62,083	845,068	4.662367	0.634637
13	8044	8729	11,270	16,235	18,144	62,422	907,490	4.687825	0.681515
14	9133	8248	14,176	14,797	17,890	64,244	971,734	4.824655	0.729762
15	8578	10,233	12,572	14,279	17,518	63,180	1,034,914	4.74475	0.777209
16	10,331	9234	12,557	14,989	16,530	63,641	1,098,555	4.779371	0.825003
17	9721	9110	12,516	13,646	16,364	61,357	1,159,912	4.607845	0.871081
18	9472	9795	11,896	13,858	16,289	61,310	1,221,222	4.604315	0.917125
19	9699	9492	11,427	13,379	9476	53,473	1,274,695	4.015765	0.957282
20	9448	9223	11,097	8137	18,977	56,882	1,331,577	4.271777	1
Total	**201,618**	**203,138**	**261,174**	**305,440**	**360,207**	1,331,577	14,682,663	100	

A. Top 30 key players in the development of telecommunications sector (sorted by alphabetic order).

ALCATEL-LUCENT, Apple, BlackBerry, Ericsson, ETRI, General Dynamics, HTC, Huawei, Innovative Sonic, Intel, InterDigital, IPR Licensing, Kyocera, LG Electronics, Motorola Mobility, NEC, Nokia (Nokia Networks + Nokia), Nortel Networks, NTT Docomo, Orange, Panasonic, Pantech, Qualcomm, Renesas Mobile, Samsung Electronics, Sharp, Sony, Texas Instruments, UPIP.

B. Citation-lag distribution for the telecommunications sector.

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