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Monitoring patterns of open innovation using the patent-based brokerage analysis

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ABSTRACT

As the paradigm of open innovation continues to proliferate in both academia and practice especially for the last decade, many studies have attempted to investigate patterns of open innovation. However, empirical and quantitative approaches to monitoring the patterns of open innovation are less conducted because of the difficulty in data collection and the lack of effective methods. Also, it is difficult to identify the patterns of open innovation when there are many cases of open innovation in a wide range of technology areas. In this respect, this paper aims to quantitatively monitor the patterns of open innovation using the patent-based brokerage analysis in the case of mobile communications technology. Using patent citation information, the knowledge flow between technology fields and firms is identified, especially for structuring the open innovation network of 5G technology. Then, the patent-based brokerage analysis based on the open innovation network is conducted to extract brokerage patents that present the patterns of open innovation: inbound and outbound innovation. Furthermore, the brokerage firms are explored to recommend the partnerships in the open innovation network. According to the results, it is expected that "strategy for open innovation dynamics" is systematically formulated based on the brokerage patents and partners in various technology areas.

1. Introduction

During the past decade, many studies that focus on the characteristics of open innovation in innovation research areas have been undertaken. Along with the trends of these open innovation studies in the academia, open innovation has become one of the emerging issues in practice. Moreover, its concept, type, pattern, and effect have so far been substantially highlighted (Chesbrough, 2003). Introduced by Chesbrough in the 2000s, many practical and theoretical articles have been published, and case studies of successful open innovation cases have also been reported (Huizingh, 2011; Jeon et al., 2012; Mazzola et al., 2016; Wang et al., 2012). The collaboration with and within groups is facilitated to achieve a common mission and to help others perform their own goals. With this, open innovation is making a concerted effort to exploit the knowledge and solutions required for both inside and outside. Such types or patterns of open innovation are called the inbound and the outbound types of innovation (Chesbrough and Crowther, 2006). For both R&D and commercialization, many collaboration types of open innovation are proposed: technology acquisition, outsourcing, R&D partnership, joint-venture, and networking (Lee et al., 2010; Jeon et al., 2011a, 2011b; Suh and Kim, 2012). As particularly related to outbound innovation, focus has also been given on innovation studies on constructing partnerships.

However, systematic research on the monitoring patterns of open innovation in the technology level has been less focused so far. To monitor the patterns of open innovation, two questions have been raised: "Which patterns of open innovation are mostly conducted?" and "How can the cases of open innovation be identified?" To answer these questions, a patent analysis provides a possible solution. Although the M&A or joint venture data can represent the open innovation patterns, the data sample is minuscule (Basole, 2009; Suh and Kim, 2012). In addition, it is difficult to identify detailed information on a common problem and solution. In contrast, the patent provides a large database with various factors such as technology classification, firms (assignee), and contents. In open innovation, there is an immediate demand for empirical studies with larger samples (West et al., 2014). The results of patent citation network give an opportunity to systematically explore the relationships between interacting technology areas and partners because the knowledge flow between inside and outside firms can be traced through patent citation information (Jeon et al., 2011a, 2011b). It is an understandable source that shows the knowledge flow; also, the concept of open innovation is included in terms of knowledge inflow

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(backward citation) and outflow (forward citation) (Choi and Park, 2009). This citation information is not directly related to formal collaboration among firms, but it is significantly helpful in identifying knowledge sharing among the firms (No and Park, 2010). Thus, patent citation is an ample resource to explore open innovation in the perspective of knowledge flow and sharing.

Despite this strength, the patent citation analysis has also a problem that it is difficult to explore and formulate the pattern of open innovation directly. In fact, previous studies are limited in conducting a simple network analysis to take into consideration all linkages as collaborations in open innovation (Jeon et al., 2011a, 2011b; Mazzola et al., 2015; Shin and Kim, 2013). This simple network linkage rarely reflects the open innovation strategy, without the differentiation between inbound and outbound collaborations. The research case that only considers network indexes, such as density or betweenness, shows a lack in exploring the network roles of positions in open innovation (Lee and Lee, 2013; Park et al., 2013). Therefore, a more significant connection in the view of open innovation should be identified to measure the synergy effect in the dynamic innovation network and group effect and to provide managerial implications for the open innovation strategy (Leydesdorff and Ivanova, 2016).

In this respect, this paper proposes the patent-based brokerage analysis to quantitatively monitor the patterns of open innovation and the R&D partnerships for open innovation. As a means to an end, the patent analysis procedure is divided into two parts: first, the patent citation network analysis is used to identify the whole structure of mobile communications technology; and second, brokerage analysis is applied and modified to match brokerage patents with patterns of open innovation during the growth of patent citation network. Using a brokerage network analysis, the types and patterns of open innovation are extracted based on the brokerage patents. Through a brokerage analysis, five types of brokerage roles can be extracted. These can include coordinator, gatekeeper, representative, consultant, and liaison. Moreover, these types match with the patterns of open innovation such as inbound and outbound innovation. The brokerage patents, which represent relationships between technological areas, help engineers and managers identify the pattern of open innovation by focusing on the characteristics of the technology and the partner. In particular, researchers can identify which patterns of open innovation are mostly dominated based on the types of brokerage patents. Moreover, partnerships among international firms are monitored based on brokerage patents through a trend of international collaborations. By exploiting the brokerage patent network for each type of open innovation collaboration, the open innovation strategy is effectively formulated, with a focus on the respective purpose and process of each type of open innovation. It is expected that the technology policy for future open innovation can also be planned in terms of brokerage technology and partnerships.

In this paper, this approach is applied to the special case of mobile communications technology such as WCDMA (Wideband Code Division Multiple Access) and LTE (Long-Term Evolution) technology. By evolving the generation of mobile telecommunications, the international standard of technology specifications is formulated through an international coordination among many global and powerful firms as well as international organizations or conferences. Thus, the mobile communications industry is a representative technology field in which open innovation is activated. In fact, many influential firms, such as *Google*, *Nokia*, *Qualcomm*, *Samsung*, and *Huawei*, are collaborating to develop a reference model of mobile communications technology and system under the control of international organizations such as the International Telecommunications Union (ITU) and the Third Generation Partnership Project (3GPP). Through the patent-based brokerage analysis, the dominant patterns of open innovation are easily investigated. Furthermore, linkage patents among the fields of mobile communications technology are explored, and these patents provide useful information on collaborative technologies and partnerships.

2. Concept of open innovation

There are fewer economies of scale in R&D than there were a generation ago as a consequence of increasing R&D costs and shorter product life cycles (Chesbrough, 2006). As these problems of increasing costs and shorter life cycles have made an impact on various industries, closed innovation has no longer been sustainable. In this respect, the concept of an open innovation model is emerging as the antidissertation of the closed innovation model. Open innovation is defined as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively” (Chesbrough, 2003). Chesbrough assumes that external ideas, as well as internal ideas, should be used within or with various areas such as technology fields, firms, industries, and societies. Also, open innovation is defined as “systematically encouraging and exploring a wide range of internal and external sources for innovation opportunities, consciously integrating that exploration with firm capabilities and resources, and broadly exploiting those opportunities through multiple channels” (West and Gallagher, 2006). With this, open innovation now focuses more on utilizing external sources of innovation such as customers, rivals, and universities. Many practicing managers also consider open innovation useful because it motivates the exploration of entirely new ways of innovating with partner organizations and individual experts (Chesbrough et al., 2006; von Krogh, 2011). In the end, the open model has taken on greater attention in light of the recent industries (Chesbrough, 2006; Jeon et al., 2015).

A central tenet of open innovation is the recognition that today, competitive advantage often comes from open innovation practices. The model of open innovation shows internal and external ideas flowing into the R&D process. Also, it shows the outputs of that process going to the market through internal and external paths, as shown in Fig. 1 (Chesbrough, 2003). Ideas can still originate from inside the firm's or industry's R&D, but some of those ideas may seep out of the firm or industry.

Furthermore, as described in Table 1, two patterns of open innovation are defined as the direction of innovation (Chesbrough and Crowther, 2006): inbound innovation and outbound innovation. *Inbound innovation* refers to inward technology transfer from other technology fields, firms, or industries. This pattern describes the practice of leveraging the discoveries of others because firms need not exclusively rely on their own R&D. Technologies developed by these activities did not originate in internal research but nonetheless are useful for the business. Some examples of inbound innovation are in-licensing and outsourcing. *Outbound innovation*, on the other hand, refers to outward technology transfer toward other technology fields, firms, or industries. This pattern suggests that firms can look for external organizations with business models that are suited for the exclusive commercialization of a technology or in addition to its internal application. In this case, technologies developed by these activities originate in internal research but are nonetheless beneficial for the business to commercialize outside. Some examples of outbound innovation include out-licensing and

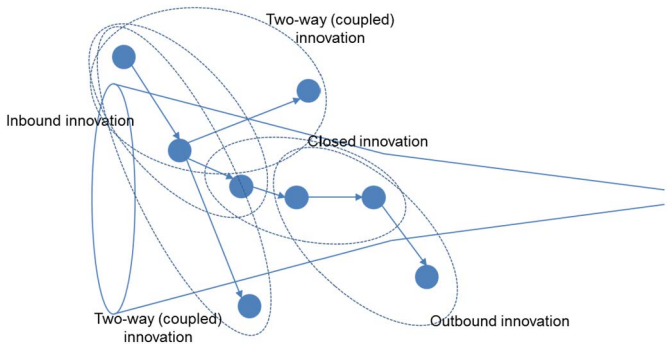

Fig. 1. Concept of open innovation.

Table 1
Types and methods of open innovation.

Type	Method	Concept	Cases
Inbound	In-sourcing	Exploring external technology or knowledge	C&D strategy of P&G
	R&D collaboration	R&D collaboration with external organization (e.g., university)	Lablet of Intel
	Acquisition	Acquisition of a company or product	M&As of Cisco
Outbound	Technology licensing	Licensing internal technology outside	MIPV of MS
	Spin-off	Spinning off an internal organization	New venture group of Lucent
	Joint venturing	Investing venture with venture capital (VC)	Venturing between HP Lab and VC
	Opening project	Opening project or source to the public	Linux

venturing (Lee et al., 2010; Suh and Kim, 2012). Furthermore, the related studies have been extended to the concept of ecosystems based on cooperative systems among industries, including input-output relationships, business models, and economy structure (Suh and Kim, 2015; Yun et al., 2016a, 2016b).

However, there is a lack of the studies on effective patent analysis which is directly able to identify the patterns of open innovation above. Rather than using concrete types of open innovation in previous studies, the researchers used patent analysis have mainly focused on developing new typology limited in their own results (Lee et al., 2010; No et al., 2015; Petruzzelli et al., 2015). Also, several studies have attempted to only select reasonable and competitive partners for open innovation, without consideration on different types of open innovation (Yoon and Song, 2014). Recently, it is more important to identify the types of open innovation network and their dynamic changes for forecasting paths of the collaboration (Yun et al., 2016a, 2016b). Thus, this study proposes an effective method, identifying the dynamic change of open innovation network and applying brokerage analysis of patent citations into the types of open innovation.

3. Proposed approach

3.1. Patent citation network analysis

The patent network analysis is one of the main patent analysis techniques (Meyer, 2000). This network analysis is usually conducted to find the relationships between patents using keywords or citation information. In particular, the patent citation network is used by the citation information, which is a direct proxy of relationships between patents (No and Park, 2010). In particular, the dynamic citation network consists of two relations: backward citation and forward citation (Choi and Park, 2009). *Backward citation* stands for a relationship between a current patent and patents that are cited by the current patent. On the other hand, *forward citation* stands for a relationship between a current patent and patents that cite current patents. These relationships can be clearly understood by referring to Fig. 2. As the open innovation network is greatly similar to these relationships between patents, the patent citation network is useful for identifying the open innovation network.

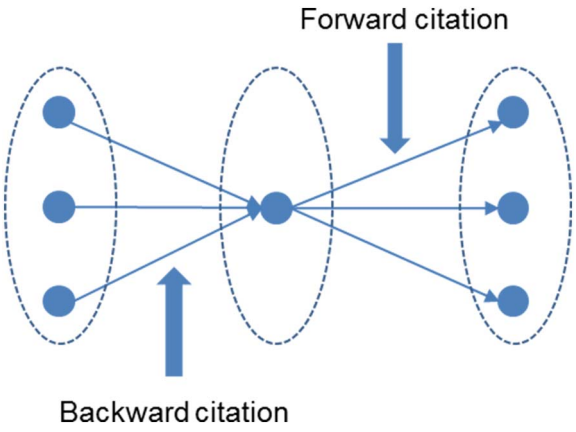

Fig. 2. Citation relationships in a dynamic citation network.

However, it is difficult to investigate the patterns of open innovation network by only using a citation network analysis. The advanced approach to finding the roles of nodes and patterns of network relationships is required for understanding open innovation. In this respect, the brokerage analysis to analyze the network characteristics will be described in the next section.

3.2. Brokerage analysis

Among the network analysis techniques, the brokerage model is one of the ego networks that consist of a focal actor as a set of alters that have ties with the ego (which is particularly located in the center as a target) as well as measurements on the ties among these alters (Wasserman and Faust, 1994). When the actor—as the "ego"—is located in the center, other alters are related around this ego. In the brokerage model, the ego is considered the broker, and the ego is the internal source related to other internal or external sources in the view of open innovation (Suh and Kim, 2015). To sum up, through the group relationships analysis, the brokerage analysis aims to find such relationships between groups or fields based on the broker. As shown in Table 2, five types of brokers are suggested and widely accepted as the representative brokerage model (Gould and Fernandez, 1989). In this study, this is a vital "metaphor" for patterns of open innovation such as inbound and outbound innovation. Through brokerage analysis, the

Table 2
Five types of brokerage roles and their pattern in network.

Broker type	Brokerage pattern ("A" in the middle is the broker)	Description
Coordinator	{A → "A" → A}	All nodes belong to the same group.
Gatekeeper	{B} → {"A" → A}	Based on the broker in group A, the giver belongs to a different group B, while the recipient belongs to the same group A.
Representative	{A → "A"} → {B}	Based on the broker in group A, the recipient belongs to a different group B, while the giver belongs to the same group A.
Consultant	{B} → {"A"} → {B}	Based on the broker in group A, both the giver and the recipient belong to the different group B.
Liaison	{B} → {"A"} → {C}	All nodes belong to different groups.

patterns of open innovation are quantitatively and automatically detected (for mathematical equations of network intensity and relatedness, refer to the study of Lee et al. (2015)). In the following part, this study focuses on how brokerage analysis is applied to open innovation patterns.

3.3. Patent-based brokerage analysis in open innovation

This study proposed the patent-based brokerage analysis to find the patents of open innovation roles. Previous research has focused on the patent network in open innovation, but this research has concentrated on brokerage patents, with corresponding types of open innovation. By identifying the brokerage patents, the open innovation strategy is effectively formulated through the purpose and process of each type of open innovation. Before, it was difficult to find supply–demand relationships in open innovation, but using a brokerage analysis indicated that those relationships could be identified. As previously pointed out, in the concept of open innovation, the broker is the internal source, mediating other internal or external sources. The external sources can be defined in various ways such as technology, product, firm, and industry. With respect to patent-based brokerage roles, the open innovation strategy has similar patterns of collaboration in the technology level as shown in Fig. 3. The detailed description of brokerage types, innovation types, and the related open innovation strategy are summarized in Table 3.

First, the internal innovation (closed innovation) is represented by a coordinator broker. This type of innovation is a traditional type for collaborating with actors in the same field. In other words, similar technologies are converged and applied in a homogeneous field. Second, the inbound and outbound innovation types are matched with a gatekeeper and a representative, respectively. These types of brokerage roles are also considered as technology convergence. The gatekeeper in field A plays a role in borrowing another field's technology to improve the technology of field A. This inbound innovation helps actors in field A to solve problems using technology that is not applied in their own fields. In contrast, the representative in field A is related to outbound innovation in which a patent in field A is used by technologies of other fields. By finding the representative, the researchers can find a path that would link with the outside of one's own field. Finally, there are consultation and liaison between brokerages, which are related to two-way innovation. The consultation patents are interacting patents between two fields. This type of patents in field A is using another technology of field B to improve their technology, and this improved part of a patent in field A can be sequentially reused by field B's technology. On the other hand, the liaison is a bridging patent between other fields. This liaison can be related to the concept of heterogeneous convergence. This is a case wherein a patent in field A is granted by applying a patent in field B and applied by a patent in field C. The convergence among the three fields happens in the center of the liaison. Thus, this type can be seen as the strongest type of open innovation.

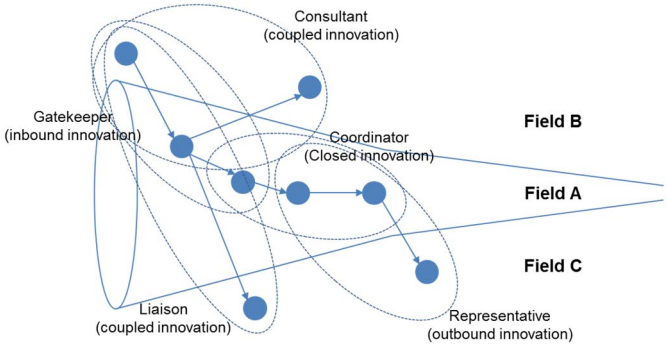

Fig. 3. Brokerage analysis for open innovation.

Table 3
Application of brokerage patents for open innovation.

Brokerage types	Innovation types	Open innovation strategy
Coordinator	Internal innovation	Finding closeness in broker patents to enhance the network
Gatekeeper	Inbound innovation	Finding solutions from other technology fields
Representative	Outbound innovation	Finding other application fields to extend technological areas
Consultant, Liaison	Two-way innovation	Finding solutions and application fields in other technology fields

Through the patent-based brokerage analysis, patents classified into each type of open innovation are used to find linking technologies and partners for the open innovation strategy. Also, different strategies are formulated to promote innovation relationships by classifying the fields based on the inbound and outbound innovation. Based on gatekeepers, the researchers found similar patents in the same field using the citation network to seek a solution from other fields. More insight to the solution can be obtained from the technologies of other fields. On the other hand, based on representatives, the application fields are derived through the relations of an outbound innovation network. The technology fields can be extended by using the representatives. The final two brokers of consultant and liaison are considered to find both solutions and applications from other technology fields. In other words, these two types of brokers have stronger convergence relationships than the prior three brokers. The consultant attempts to find the solution and application field in the same area, but the liaison tries to carry out the solution and application field in a different area. Such a broker can have various features of various technology fields. To sum up, by using the brokers, the open innovation strategy in the technology level can be supported.

4. Open innovation in mobile communications technology

Recently, ICT innovation is mainly introduced along with the revolution of mobile communications technology. The evolution of the mobile communications generation has now reached fourth generation (4G) and is considered International Mobile Telecommunications (IMT)–advanced. Through the rapid innovation of mobile communications technology, the specification of hardware and software has radically improved. The hardware and software for network servers, transceivers, and terminal units have evolved along with the fundamental mobile technology. The market of this mobile technology has explosively increased, making it possible to refer to many clues to the global economy growth, which dominated global mobile communications firms. The market size of mobile communications made by global firms, such as *Nokia*, *Ericsson*, and *Huawei*, was expected to be USD 2 trillion in 2015. The smartphone, one of the main terminal units, has also been a major market recently in the global economy including firms such as *Apple* and *Samsung*.

With the current mobile revolution, one of the main phenomena is the international coordination for R&D and the commercialization of mobile communications technology. For the global use of mobile communications services, countries and global firms are coordinated with each other, depending on the global standards of mobile communications technology. If one country applies a different format of mobile access technology, a foreigner will find it impossible to use the other country's mobile communications because of the different spectrum band or hardware/software specification. Thus, recent mobile communications technology has been developed through a collaboration with global firms. Also, the unified standard for this technology has been set through an international agenda and acts under the international organizations or conferences such as the ITU, 3GPP, and the World Radio Conference (WRC). For the next generation of mobile

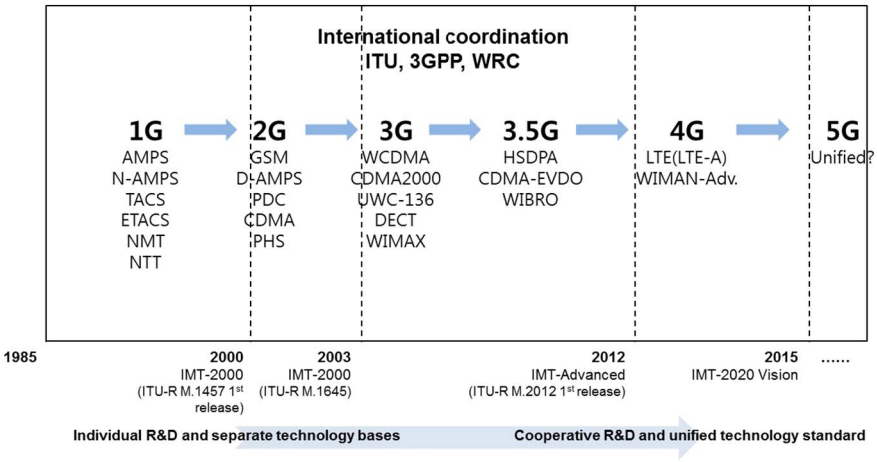

Fig. 4. International coordination in each generation of mobile communications technology.

communications technologies, many multinational firms, such as *Qualcomm*, *Google*, and *Nokia*, are now collaborating to develop the most relevant technology, which would match the international standard with technology specifications. Naturally, open innovation facilitates the field of mobile communications in the converging and evolution of the generation of mobile communications technology. Open innovation comes to the fore as the essential strategy in mobile communications sectors.

As shown in Fig. 4, the basic mobile communications technology was developed in the 1980s. Many types of technology were used without any consensus on global uses. In this age, the firms were completely disconnected. With regard to this fundamental mobile communications technology, the second generation (2G) has been started, with a focus on voice call. These days, many individual specifications of mobile communications have been published—*GSM* (Global Systems for Mobile communications), *D-AMPS* (Digital-Advanced Mobile Phone Service), *CDMA* (Code Division Multiple Access), and *PHS* (Personal Handyphone Service)—having no international coordination or collaboration. In other words, the mobile communications technology was individually developed through internal or closed innovation. Although individual development continued in the third generation (3G), the need for coordinating the technology specification has been discussed from the 3G, known as IMT-2000, based on ITU-R's first release. The number of technology specifications was reduced through the international coordination under international organizations or conferences such as the ITU, 3GPP, and WRC. As a result, few kinds of technologies were developed such as *WCDMA*, *CDMA2000*, *UWC-136* (Universal Wireless Communications Consortium), and *WiMAX* (World Interoperability for Microwave Access). The international coordination began in earnest from 3.5G, such as *HSDPA* (High-Speed Downlink Packet Access) and *WiBro* (Wireless Broadband Internet), and 4G as the importance of global roaming and data service continues to increase. In 4G, mobile communications technology has been dramatically changed based on the *LTE* with respect to speed, coverage, and spectrum efficiency.

From 4G, multinational companies have been starting collaborations because the level of technology to increasing the data speed and coverage is too advanced. Focusing on development capital, they share mobile communications technologies. Thus, the mobile communications technology has been co-developed through open innovation among several multinational companies of manufacturers, network developers, and service providers. In the next generation of the fifth generation (5G), it is highly possible to use completely unified specification mobile communications technologies. During this 5G, open innovation among corporations, institutes, and even nations will play a more vital role in identifying and developing core technologies.

In this context of open innovation, patent and M&A information has been widely applied to monitor the evolution of mobile communications technologies. Through a patent network analysis or firm network analysis, the evolution paths of technology are analyzed. However, when only a network analysis is used, it becomes difficult to explore and formulate the open innovation strategy. In the open innovation strategy, various types of collaborations are suggested, divided into inbound and outbound collaborations. Previous studies were limited in conducting simple network analyses to consider all linkages as collaborations in open innovation. This simple network linkage rarely reflects the open innovation strategy, differentiating between inbound and outbound collaborations. Thus, a more significant connection from the view of open innovation should be identified to provide managerial implications for the open innovation strategy. Furthermore, analyzing the significant network in open innovation is more important in the field of mobile communications because many collaborations are required to develop a technology that satisfies global standards.

5. Patent-based brokerage analysis for open innovation

5.1. Collection of patent data

First, the data of patents granted from 2006 and 2015 were collected, along with the planning of the ITU. From the stage of IMT-2000 deployment, the patents are focused on WCDMA, HSDPA, LTE, and LTE-A granted in the international patent class of H04. By using the keywords of these main generation terms, 1281 patents are collected. Among these patents, outperformed patents, which are at a level of *S* and *A* rated by a patent examiner, were selected as core patents. As a result, 138 core patents were chosen. To be specific, for each generation of mobile telecommunications, the data consist of 28 patents searched with the keyword "*WCDMA*" for 3G, 28 patents searched with the keyword "*HSDPA*" for 3.5G, 66 patents searched with the keyword "*LTE*" for 4G, and 16 patents searched with the keyword "*LTE-Advanced*" for 4G. Based on these patents, the researchers more collected 98 backward citation patents, which are patents cited by core patents, and 56 forward citation patents, which are patents citing core patents. Also, the backward citation patents are considered as fundamental mobile technology, while the forward citation patents are monitored as candidates for IMT-2020. Among these 292 patents, the patents that have the number of backward and forward citations below 5 were removed because they lack significance in patent citation networks. Consequently, 287 patents were used for constructing the patent citation network.

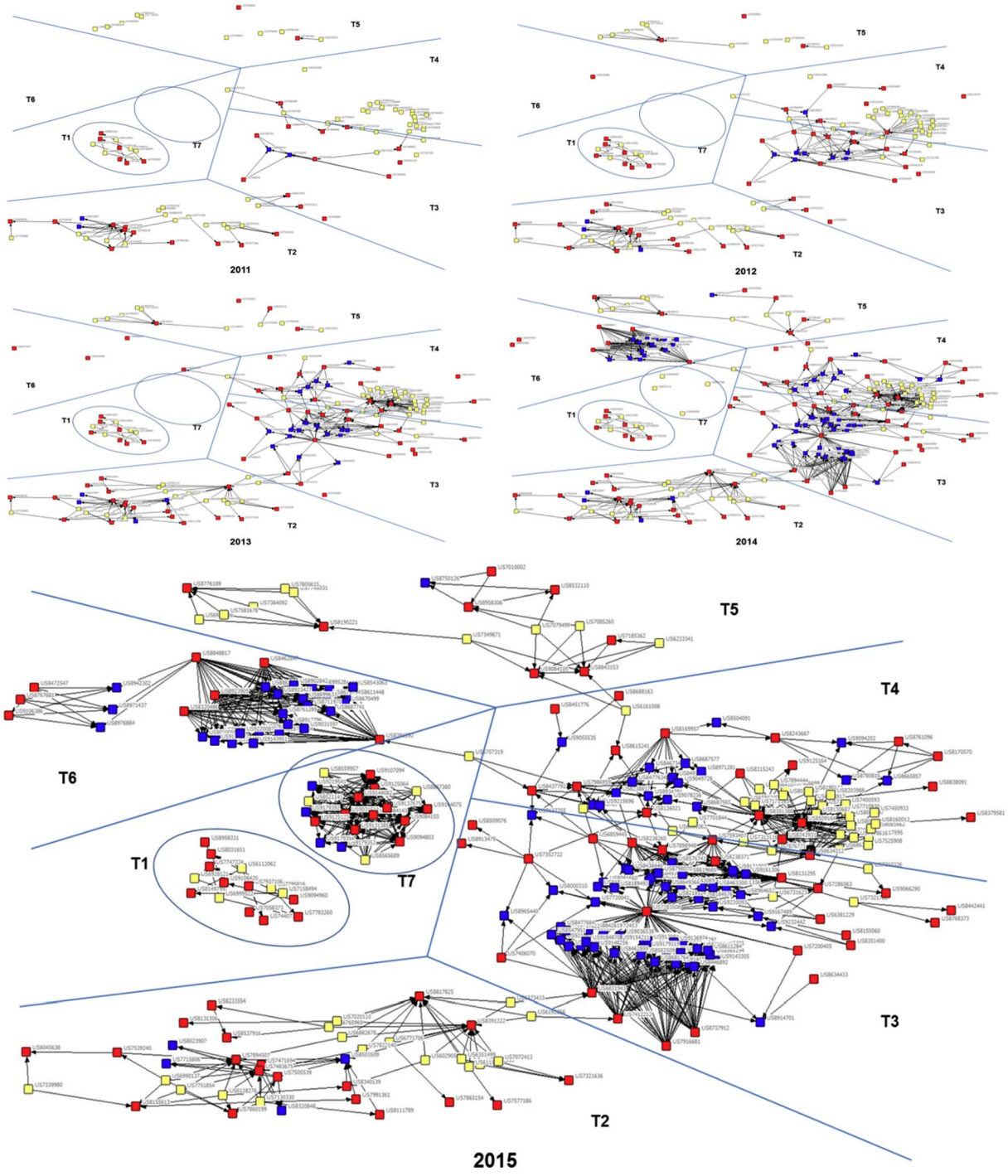

Fig. 5. Growth of patent citation from 2011 to 2015: WCDMA, HSDPA, and LTE (the red square means the core patent). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5.2. Technology areas in patent citation network

Using the citation information on highly rated patents related to WCDMA, HSDPA, LTE and LTE-A, Fig. 5 shows how the snapshot of the patent citation network from 2011 to 2015 is constructed. The dynamic snapshot shows the growth and change pattern of the patent citation network. This network is divided into seven technology clusters from T1 to T7. Through multidimensional scaling (MDS) methods based on the citation matrix, the technology areas were classified as described in Table 4. The technology area is defined using the keywords extracted by applying a text-mining algorithm into patents in each area.

First, T1 is a technology area that includes HARQ, CA, and signal control. These three main keywords commonly indicate the spectrum efficiency, and T1 is mostly constructed with patents related to WCDMA. The average granted year is 2011, and, thus, the patent network was mostly constructed in 2011. Second, T2 is a technology area that can increase data rate based on the WCDMA and HSDPA. There are many fundamental technology keywords related to modulation/demodulation and antenna technology such as OFDMA, MIMO, and weight antenna. The average granted year is 2010, and this technological area comes to an old area compared to the other seven clusters. Third, T3 and T4 areas are related to fundamental mobile communications

Table 4
Clusters of mobile communications technology (year 2015).

Clusters	Main generation	Year	Number of core patents	Keyword	Description
T1	WCDMA	2011.3	10 (7.2%)	HARQ/CA/signal control	Spectrum efficiency
T2	WCDMA/HSPA	2010.8	19 (13.8%)	OFDMA/spatial multiplexing/MIMO/single channel, weight antenna	Technology for increasing data rate
T3	WCDMA/HSPA/LTE	2010.1	23 (16.7%)	Packet/MAC/WCDMA/HS-SCCH/recovery/relay	Network operations
T4	LTE, LTE-A	2012.9	18 (13.0%)	Uplink/downlink/random access/transmission	Radio access
T5	WCDMA/LTE	2012	8 (5.8%)	Data processing/broadband/mobile traffic/optimization	Broadband network operations
T6	LTE, LTE-A	2013.5	8 (5.8%)	Precoding MIMO/MU-MIMO/CoMP/beam forming	Technology for increasing data rate
T7	LTE-A	2015	11 (7.8%)	LTE-TDD/agile beam-forming techniques/all-purpose broadband/ sensor data network	Technology for increasing data rate/ connectivity
Isolation	LTE	2012.8	41 (29.7%)	Sensor/shared channel/front end/D2D	Spectrum efficiency/connectivity

Note: HARQ (Hybrid Automatic Repeat Request), CA (Carrier Aggregation), OFDMA (Orthogonal Frequency Division Multiple Access), MIMO (Multiple-Input Multiple-Output), HS-SCCH (High-Speed Shared Control Channel), CoMP (Coordinated Multipoint Access), TDD (Time Division Duplex), and D2D (Device-to-Device).

technologies for network operations and radio technology. The keywords of T3 are *packet*, *MAC*, *HS-SCCH*, *recovery*, and *relay*. All technology generations are included in this T3, which consists of many patents that were granted in 2010 on average. T4 has basic technologies related to radio technologies and includes keywords such as *uplink*, *downlink*, *random access*, and *transmission*. Contrary to T3 patents, the target generation of patents in T4, which were granted in 2012 on average, are LTE and LTE-A.

Fourth, T5 is a significant technology area in recent mobile communications technology that focuses on mobile broadband. As mobile broadband services are essential in the era of mobile data, technology has been advanced to data transmission based on a mobile broadband spectrum. Keywords, such as *management of mobile broadband data processing*, *mobile traffic*, and *optimization*, have thus emerged. Since the development of smartphones, it has been important to provide high-quality mobile data traffic by optimizing the cell structure.

Finally, T6 and T7 areas, which dominated 2014 and 2015, are the most recent technologies to reach the goal of high-speed mobile data service and hyperconnectivity. With this, there are three critical technologies for increasing the data speed: MIMO, CoMP, and beam forming. First, MIMO is a vital technology for enhancing the speed and the spectrum capacity. Prior to the 4G era, the dominating technology is single-user MIMO. However, as high-speed mobile transmission is continuously required, multiuser MIMO that uses antenna grouping has been developed. Second, CoMP is used to control the cell-edge traffic to balance the mobile traffic in the cell. Finally, beam forming is a technology that transmits the radio frequency to a specific direction and is highly possible to be used for 5G mobile communications. The significant patents related to beam forming were recognized as the “agile” beam-forming techniques in 2015. In addition, a type of TDD is extracted as a new key word beyond the FDD (Frequency Division Duplex) technologies. In fact, based on China, a trial to promote TDD as a dominating duplex technology has been going rampant since 2014. In this respect, LTE-TDD is derived as one of the significant keywords. Furthermore, sensor data and all-purpose broadband indicate the importance of hyper-connectivity. These patents were granted as preparation for the era of Internet of Things (IoT).

Furthermore, there are patents that are isolated from clusters. The average age is 2012, and 41 patents were derived to present the disconnected technologies such as sensor, shared channel, and D2D. However, these partial technologies are highly plausible to connect to other clusters in the future because the sensor and D2D patents are highly related to IoT technologies. In the future, there is a critical need to find this missing link to monitor the pattern of open innovation.

5.3. Patent-based brokerage analysis and open innovation

5.3.1. Patterns of technology development in open innovation

Although the patent citation network is constructed, in this complex structure, it is difficult to identify the patterns of open innovation. Thus, based on the patent citation network, the researchers propose the patent-based brokerage analysis to monitor the patterns of open innovation. In general, a patent, which is citing other patents, tends to find a solution from the citing patents. The cited patents have a high possibility of representing a good solution. In this respect, the brokers between technology fields in the network are the useful measures to identify the problems and the solutions in the context of open innovation. Table 5 presents the patents of brokers in the patent network according to the types of open innovation.

Among the 138 patents, the total of brokerage patents is 30 (21.7%), and the number of internal, inbound, outbound, and two-way (coupled) innovation is 15 (10.9%), 10 (7.2%), 4 (2.9%), and 1 (0.7%), respectively. From 2011 to 2015, there have been a few patterns of inbound and outbound innovation related to the gatekeeper and the representative. A case of the consultant, which means two-way open innovation, is also extracted, but only one case is found. From 2011 and 2013, the number of internal innovation is reduced as time passes, but the number of inbound innovation (gatekeeper patents) is increased. In contrast, in 2014 and 2015, the patents through internal innovation increased again as T7 emerges as a new technological area for 5G mobile communications. Currently, the number of outbound innovation (representative patents) is also on the rise. This means that closed and open innovations have been recently achieved simultaneously.

Furthermore, the characteristics of clusters can be identified from the distribution of brokerage patents as described in Table 6. The brokerage patents are mainly included in T3 (30.0%) and T4 (33.3%) among the total of 138 patents as these clusters are representatives of the fundamental mobile communications technologies for network operations and radio technology. However, in more detail, the brokerage patents in T3 and T4 are applied less to other advanced technologies. Rather, T3 and T4 often interact, except in three cases of inbound innovation (US6831943 and US7412212 in T2, and US8391392 in T6). Here, it was found that open innovation has not yet been promoted toward the applications area in mobile communication technologies such as increasing the data rate and broadband network operations. Despite this result, the researchers highlight one more critical trend in which the patent citation network has been growing toward the LTE application areas of T5, T6, and T7 as time advanced. As the individual technology for increasing the LTE data rate has been developed, network operations and radio access technologies can

Table 5
Brokerage patents and open innovation types.

Year	Closed innovation	One-way open innovation		Two-way (coupled) open innovation	
		Inbound innovation	Outbound innovation		
	Coordinator	Gatekeeper	Representative	Consultant	Liaison
2011	US7283508(3) US7483675(2) US7505539(2) US7894507(2)				
2012	US7286563(3) US7986959(4)	US7286563(4-3-3), US7898948(4-3-3), US8238371(4-3-3)		US8126021(3-4-3)	
2013	US8351388(4)	US6831943(2-3-3), US7412212(2-3-3), US8437792(3-4-4)			
2014	US8243931(5) US8532110(5) US8761096(4)	US8391392(4-6-6) US7593407(4-3-3)	US7593407(3-3-4)		
2015	US8243667(5) US8958306(5) US9107094(7) US9125123(7) US9131385(7)	US8243931(3-4-4) US8351388(3-4-4)	US8126021(4-4-3) US8238371(4-4-3) US8634312(4-4-3)		
Total	15(10.9%)	10(7.2%)	4(2.9%)	1(0.7%)	

Note: A-B-C in the parenthesis means a path among fields A, B (broker), and C. In other words, the path, "4-3-3" means the gatekeeper network which has the broker "3" in the middle.

Table 6
Distribution of brokerage patents in each technology cluster.

Clusters	Main generation	Closed innovation	One-way open innovation		Two-way (coupled) open innovation		Total
			Inbound innovation	Outbound innovation			
		Coordinator	Gatekeeper	Representative	Consultant	Liaison	
T1	WCDMA	None					0
T2	WCDMA/HSPA	3 (10.0%)	–	–	–	–	3 (10.0%)
T3	WCDMA/HSPA/LTE	2 (6.7%)	6 (20.0%)	1 (3.3%)	–	–	9 (30.0%)
T4	LTE, LTE-A	3 (10.0%)	3 (10.0%)	3 (10.0%)	1 (3.3%)	–	10 (33.3%)
T5	WCDMA/LTE	4 (13.3%)	–	–	–	–	4 (13.3%)
T6	LTE, LTE-A	–	1 (3.3%)	–	–	–	1 (3.3%)
T7	LTE-A	3 (10.0%)	–	–	–	–	3 (10.0%)

be applied to LTE technologies. Thus, the open innovation network will be structured through the link between a fundamental technology area and an application technology area. Through a foresight in future technology, the insight for open innovation in mobile communications technology can be obtained in greater detail.

5.3.2. Patterns of partnerships in open innovation

From the information on assignees contained in patent document, the pattern of partnerships has been identified. In particular, through brokerage analysis, the dominant players with and within technology clusters are extracted. As shown in Table 7, the brokerage partners who have brokerage patents in Table 5 are listed from 2011 to 2015. The main brokerage partners are involved in various fields such as consumer electronics, semiconductor producers, communication equipment, and computer equipment. Here, it is noted that most firms, such as *Samsung Electronics*, *Qualcomm*, *Nokia*, and *Marvell World Trade* (a subsidiary of *Marvell Technology Group*), focus on the inbound innovation strategy in which the solutions are applied from other firms. In fact, this result is trivial as many studies have already suggested that firms should try to find more solutions from external sources and not look for application areas of the technology they developed. In-licensing or R&D collaboration is one of the representative strategies in open innovation. In contrast, some companies have simultaneously conducted outbound innovation. For example, *LG Electronics* focuses on both inbound and outbound innovation. Bringing the technology from other technology fields and applying the technology to other technology fields, *LG Electronics* has, so far, conducted a greater variety of R&D projects than other firms. On the other hand, *InterDigital Technology* is a special case of coupled innovation.[1] This firm is one of the Non-Practicing Entities (NPEs), which buy the useful patents to make a sale form intellectual properties, and thus, it is highly possible that these patents of coupled innovation types are valuable. This firm refers to patents from other fields and develops new technology from the patents and vice versa. Then, the new technology is applied to the fields where the firm referred the patents. In other words, *InterDigital Technology* focuses on both inbound and outbound innovation with respect to the patent of US8126021.

Next, the distribution of brokerage partners in each technology cluster from T1 to T7 is explored as described in Table 8. Most firms, such as *Samsung Electronics*, *InterDigital Technology*, *LG Electronics*, and *Nokia*, are brokerage partners in T3 and T4. They have positioned main roles for inbound and outbound innovation, but T3 and T4 are the basic area, not the promising area. Recently, broadband network and high-speed data rate in T5, T6, and T7 have become a critical issue in the telecommunications industry, and patents in these areas will be

[1] The *InterDigital Technology* is one of the largest NPEs worldwide, referred to as *Patent Troll*. The main activity of these NPEs is to find valuable patents that contain next-generation technology. Thus, it is highly possible to balance the patent portfolio based on coupled innovation.

Table 7
Brokerage partners in mobile communications and open innovation types.

Year	Closed innovation	One-way open innovation		Two-way (coupled) open innovation	
		Inbound innovation	Outbound innovation		
	Coordinator	Gatekeeper	Representative	Consultant	Liaison
2011	*Samsung Electronics Broadcom*				
2012	*Samsung Electronics Qualcomm*	*Samsung Electronics InterDigital Technology LG Electronics*		*InterDigital Technology*	
2013	*LG Electronics*	*Texas Instruments Nokia Qualcomm*			
2014	*LG Electronics Tekelec*	*Marvell World Trade LG Electronics*	*LG Electronics*		
2015	*LG Electronics Tekelec All Purpose Networks*	*LG Electronics*	*InterDigital Technology LG Electronics*		

prioritized higher in the next generation of mobile communications technologies. *Marvell World Trade* is also one of NPEs who focuses on the application of external sources to achieve high-speed data rate for the next generation of mobile communications. Although *LG Electronics*, *Tekelec*, and *All Purpose Networks* focus on new technology areas of T5, T6, and T7, they have only attempted to combine technologies in a single field. Thus, these firms should focus on the external sources to develop more valuable technologies.

6. Implications for open innovation of 5G technology

As previously pointed out, the generation of mobile telecommunications has reached IMT-2000 (4G), and now it will be transformed into IMT-2020—5G. In early 2016, the ITU published the key requirements for 5G technology standard such as speed, capacity, and coverage. Thus, many global firms and research institutes will struggle to adapt the dynamic change in the technology requirements of 5G mobile communications by collaborating with each other to develop a new mobile communications technology. Thus, it should be important to explore the key technology patents and partners. The patterns of open innovation can be applied to take into account this exploration.

The key requirement of 5G technology is described in Fig. 6 (ITU-R, 2015), and the relationships between the key requirements are represented through the help of experts in the telecommunications research institute of Korea. As Table 9 shows, the technology clusters derived by this research are related to five technology requirements: data rate, spectrum efficiency, mobility, latency, and connectivity. The broker patents can be considered as the core patents because they are highly intermediated with other patents. These core broker patents are extracted based on the betweenness, which is an index that indicates the degree of relationships. In general, the longer the length of a network path is, the higher the value of the betweenness index is. Betweenness is one of the appropriate measures to find the core patents because connectivity in a network is vital.

As a result, the core broker patents are extracted with respect to the key requirements and their features, which are described in Table 9. According to the broker type and the betweenness index, open innovation dynamics based on the technology links and partnerships between patents, in terms of relationships between key requirements and broker firms, can be predicted. For example, to increase the data rate, the related technology requirements are spectrum efficiency and latency. To connect the data rate technology and the spectrum efficiency technology, the related clusters are derived as T2, T5, T6, and T7. Thus, broker patents in T2, T5, T6, and T7 can be applied first and then studied as a candidate to develop new technology. Also, as presented in Fig. 7, open innovation partnership can be constructed based on *Broadcom*, *Marvell World Trade*, *All Purpose Networks*, and *Tekelec*. In fact, the patents recently granted by these firms are continuously focusing on the spectrum efficiency technology. For example, *Tekelec* developed new technology of “diameter signaling router” for enhancing network efficiency. Moreover, to connect the latency, the related clusters should be T3 and T4, which involve the brokerage of *LG Electronics*. Thus, an open innovation partnership can be structured with *Broadcom*, *Marvell World Trade*, *All Purpose Networks*, and *LG Electronics*. Consequently, collaboration links and partnerships in the open innovation dynamics can be forecasted using patent-based brokerage analysis.

Furthermore, the strategy of open innovation can be differentiated according to types of firms. There are several open innovation strategies between firms such as outsourcing, consulting, joint venture, and licensing. As pointed out before, the 5G technology is applied into wireless, network, and hardware technology. In this respect, the joint venture is effective for different types of firms to develop convergence technology between mobile service and device. The network corporates such as *Broadcom* and *Tekelec* are capable of establishing the joint venture company with hardware company such as *LG Electronics* and

Table 8
Distribution of brokerage partners in each technology cluster.

Clusters	Main generation	Closed innovation	One-way open innovation		Two-way (coupled) open innovation	
			Inbound innovation	Outbound innovation		
		Coordinator	Gatekeeper	Representative	Consultant	Liaison
T1	WCDMA	None				
T2	WCDMA/HSPA	*Broadcom*				
T3	WCDMA/HSPA/LTE	*Samsung Electronics*	*Samsung Electronics InterDigital Technology LG Nokia*	*LG Electronics*		
T4	LTE, LTE-A	*Qualcomm*	*Qualcomm LG Electronics*	*LG Electronics InterDigital Technology*	*InterDigital Technology*	
T5	WCDMA/LTE	*LG, Tekelec*				
T6	LTE, LTE-A		*Marvell World Trade*			
T7	LTE-A	*All Purpose Networks*				

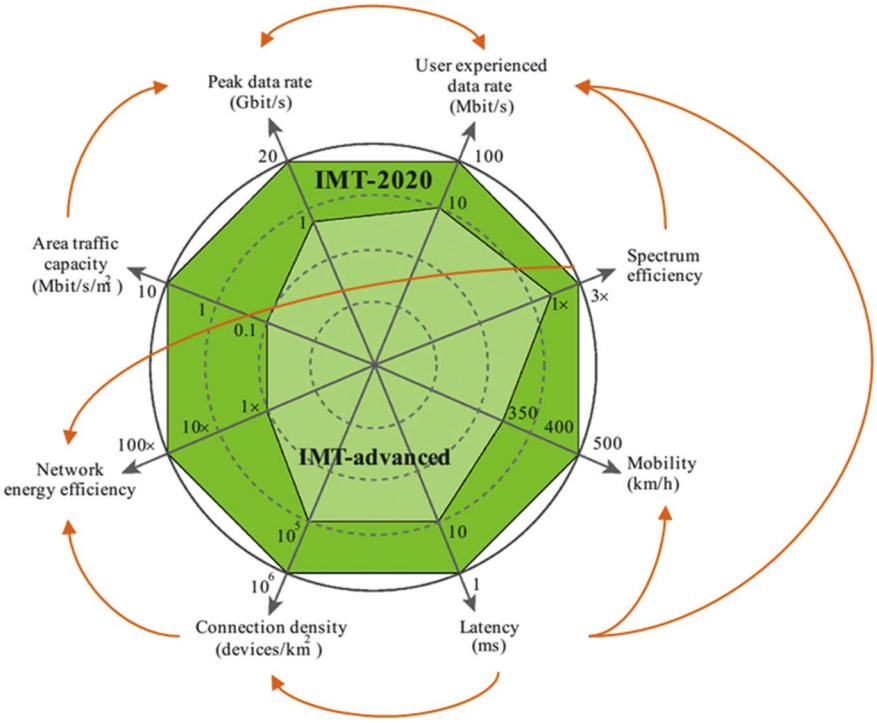

Fig. 6. Technology relationships between key capabilities.
(Adapted from ITU-R (2015).)

Table 9
Key capabilities for 5G technology standard and related patents and firms.

Key capability	Related clusters	Core brokerage patents	Normalized betweenness	Brokerage firms
Data rate	T2	US7483675(C)	0.016	Broadcom
	T6	US8391392(G)	0.023	Marvell World Trade
	T7	US9131385(C)	0.015	All Purpose Networks
Spectrum efficiency	T1	–	–	–
	T5	US8958306(C)	0.010	Tekelec
Mobility	T3	US7898948(G)	0.071	InterDigital Technology
		US7593407(G, R)	0.065	LG Electronics
Latency	T3	US8238371(G, R)	0.010	LG Electronics
	T4	US8634312(R)	0.079	
Connectivity	T7	US9131385(C)	0.015	All Purpose Networks

Note: C (coordinator), G (gatekeeper), R (representative).

Samsung Electronics. Also, NPEs focus on their capability to find licensing partners possessing only intellectual rights without having the factory or the laboratory. Thus, licensing strategy is effective for NPEs such as *Marvell World Trade* and *All Purpose Networks* among the open innovation channels.

7. Conclusions and future research

As part of the efficiency and effectiveness of R&D management, open innovation has been highlighted in both the academia and in practice. The first concept of open innovation is to introduce the importance of external sources and external collaboration among players and partners. After that, open innovation types were suggested, and practical studies on the effectiveness of open innovation dynamics were reported. The coverage of open innovation studies is expanding from technology to business, and new research attempts to incorporate internal and external sources are proposed. However, previous studies lack systematic and concrete methods to find empirical cases of open innovation according to patterns of open innovation. It is difficult to explore the M&A or collaborations among the firms because of a lack of data samples. Also, quantitative methods to identify the patterns of open innovation have not been addressed yet.

In this respect, this study has two critical contributions in terms of the data source and the method. First, researchers have used patent information to construct a citation network. The citation is an understandable source to show the knowledge flow, and the concept of open innovation is included in terms of knowledge inflow (backward citation) and outflow (forward citation) using citation information. This citation information is not directly related to formal collaboration, but it is highly helpful in identifying the knowledge sharing among the firms. Thus, patent citation is an ample resource to explore the open innovation dynamics of knowledge sharing. Inbound innovation and outbound innovation are identified using backward and forward citation information. Second, a brokerage analysis is used to directly identify the patterns of open innovation such as inbound and outbound innovation. Based on the relationships between groups or fields derived from the brokerage analysis, patterns that were mostly achieved and partners that were located in the bridge in the open innovation network were found. To sum up, this study investigated the brokers in the technology clusters of open innovation network by using patent citation information. Also, the dynamic change of brokers and relationships from 2011 to 2015 is explored.

With regard to contributions, this research provides opportunities for future studies. First, although this study presents the knowledge flow between firms, this is not a real collaboration, and it might be difficult to indicate direct collaboration. Thus, the real case of open innovation should support the result of this study's approach. Second, a brokerage analysis is a useful technique for directly identifying the patterns of open innovation, but there is a lack of suggesting the reasons of collaboration. In other words, it should be noted that there is a need for in-depth analysis of the common problems and solutions during the process of open innovation dynamics. The contents analysis or semantic

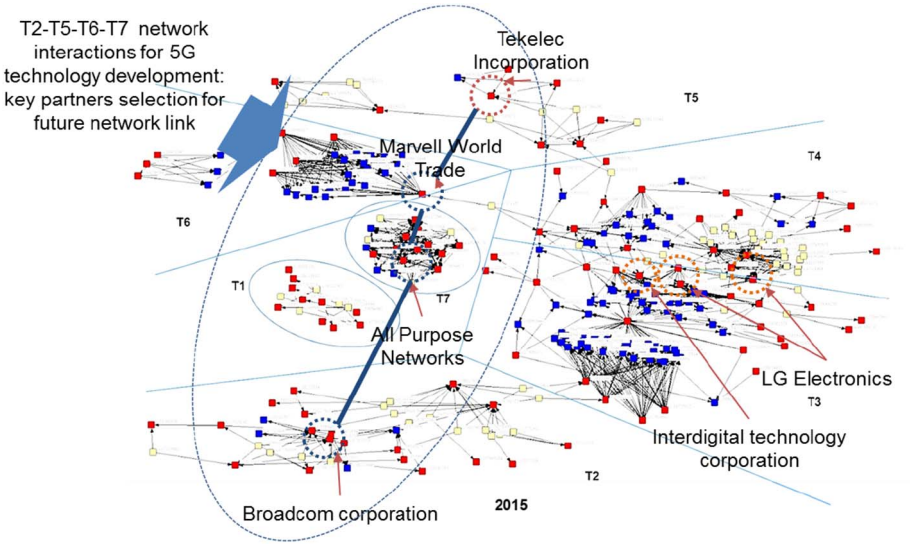

Fig. 7. Open innovation partnership for increasing data rate in relation to spectrum efficiency.

analysis of patent documents can be helpful for understanding the detailed information on open innovation. This current study focuses more on an exploratory approach to the monitoring patterns of open innovation using the mathematical technique which is capable of calculating network intensity and relatedness, but a more advanced approach to understanding the context of open innovation is an inevitable work for future studies such as textmining and semantic analysis.

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