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Extracting commercialization opportunities of the Internet of Things: Measuring text similarity between papers and patents

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ABSTRACT

In the field of technology management, methods have been developed to detect technologies that are important in industry by analyzing massive numbers of documents. Such methods have been applied to the field of the Internet of Things as well to investigate technological trends. The Internet of Things consists of several conventional concepts, such as radio frequency identification, near field communication, and sensor networks. However, no research compares these technologies by analyzing massive quantities of papers and patents. Thus, in this study, we explored the research areas of technologies related to the Internet of Things, for which there are opportunities for commercialization in the near future. We also discuss potential applications of these technologies in diverse systems.

1. Introduction

1.1. Internet of Things

The Internet of Things (IoT) has started to be recognized as an essential emerging technology among various stakeholders. Ashton first used the term IoT (Ashton, 2009). Whitmore et al. showed that the IoT is a paradigm in which "everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to accomplish some objective" (Whitmore et al., 2015). However, the IoT has many definitions. Tsai et al. showed seven definitions and standards of the IoT (Tsai et al., 2014), although the IoT is not well defined and is still rather fuzzy and subject to philosophical debate (Dieter et al., 2011). Meanwhile, it is estimated that the market of the IoT will have a total potential economic impact of US$ 3.9–11.1 trillion per year by 2025 (Mckinsey.com, 2016). There are several other reports (Bradley et al., 2013; Middleton et al., 2013), but in general they have described the IoT as having strong impact on industries and economies in the near future. Even though there are high expectations about the IoT in society, the term "IoT" has been used as a buzzword even in scientific research as well as in marketing and sales strategies (Yan et al., 2015). Therefore, several studies have focused on clarifying the definition of the IoT and have attempted to discuss its future research directions (Tsai et al., 2014).

1.2. Forecasting IoT-related technologies

Some previous studies have tried to forecast IoT-related technologies by reviewing literature or conducting evaluations with experts. Visions, architectural elements, and future directions of IoT have been discussed (Gubbi et al., 2013), topics and trends of IoT have been summarized through literature reviews and applications, and open problems have been presented (Whitmore et al., 2015; Li et al., 2015; Xu et al., 2014; Atzori et al., 2010). Suwon and Seongcheol invited 31 information and communications experts and applied an analytic hierarchy process (AHP) model to assess the most promising domain in the IoT ("killer IoT application") in Korea (Kim & Kim, 2016). However, the procedure of these studies are subjective (while AHP is surely a method capturing subjective aspects) and might be too time-consuming to evaluate technology because the authors manually reviewed large numbers of previous studies or needed to conduct interviews many times.

On the other hand, there is some previous literature that has applied information science to forecast or comprehend technological trends. Table 1 summarizes the IoT-related literature that has applied bibliometric methods. These studies are divided into two categories based on document type: article-based studies and patent-based studies. Article-

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Table 1
Summary of IoT-related literature that applied bibliometric methods.

	Year	IoT-related target	Database	Methods	Ref.
Article-based	2017	IoT	Web of Science (no specific name of database)	Co-occurrence network analysis (authors keywords) and centrality measures	(Dotsika & Watkins, 2017)
	2017	IoT (for circular economy)	Scopus	Co-occurrence network analysis (article's keywords) am content analysis	(Nobre & Tavares, 2017)
	2017	IoT	Web of Science (no specific name of database)	Co-occurrence network analysis (words frequency, and distance) and its trends	(Kim et al., 2017)
	2016	IoT	Scopus	PageRank and co-citation analysis	(Mishra et al., 2016)
	2016	IoT	SCIE, SSCI, A&HCI	Co-occurrence network analysis (international authorship, institution and centrality measures	(Mehmood et al., 2016)
	2016	RFID	SCI, SSCI	Distribution analysis (country, organization, funding agency, source title, publication year, author, research area, WOS category, number of times cited), contents analysis and classification of top 100 most-cited documents	(Shakiba et al., 2016)
	2016	IoT (in manufacturing)	Compendex and Inspec database	Co-occurrence network analysis (keywords)	(Radhakrishnan & Kamarthi, 2016)
	2015	Information technology	SCI, SSCI, CPCI, etc.	(Direct) Citation network analysis (centrality measures, path analysis, cluster analysis, flow vergence model)	(Prabhakaran et al., 2015)
	2015	IoT	SCI-Expanded, SSCI	Co-occurrence network analysis (keywords)	(Yan et al., 2015)
	2011	RFID	SCI, SSCI	Citation analysis	(Liao et al., 2011)
	2011	Pervasive/ubiquitous computing	SCI	(Co-) Citation network analysis (subject category/country/journal/author network, timeline)	(Zhao & Wang, 2011)
	2007	RFID	SCI	Citation analysis	(Chao et al., 2007)
Patent-based	2016	IoT	13 countries or organizations databases (Europe, USA, Japan, Korea, China, WIPO, etc.)	Trend analysis considering characteristics of patent network using natural language processing techniques	(Gim et al., 2016)
	2016	IoT (in logistics)	13 countries or organizations databases (Europe, USA, Japan, Korea, China, WIPO, etc.)	Trends of International Patent Classification codes and abstracts by using text mining	(Jung et al., 2016)
	2013	RFID	PATSTAT	Citation analysis (citation to patents/non-patent literature/pioneering innovations, and technology cycle time)	(Karvonen & Kässi, 2013)
	2011	RFID	SIPO	K-means, S-curve	(Trappey et al., 2011)
	2010	RFID	USTPO	Citation network analysis (centrality measures)	(Hung & Wang, 2010)
	2010	RFID	USPTO, JPO	Non-exhaustive overlapping clustering	(Trappey et al., 2010)
	2009	RFID	USTPO	Text mining, citation network analysis	(Lee et al., 2009)
	2009	RFID	WIPO	Fuzzy ontological knowledge document clustering	(Trappey et al., 2009)

based studies use article papers obtained from such databases as Science Citation Index (SCI), Social Sciences Citation Index (SSCI), and Conference Proceedings Citation Index (CPCI)-Science/Social Sciences and Humanities. Previous article-based studies studied IoT-related article-based studies include information technology, IoT, RFID, and pervasive or ubiquitous computing with citation analysis (Prabhakaran et al., 2015; Mishra et al., 2016; Shakiba et al., 2016) and co-occurrence network analysis (Yan et al., 2015; Dotsika & Watkins, 2017; Nobre & Tavares, 2017; Kim et al., 2017; Mehmood et al., 2016; Radhakrishnan & Kamarthi, 2016). For an example, Mishra et al. (Mishra et al., 2016) identified top contributing authors, key research topics, the most influential works, established and emerging research clusters in the field of IoT through a bibliometric analysis using papers published from 2000 to 2015. Patent-based studies use patents obtained from such databases as the State Intellectual Property Office of the People's Republic of China (SIPO), EPO Worldwide Patent Statistical Database, also known as PATSTAT, United States Patent and Trademark Office (USPTO), Japan Patent Office (JPO), and World Intellectual Property Organization (WIPO). Previous studies apply citation analysis (Karvonen & Kässi, 2013), K-means and S-curve (Trappey et al., 2011), citation network analysis (Hung & Wang, 2010; Lee et al., 2009), text mining (Lee et al., 2009; Gim et al., 2016; Jung et al., 2016), non-exhaustive overlapping clustering (Trappey et al., 2010), and fuzzy ontological knowledge document clustering (Trappey et al., 2009). Scope of analysis in patent-based studies on technologies relating IoT includes RFID and IoT as shown in Table 1. For an example, Jung et al. (Jung et al., 2016) studied IPC codes and abstracts of patents in the field of IoT for logistics issued from 2010 to 2015 in the Korea and 12 other countries or organizations databases, and demonstrated that the technologies are evolving by combining with the cloud and big data technologies.

This paper investigates research and technological trends of IoT and related technologies by analyzing both papers and patents and also intersections of those. IoT systems consist of many subsystems, and it is difficult to forecast IoT-related technologies comprehensively since they include several conventional concepts. There is no research that compares IoT-related technologies by analyzing massive numbers of papers and patents. Thus, in this study, we explored the research areas of IoT-related technologies that have opportunities for commercialization in the near future.

2. Methodology

A brief overview of the methodology used in this study is given in Fig. 1. First, patents and papers were retrieved from the databases. Then, they were connected as citation networks. Networks are divided into sub networks. Finally, semantic similarities between patents network and papers network were measured. The methodology is a combination of citation analysis and text analysis and can assess plausible opportunities between academic research and technological development (Shibata et al., 2010).

2.1. Data collection

In step (1) shown in Fig. 1, bibliographic records were obtained. Subsystems of IoT consisted of sensing layer, network layer, service layer, an interface layer as shown in Fig. 2. Sensing layer consisted from hardware that collects data from tags or sensors by monitoring environment. Network layer aggregates data from the sensing layer and share data with the connected things that to be able to management and processing. Service layer is enabler of services and application in IoT that consisted of middleware technology. Interface layer solve the compatibility issue among the heterogeneous things. Among these layers, sensing layer is the key because each sensor follows communication standard. The standard defined communication frequency, distance, and usage. Therefore, in this study, we focus on the sensing layer because it defines application of IoT. Whitmore et al. (Whitmore et al., 2015) reviewed IoT literature, and have shown that when the hardware of the IoT system is focused on, it consisted of subsystems, namely and radio frequency identification (RFID), near field communication (NFC), and sensor networks.

Hence, we follow these definitions and treat these subsystems as IoT-related technologies, and the queries shown in Table 2 were used to retrieve and collect papers and patents. Papers published by 2014 were collected from the Science Citation Index Expanded, Social Sciences Citation Index, and Conference Proceedings Citation Index-Science by using Web of Science. Patents published by August 20, 2015 were retrieved from enhanced patent data–Derwent World Patents Index and Derwent Patents Citation Index by using Thomson Innovation.

2.2. Network construction

Once the corpus of documents is obtained, several strategies can be used to establish the links between the documents. Different methods will lead to different results even though the data is the same. Gläser et al. summarized most of bibliometric methods and mentioned precisely that the lack of gold standard or ground truth makes difficult to define the accuracy of topics, regardless the method (Gläser et al., 2017). However, bibliometric methods share same process. Frist, in the data preparation step, relationship of data is selected. Then, in the data processing step, the relationship is analyzed by applying algorithm(s). These construction methods are mainly divided into category-based,

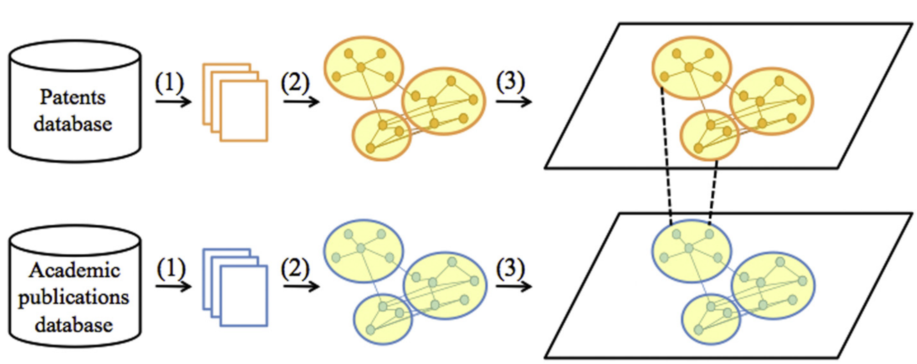

Fig. 1. Overview of methodology used in this study.

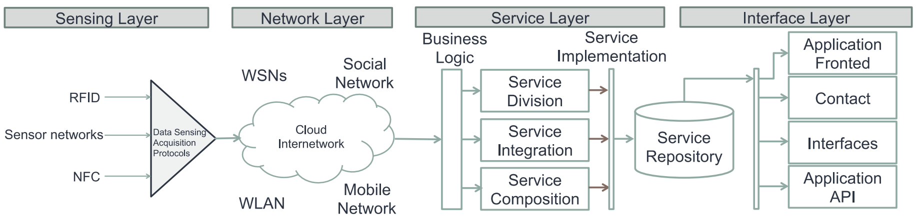

Fig. 2. Layers of IoT system.

Table 2
Queries used in this study.

Domain	Query
RFID	(“radio frequency identification”) or (“RFID”)
NFC	(“near field communication”) or (“NFC”)
SN	“sensor networks”
IoT	(“internet of things”) or (“IoT”)

and non-category-based.

As for category-based, first, type of category is selected such as among scientific discipline (Rafols et al., 2010), international patent class (IPC) (Kay et al., 2014; Leydesdorff et al., 2014), and Medical Subject Headings (MeSH) (Leydesdorff et al., 2012). Then, clustering algorithm such as co-classification (Rafols et al., 2010; Kay et al., 2014; Leydesdorff et al., 2014; Leydesdorff et al., 2012) is chosen. However, category-based has some limitations: sometimes there are no appropriate ISI WoS subject categories for emerging topic, IPC-network made a poor representation of the technology space (Leydesdorff, 2008), and MeSH is only available for the medical publications.

Non-category consists from text-based and citation-based. As for text-based, first, text preparation is conducted. Selection of text fields, using words or phrases, the cleaning strategy of the text corpus influences on the performance of analysis. To be able to classify the data, bag-of-words model (n-grams, unigram) (Uijlings et al., 2009) is commonly applied. Then, clustering algorithm such as text similarity (Hamedani & Kim, 2014) and topic modeling (Yau et al., 2014) is selected. However, there is still no consensus and no significant evidence that will make researchers choose one method over the other (e.g., tuning of parameters in the algorithms).

As for citation-based, first, type of citation is selected among direct citation (de Solla Price, 1965), co-citation (Small, 1973), and bibliographic coupling (Kessler, 1963). Then, clustering algorithm such as Newman (Newman, 2004), Louvain (Blondel et al., 2008), and Random walk (Rosvall & Bergstrom, 2008) is selected. Compared to the above two approaches (category-based and text-based), citation-based reached to consensus: direct citation is the best to detect emerging research fronts (Waltman & Van Eck, 2012; Shibata et al., 2009; Klavans & Boyack, 2017). Therefore, in this study, we decided to utilize citation network analysis based on direct citation.

Step (2) shown in Fig. 1 involves the creation of citation networks. After obtaining documents in Section 2.1, citation networks are created by direct citation. Fig. 3 shows the conventional flows of creating citation networks for papers and patents. They were connected by the citations among them. Then, the maximum component was extracted and divided into sub networks by clustering using Newman's algorithm, which can identify tightly knit clusters in a large network (Newman, 2004). However, the maximum component of patents network tends to be sparse compared to that of papers network (Shibata et al., 2010). This is because there are two kinds of patents: parent patents and child patents. A parent patent is “a patent with priority under the Paris convention for the protection of industrial property or a patent applied first among the family members,” and child patents are other family members (Nakamura et al., 2015). Patent analysis tends to deal with only parent patents (Trippe & Article, 2013). A conceptual image of citation relationship of parent patent K, L, M, and N is shown in the square balloon of Fig. 3. Parent patent K is cited by M, as represented by the arrows. Dealing with parent patents only is problematic since the number of nodes in the maximum component of network becomes small. In other words, if the unit of analysis is parent patents, it lacks richness of information.

To solve the problem, Nakamura et al. proposed patent family analysis (Nakamura et al., 2015). In their study, patent family members consisted of parent and child patents that were aggregated as one node. Fig. 4 shows the flows of creating a citation network using patent family analysis. A conceptual image of the citation relationship of family K, L, M, and N is shown in the square balloon of Fig. 4. The contents of invention in parent patent K is patented in other countries as child patents k and k′. In this case, K, k, and k′ refer to the same invention, and thus, they are defined as a family. In the same manner, parent patents L, M, and N have a family relationship with their children. Let us consider a condition when parent patent K is cited by parent patent M and child patent l, and child patent k′ is cited by child patent n′. This condition means that family K is cited by family L, M, and N (Fig. 4), which is missed if we only take citations among parents (Fig. 3). Therefore, in this paper, we adopted patent family analysis.

Then, clusters were formed by recursive clustering. Fig. 5 shows an example of the case in which clusters of SN were formed by clustering recursively. Here, in Fig. 5, citation networks were visualized by large graph layout algorithm (Adai et al., 2004). Numbers after “S” (which stands for the first initial of “SN”) are the cluster's ID. Cluster is numbered in the order of the number of the nodes in that cluster. For instance, S1 is the largest cluster and S2 is the second largest cluster SN. We identified topics of each cluster by investigating bibliographic records including title, abstract, and keywords. For an example, we identified S1 as a cluster about localization technology by investigating those. We identified details of clusters by recursive clustering and characterized sub clusters. For an example, S1-4, the 4th largest sub cluster of S1, is extracted gain after clustering S1. After investigating bibliographic records of papers, we found that the research cluster, S1-4, is about algorithms for exchanging and computing information of the network to estimate the location. We can also extract sub clusters of S1-4. For an example, S1-4-5 is detected from S1-4, which is about distributed particle filtering (DPF) algorithms. DPF algorithms are sequential state estimation algorithms that are executed by a set of agents. As shown in the previous paper (Takano et al., 2017), it is beneficial to divide sub clusters until when the size of a sub cluster is approximately several tens or hundreds (Takeda & Kajikawa, 1965).

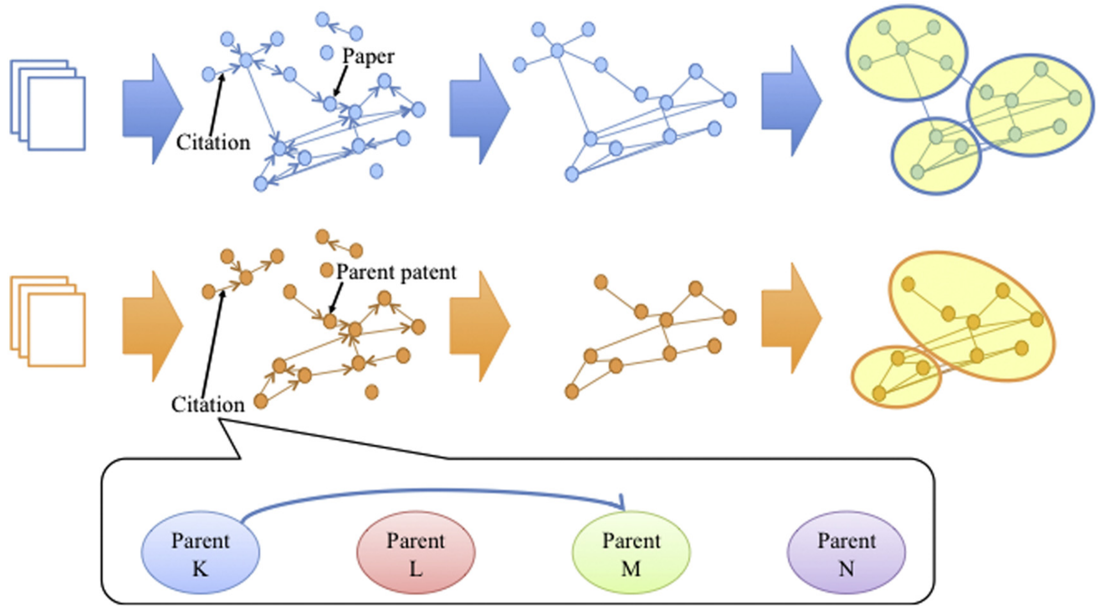

Fig. 3. Conventional flows of a creating citation network for papers and patents.

After the recursive clustering, the datasets used in this study were obtained. The number of documents and clusters are summarized in Table 3. The coverage of documents in the component is shown in parentheses.

2.3. Linkage analysis and cluster classification

Step (3) shown in Fig. 1 was conducted for linkage analysis. We used the method proposed by Shibata et al. shown in Fig. 6 to discover potential opportunities for industrial commercialization (Shibata et al., 2010). Patents clusters (the upper part of the right side of clusters in Fig. 6) and papers clusters (the lower part of the right side of clusters in Fig. 6) were compared in terms of their text contents. Text similarity was measured by calculating cosine similarity of all pairs between patents clusters and paper clusters of the same technology. Based on the existence of clusters of paper citation network and patent citation network, and the text similarity, the clusters were categorized into four areas: A, B, C, and D. When the value of text similarity was larger than

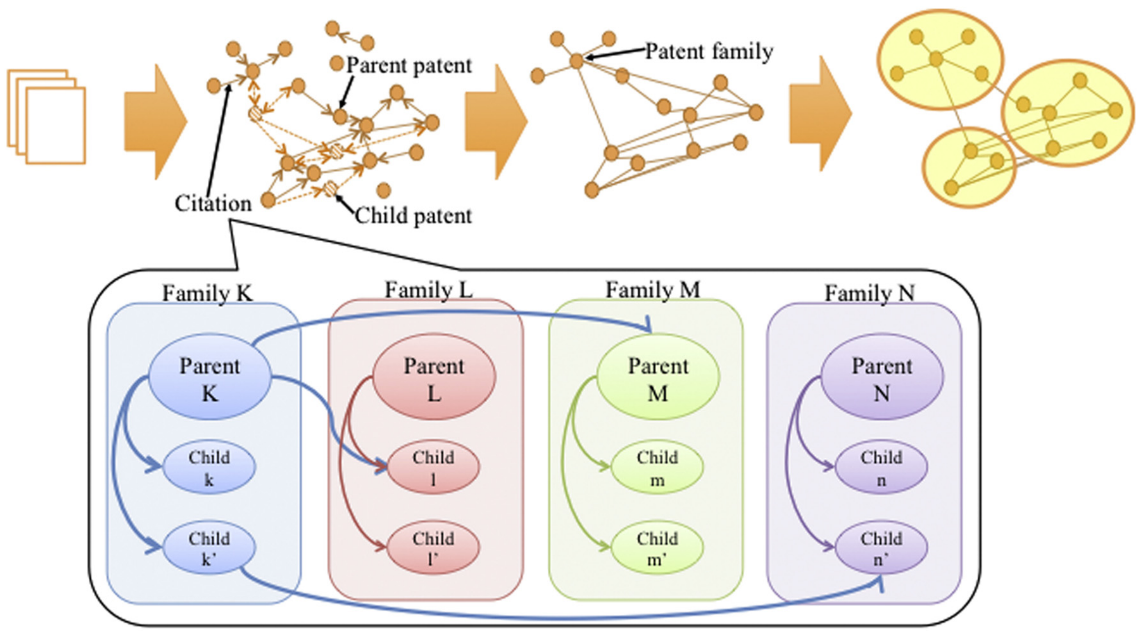

Fig. 4. Flow of creating a citation patent network by applying patent family analysis.

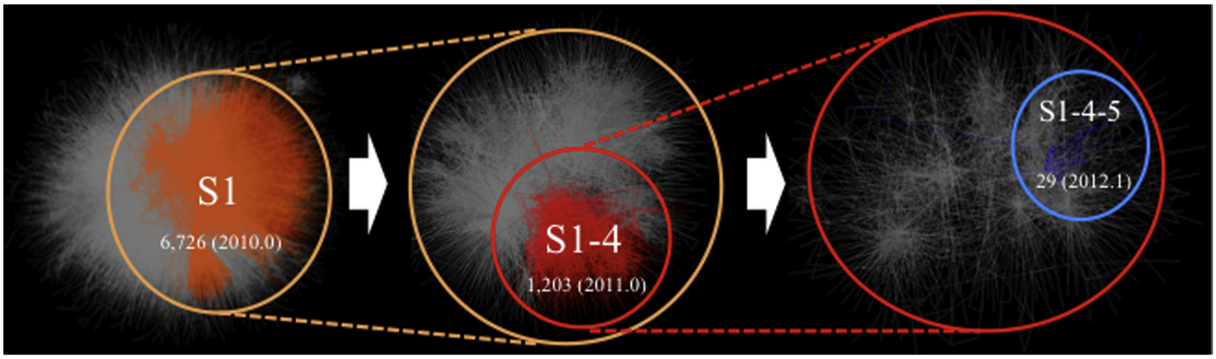

Fig. 5. Recursive clustering.

Table 3
Datasets used in this study.

Domain	Paper		Patent	
	# papers	# clusters	# patents	# clusters
RFID	7253 (92.5%)	39	22,907 (91.2%)	217
NFC	119 (100%)	10	2644 (94.4%)	24
SN	28,448 (92.0%)	221	17 (100%)	5
IoT	908 (95.4%)	13	76 (100%)	9

average, the papers and patents clusters were categorized as area A. In area A, science and technology has strong semantic relatedness, which implies the technology readiness level and attention from industry are high. Area B corresponds to the case in which papers clusters exist but the value of text similarity is less than average. It means that the research is too basic to be patented or has a potential to be developed for industrial technology. When patents clusters exist but the value of text similarity is less than average, those technologies belong to area C. Topics in C could be overly application oriented, and researchers do not pay attention to these topics. Area D has neither papers nor patents.

The number and percentage of papers/patens clusters categorized in each area are summarized in Table 4. The objective of this study is to explore the research areas of IoT-related technologies that have opportunities for commercialization in the near future. Hence, area B could be an appropriate candidate for extraction because topics in area B are regarded as hidden opportunities for industry where less attention

Table 4
The number and percentage of papers/patens clusters categorized in each area.

	Area A	Area B	Area A	Area C
RFID	20 (7.7%)	19 (7.3%)	23 (8.9%)	197 (76.1%)
NFC	4 (11.8%)	6 (17.6%)	5 (14.7%)	19 (55.9%)
SN	22 (9.7%)	199 (88.1%)	5 (2.2%)	0 (0.0%)
IoT	2 (9.1%)	11 (50.0%)	3 (13.6%)	6 (27.3%)

is paid but will be developed and implemented in the near future. In this study, we focus on the top emerging 10 clusters for each technology in terms of the average publication year (and list up top 11–20 cluster in Appendix i–iii), assuming that technology in the cluster is active and rapid when the average publication year is relatively low, except for NFC where the number of clusters are less than 10.

IoT is still a seed of technology-push innovation and future application and market are unclear. In the mapping of IoT, Yan et al. (Yan et al., 2015) classified IoT into in two levels: application and technology. We also categorized extracted clusters in area B were in IoT application and IoT technology to discuss future applications of IoT (Fig. 7). Finally, to validate usefulness of the result, detected clusters were compared to a public government document that contained IoT technology policy. The document was made by experts in the field, and it listed up plausible future applications and technologies to accomplish the applications. Therefore, it is suitable to use the document for the validation of the results.

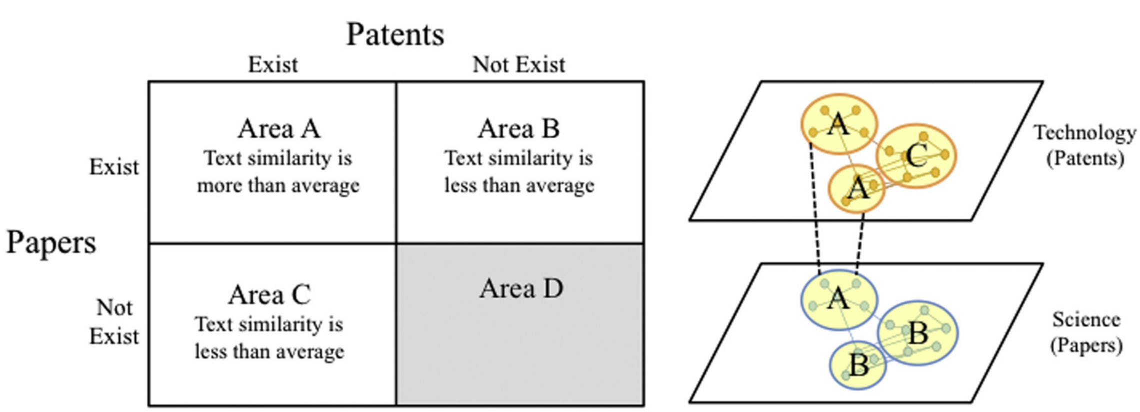

Fig. 6. Relationships between science and technology.

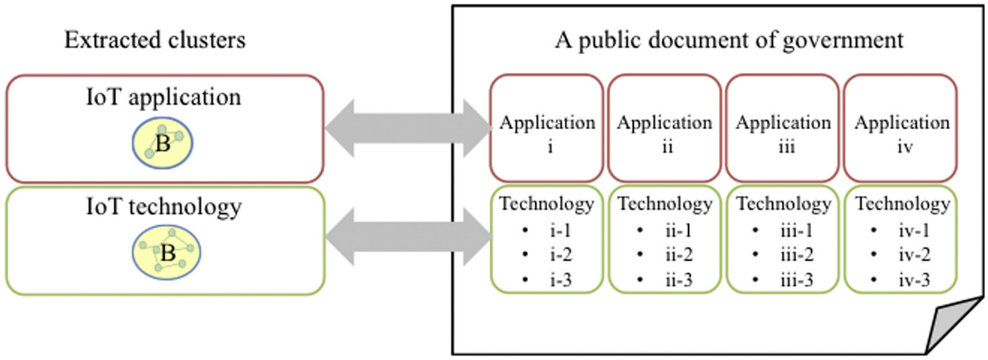

Fig. 7. Two levels of technology and correspondence with a public government document.

3. Results

The extracted emerging clusters in area B of IoT, RFID, NFC, and SN are summarized in Tables 5, 6, 7, and 8, respectively. Italic bold cluster names of the research field show application level; others are technology level. The abbreviations #N, #E, and Ave. year represent the number of nodes or documents in the cluster, the number of links or edges inside the cluster, and average publication year of the cluster, respectively. The top five countries and organizations are listed up.

3.1. Emerging RFID clusters

Table 5 shows the top 10 RFID clusters that have opportunities for commercialization in the near future. In the field of RFID, 4 out of 10 clusters were categorized as application level, and the other clusters as technology level.

6 technology level RFID clusters were:

- R1-4: passive tag and improvement of backscattering communication. RFID is one of the backscatter radio systems that can communicate with very little power consumption. The RFID tag “modulates the electromagnetic waves scattered from its antenna(s) by changing the reflection coefficient at the antenna's terminals. The signal that is scattered by the RFID tag is supplied by an interrogator, or reader, and is detected by the reader's receiver” (Griffin & Durgin, 2010).
- R1-5: chipless RFID. The cost of the entire RFID system is “dependent on the cost of the tag, which is dependent on the cost of its IC,” and thus, “efforts have been put in developing chipless RFID tags with no ICs, which mean that the main cost of the tag is being removed” (Preradovic & Karmakar, 2010).
- R3-2: authentication protocol for security and privacy. “Authentication is required for a tag reader to authenticate genuine tags for inquiring information, and for tags to provide information to authenticated readers only. After authentication, only authenticated readers can access the contents of tags” (Chien & Chen, 2007).
- R3-7: distance bounding protocols to prevent relay attacks. “Distance bounding protocols represent a promising way to thwart relay attacks, by measuring the round trip time of short authenticated messages” (Kim et al., 2008).
- R4-5: separation and grouping of RFID signals. “If two or more tags send back their information concurrently then their response collide and thus cannot be decoded correctly by the reader” (Dhakal & Shin, 2013). Some solutions are based on collision avoidance using Medium Access Control protocols, such as Framed Slotted Aloha (FSA) and some variations of FSA (Su et al., 2010), or an antenna array in combination with blind source separation techniques for separating multiple overlapping tag signals (Mindikoglu & Van Der Veen, 2008).
- R4-6: data stream processing. Despite the improvement of data stream management, RFID data raise “new challenges since it may be insufficient, incomplete, and voluminous” (Nie et al., 2012). To solve the problems, some research, such as data cleaning, supporting big volume data, handling new types of queries, event processing, data interpretation, and compression, have been studied (Fan et al., 2012).

4 application level RFID clusters were:

- R2-3: RFID-based wireless manufacturing (WM). Shop floors with fixed-position assembly islands suffer from “limited spaces at work centres and high dynamics of material and manpower flows in addition to common shop-floor problems” (Huang et al., 2007). WM, as one of the emerging advanced manufacturing technologies, has been proposed. It relies substantially on wireless devices, such as RFID, auto ID sensors, and wireless information networks for the collection and synchronization of real-time field data from manufacturing workshops.
- R2-4: application for the construction sector. Even though construction materials and installed equipment may account for 50–60% of the total cost of a construction project (Gurski, 1955), there are human errors (e.g., misplacement of tools or materials and wrong delivery in procurement process) and the cost tends to become large. Therefore, to solve these issues, some solutions have been proposed, such as concrete processing and handling, cost coding for labor as well as equipment and materials control (Jaselskis et al., 1995), and tracking and locating components (Ergen et al., 2007; Song et al., 2006).
- R2-6: new applications using RFID compared to conventional applications, such as logistics usage. Applications in education and entertainment were detected. For educational applications, ubiquitous learning has been proposed to overcome limitations of traditional classroom learning, such as difficulty supplying the right content at the right time and right place, or such constraints as time

Table 5
Emerging RFID clusters with opportunities for commercialization in the near future.

Rank	ID	Research field	# N	# E	Ave. year	Top 5 countries	Top 5 organizations
1	R1-5	Chipless RFID	228	639	2011.44	US 38; Australia 37; France 30; China 25; Spain 18	Monash Univ 34; Univ Rovira & Virgili 13; Grenoble Inst Technol 8; Helsinki Univ Technol 7; Gvr Trade Sa 7; Royal Inst Technol Kth 7
2	R1-4	Passive tag and improvements of backscattering communication	233	430	2011.03	US 54; Germany 30; China 26; France 14; South Korea 14	Georgia Inst Technol 12; Aristotle Univ Thessaloniki 10; Univ Erlangen Nurnberg 9; Tech Univ Crete 8; Univ Washington 7; Tampere Univ Technol 7; Univ Nicosia 7
3	R4-6	Data stream processing (data cleaning, supporting big volume data, handling new types of queries, event processing, data interpretation and compression, etc.)	108	162	2011.03	China 43; US 21; South Korea 13; Australia 12; Canada 4; Italy 4; Spain 4; Taiwan 4	Univ Adelaide 7; Natl Univ Def Technol 5; Univ Massachusetts 4; PUSn Natl Univ 4; Korea Adv Inst Sci & Technol 4
4	R3-7	Distance bounding protocols to prevent relay attacks	51	112	2010.82	England 9; US 8; Belgium 7; Spain 7; France 4; Switzerland 4	Catholic Univ Louvain 6; Univ London 4; Univ Malaga 3; Ecole Polytech Fed LaUSnne 2; Tubitak Uekae 2; Univ Carlos Iii Madrid 2; Univ Bergen 2; Univ Calif Irvine 2; Univ Cambridge 2; Univ Ottawa 2; Eurecom 2; Univ Luxembourg 2; Iran Univ Sci & Technol 2; Northeastern Univ 2; Ryerson Univ 2; Univ Helsinki 2; Univ Portsmouth 2
5	R2-6	***New applications (ubiquitous learning, auto-scoring system for billiards games, anti-swindle mahjong leisure system,*** **etc.)** ***compared to conventional applications (logistics,*** **etc.)**	54	67	2010.70	Taiwan 20; China 9; South Korea 6; US 5; England 3; Japan 3; Spain 3	Natl Taipei Univ Technol 6; Natl Taipei Coll Business 4; Univ Loughborough 3; Univ Tokushima 3; Natl Chiao Tung Univ 2; Lunghwa Univ Sci & Technol 2; Univ Sci & Technol Beijing 2; Univ Zaragoza 2; Natl Tsing Hua Univ 2; Natl Taiwan Univ Sci & Technol 2; Hong Kong Polytech Univ 2; Seoul Natl Univ 2
6	R3-2	Authentication protocol for security and privacy	300	889	2010.50	China 84; Taiwan 61; US 34; Spain 17; South Korea 17	Univ Carlos Iii Madrid 12; Chaoyang Univ Technol 10; Natl Chi Nan Univ 8; Univ Florida 8; Rfid European Lab 7; Delft Univ Technol 7; Iran Univ Sci & Technol 7; Natl Chung Hsing Univ 7; Natl Taiwan Univ Sci & Technol 7
7	R4-5	Separation and grouping of RFID signals (anti-collision algorithm, antenna array solution, etc.)	129	140	2010.43	China 28; Taiwan 18; South Korea 13; US 11; France 10; Italy 7	Telecom Sudparis 5; Natl Chiao Tung Univ 4; Univ Paris 06 4; Univ Roma Tor Vergata 4; Nanyang Technol Univ 4
8	R2-4	***Construction applications (concrete processing and handling, cost coding for labor and equipment, materials/tools control and tracking,*** **etc.)**	188	844	2010.31	US 57; China 31; South Korea 24; Taiwan 23; Canada 19	Univ Waterloo 12; Istanbul Tech Univ 11; Georgia Inst Technol 8; Carnegie Mellon Univ 8; Univ Loughborough 7; Univ Maryland 7; Hong Kong Polytech Univ 7
9	R2-7	***Location awareness in indoor environment (library, warehouse, home,*** **etc.)**	44	47	2010.20	Taiwan 12; China 7; Spain 7; US 4; Turkey 3; England 3	Natl Taiwan Univ Sci & Technol 3; Univ Alcala De Henares 3; Univ Loughborough 2; Sun Yat Sen Univ 2; Natl Cheng Kung Univ 2
10	R2-3	***RFID-based wireless manufacturing***	246	638	2010.18	China 111; US 35; Taiwan 20; England 14; Germany 13; South Korea 13	Univ Hong Kong 25; Hong Kong Polytech Univ 19; Xi An Jiao Tong Univ 15; Guangdong Univ Technol 8; Univ Cambridge 7

Table 6
Emerging NFC clusters with opportunities for commercialization in the near future.

Rank	ID	Research field	# N	# E	Ave. year	Top 5 country	Top 5 organization
1	N9	***Context-awareness system (mobile payment, smart home, loyalty applications, etc.)***	7	6	2012.29	Taiwan 3; Turkey 1; India 1; China 1; South Korea 1	Natl Taipei Univ 3; Univ Elect Sci & Technol China 1; Jaipur Engn Coll & Res Ctr 1; Isik Univ 1; Natl Cent Univ 1; Natl Yunlin Univ Sci & Technol 1; Ajou Univ 1; Sejong Univ 1; Tunghai Univ 1
2	N5	Relay attack and security	11	10	2012.18	England 5; US 2; Luxembourg 2; France 2; Austria 2	Univ London 2; Univ Luxembourg 2; Royal Holloway Univ London 1; Univ Appl Sci Upper Austria 1; Univ Cambridge 1; Catholic Univ Louvain 1; Telecom Paristech 1; Graz Univ Technol 1; Univ Alabama Birmingham 1; Univ Surrey 1; Rfid European Lab 1; Aalto Univ 1; Univ Helsinki 1; Inst Natl Sci Appl 1; Univ Florida 1
3	N7	***Ambient Assisted Living (monitoring of elderly people, supporting chronic disease, etc.)***	9	8	2012.00	Spain 6; Germany 3; England 1; Norway 1; North Ireland 1	Univ Deusto 2; Univ Kassel 2; Univ Murcia 2; Charite 1; Tellu As 1; Accord Grp 1; Stickyworld Ltd. 1; Reg Campus Int Excellence Campus Mare Nostrum 1; Univ Ulster 1; Deustotech Deusto Inst Technol 1; Catholic Univ San Antonio 1; De Montfort Univ 1; Castilla La Mancha Univ 1; Berliner Inst Sozial Forschung 1; Univ Castilla La Mancha 1; Karde As 1
4	N6	***Telemonitoring (blood pressure, body weight, glucose, oxygen saturation, ECG signals, etc.)***	11	12	2010.91	Austria 8; Japan 2; Australia 1	Ait Austrian Inst Technol Gmbh 4; Kobe Univ 2; Med Univ Graz 2; Austrian Inst Technol Gmbh 2; ROHM 1; Ait Austrian Inst Technol 1; Allgemeines Offentl Krankenhaus Elisabethine Linz 1; Versicherungsanstalt Eisenbahnen & Bergbau 1; Univ New S Wales 1; Austrian Res Ctr Gmbh 1
5	N3	***Ambient intelligence (touristic-cultural field: mobile guide for museum visitors, city navigation, access to bibliographic sources, etc.)***	16	19	2010.81	Spain 5; Italy 3; Finland 3; Canada 1; Portugal 1; Germany 1; Switzerland 1; Taiwan 1; China 1	Univ Cordoba 4; Univ Roma Tor Vergata 2; Univ Roma La Sapienza 2; Univ Calgary 1; Univ Munich 1; Univ Oulu 1; Vtt Tech Res Ctr Finland 1; Vtt Elect 1; ETH 1; Chongqing Normal Univ 1; Vtt Informat Technol 1; Docomo Eurolabs 1; Univ Castilla La Mancha 1; Natl Taichung Univ Sci & Technol 1; ISEL 1
6	N10	Integration of NFC with other technologies for touching interaction	6	5	2008.33	England 3; Canada 1; Taiwan 1; Spain 1	Univ Bath 3; Chung Yuan Christian Univ 1; Univ Waterloo 1; Univ Castilla La Mancha 1

and space (Chen & Huang, 2012). Meanwhile, some entertainment applications have been developed, such as an auto-scoring system for billiards games (Tang, 2012) and an anti-swindle mahjong leisure system (Tang, 2014).

- R2-7: location awareness in indoor environments. RFID in a library allows for the inventorization of hundreds of thousands of items in days instead of months (Singh et al., 2006). Moreover, RFID combined with artificial intelligence can help to determine "the physical location of a book within the library and to provide assistance to users to arrive to the desired locations" (R-Moreno et al., 2014). For homes, the household effects management system has been proposed. RFID technology is used for "location management of household objects, and integrated schedule information to remind the family members or confirm the belongings being carried; also keep the house properties secured and managed" (Yang et al., 2011). Another application is in warehouses. Kuo et al. used the received signal strength indication values of RFID to predict the position of picking staff for warehouse management (Kuo et al., 2013).

3.2. Emerging NFC clusters

Table 6 shows the top six NFC clusters that have opportunities for commercialization in the near future. In the field of NFC, four out of six clusters were categorized as application level and two clusters as technology level. The total number clusters belonging to area B was less than 10 because the number of all clusters before linkage analysis was originally 10, as shown in Table 3.

2 technology level NFC clusters were:

- N5: relay attack and security. Relay attack is a type of hacking technique related to man-in-the-middle and replay attacks. It has been suggested that NFC systems are particularly vulnerable to relay attacks. A number of studies described cases such as how a relay attack against peer-to-peer NFC system could be practically implemented (Francis et al., 2010), or software-based relay attack scenario to Google Wallet to verify its applicability (Roland et al., 2013). Some countermeasure is distance bounding, that is, "an authentication protocol where time-critical sessions allow computing an upper bound of the distance between the prover and the verifier (Trujillo-Rasua, 2014; Hancke, 2012).
- N10: integration of NFC with other technologies for touching interaction. RFID tag structures, context profile from NFC and services make it easy to interact with the context (Bravo et al., 2008a). New trend is social Internet of Things (SIoT) that integrates IoT and social networks. In dynamic SIoT scenarios, NFC technique is an enabler for interacting with cyber-physical systems. A study proposed an ontology-based framework to realize an NFC-based intelligent agent by combining NFC with "context-acquisition, ontology-knowledge-base, and semantic-adaptation modules to be aware of location, time, device, and activity contexts with respect to personal and social profiles" (Lin et al., 2014).

4 application level NFC clusters were:

- N3: ambient intelligence (touristic-cultural field: mobile guide for museum visitors (Ceipidor et al., 2013), city navigation (Borrego-Jaraba et al., 2011), access to cultural heritage (Ceipidor et al., 2013), access to bibliographic sources (Borrego-Jaraba et al., 2013), etc.) Ambient intelligence emphasis "natural interaction between user and functions and services embedded in the environment or available through mobile devices" (Ailisto et al., 2006). Tourism is an important economic sector (Borrego-Jaraba et al., 2011), and thus, to offer indoor/outdoor locations and navigations, many applications of ambient intelligence had been proposed.
- N6: telemonitoring (monitoring health-related parameters (Morak

Table 7
Emerging SN clusters with opportunities for commercialization in the near future.

Rank	ID	Research field	# N	# E	Ave. year	Top 5 country	Top 5 organization
1	S1-8	Radio tomography for device-free localization	43	74	2012.51	China 15; US 12; Canada 4; Italy 4; Finland 4; Serbia 4	Univ Utah 7; Aalto Univ 4; Beijing Univ Posts & Telecommun 3; Mcgill Univ 3; Univ Trento 2; Rt Rk 2; Univ Novi Sad 2; Xandem Technol 2; Dalian Univ Technol 2
2	S2-4-9	Detecting and preventing intrusions in wireless sensor networks	30	46	2012.50	China 9; Malaysia 6; England 5; IRAN 4; India 4	Univ Malaya 5; Jiaxing Univ 4; Islamic Azad Univ 3; Donghua Univ 3; Atilim Univ 2; Univ Kebangsaan Malaysia 2; Univ Kingston 2
3	S1-4-9	Speech enhancement with wireless acoustic sensor networks	19	32	2012.42	Belgium 7; Israel 5; Netherlands 5; Germany 2; US 2	Katholieke Univ Leuven 7; Bar Ilan Univ 5; Delft Univ Technol 4; Technion Israel Inst Technol 2; Int Audio Labs Erlangen 1; Carl Von Ossietzky Univ Oldenburg 1; Qualcomm Inc. 1; N Carolina State Univ 1; Ibbt Future Hlth Dept 1; Philips Res 1; Microsoft Corp 1; Univ Ghent 1
4	S5-17	Underground/water sensor networks	30	37	2012.33	US 10; Germany 5; Italy 4; Saudi; Arabia 3; South Korea 3	Georgia Inst Technol 8; Suny Buffalo 5; Politecn Torino 4; Univ Erlangen Nurnberg 4; Korea Adv Inst Sci & Technol 3
5	S2-9	Cognitive radio sensor networks	110	196	2012.23	South Korea 19; Canada 17; China 17; Turkey 11; US 11	Koc Univ 9; Ryerson Univ 4; Yonsei Univ 4; Zhejiang Univ 4; Beijing Jiaotong Univ 3; Univ Politecn Madrid 3; Univ Estadual Campinas 3; Chosun Univ 3; Queens Univ 3; Univ Ottawa 3; Natl Univ Singapore 3
6	S1-4-5	Distributed particle filtering	29	52	2012.14	US 7; Canada 5; Brazil 5; Austria 5; Australia 2; China 2	Vienna Univ Technol 4; York Univ 3; Inst Tecnol Aeronaut 3; Embraer Def & Secur 3; Univ Minnesota 2; Suny Stony Brook 2
7	S2-4-6	Two-factor user authentication	81	284	2012.06	South Korea 20; China 19; Taiwan 12; India 8; Saudi Arabia 6	King Saud Univ 6; Int Inst Informat Technol 5; Univ Maribor 4; Sungkyunkwan Univ 4; Dongseo Univ 4
8	S2-3-8	***Wireless sensor networks for healthcare (monitoring in mass-casualty disasters, vital sign monitoring in hospitals, at-home and mobile aging, assistance with motor and sensory decline, large-scale in-field medical and behavioral studies,* etc.*)***	40	41	2012.05	US 8; France 6; China 4; Spain 4; South Korea 4	Univ Paris 05 3; Univ St Andrews 1; Texas A&M Univ Qatar 1; Nui Maynooth 1; Fed Inst Santa Catarina 1; Univ Las Palmas Gran Canaria 1; Heartspring 1; Huazhong Univ Sci & Technol 1; Michigan State Univ 1; IIT 1; Dalian Ocean Univ 1; Hanbat Natl Univ 1; Coventry Univ 1; Mokwon Univ 1; Sliet 1; Chinese Acad Sci 1; Dalian Polytech Univ 1; Texas A&M Univ 1; Univ So Calif 1; Univ Carlos Iii Madrid 1; Seoul Natl Univ 1; Univ Porto 1; Wuhan Univ Technol 1; Inria 1; Thapar Univ 1; Univ Memphis 1; Univ Calif Los Angeles 1; Zhejiang Univ 1; Jcp Connect 1; Univ Virginia 1; Univ Pittsburgh 1; Bharathiar Univ 1; Univ Waterloo 1; Tech Univ Dresden 1; Univ Oslo 1; Washington Univ 1; I Shou Univ 1; Harvard Univ 1; Univ Fed Santa Catarina 1; Univ Maryland 1; Swansea Univ 1; Elect & Telecommun Res Inst 1; Univ Antilles Guyane 1; Univ Politecn Valencia 1; Linkoping Univ 1; Johns Hopkins Univ 1; Tsinghua Univ 1; Dalian Univ Technol 1; Fdn Res & Technol Hellas 1; Univ Tsukuba 1; Kansas State Univ 1; Clermont Univ 1; Politecn Milan 1; Ajou Univ 1; Tech Univ Madrid Upm 1; Hong Kong Univ Sci & Technol 1; Aalto Sch Elect Engn 1; Univ Western Macedonia 1; Ctr Tecnol Telecommun Catalunya 1; Univ Jj Strossmayer 1
9	S2-3-7	Handover mechanism and mobility support	54	93	2011.87	Portugal 13; South Korea 11; China 11; Spain 5; Canada 3; France 3; Malaysia 3	Univ Beira Interior 10; Kyung Hee Univ 6; Changshu Inst Technol 4; Univ Coimbra 4; ETRI 2; Comsats Inst Informat Technol 2; Beijing Jiaotong Univ 2; Dalhousie Univ 2; Univ Haute Alsace 2; King Saud Univ 2; Univ Politecn Valencia 2; Univ Putra Malaysia 2; Univ Murcia 2
10	S4-2-10	Efficient massive processing method (top-k query, skyline query, skeleton extraction, etc.)	40	71	2011.78	China 29; US 11; Canada 4; Australia 4; Taiwan 3; Singapore 2; South Korea 2	Huazhong Univ Sci & Technol 12; Australian Natl Univ 4; Hong Kong Polytech Univ 3; Chinese Univ Hong Kong 3; Chinese Acad Sci 2; Nanjing Univ Aeronaut & Astronaut 2; Suny Stony Brook 2; Case Western Reserve Univ 2; Penn State Univ 2; Northeastern Univ 2; Nec Labs Amer 2; Interdigital Commun 2; Hong Kong Univ Sci & Technol 2; Hubei Univ Econ 2

Table 8
Emerging 10 IoT clusters with opportunities for commercialization in the near future.

Rank	ID	Research field	# N	# E	Ave. year	Top 5 countries	Top 5 organizations
1	I4	***IoT in industry (cloud manufacturing, supply chain management, compliance checking,* etc.*)***	82	249	2013.22	China 48; US 32; England 9; Sweden 6; Portugal 4	Old Dominion Univ 28; Chinese Acad Sci 28; Shanghai Jiao Tong Univ 21; Univ Sci & Technol China 20; Beihang Univ 5
2	I9	Various research (resource-constrained systems, cognitive management framework, Wi-Fi enabled sensors, knowledge-aware and service-oriented middleware, distributed service-based approach for sensor data fusion, cloud-based IoT, web-of-objects, fiber-wireless, observations on economics, pricing, and penetration of IoT, etc.) and the review paper of this research	40	40	2012.88	Spain 10; China 9; Germany 5; Italy 3; England 3; South Korea 3	Nec Labs Europe 2; Univ Malaga 2; Hankuk Univ Foreign Studies 2; Univ Politecn Madrid 2; Natl Chiao Tung Univ 1; Key Lab Comp Network Shaanxi Prov 1; Inst Natl Rech Sci 1; Create Net 1; Astar 1; Tech Univ Darmstadt 1; Ericsson R&D Madrid Ctr 1; Xi An Jiao Tong Univ 1; Tech Univ Madrid 1; Tohoku Univ 1; Beihang Univ 1; Orange Labs 1; Qingdao Univ Sci & Technol 1; Sap Switzerland Inc. 1; Univ Carlos Iii Madrid 1; Robert Bosch Llc 1; Natl Tech Univ Athens 1; Univ Paderborn 1; Univ Piraeus 1; Jacobs Univ Bremen 1; Sintef Fdn Sci & Ind Res 1; Shanghai Jiao Tong Univ 1; Univ Surrey 1; Kt Powertel 1; Inst Methodol Environm Anal 1; Disney Res Zurich 1; Univ Bern 1; Sintef Ikt 1; Univ Southampton 1; Mcgill Univ 1; Univ Granada 1; Beihang Univ Shengzhen 1; Korea Elect Technol Inst 1; INRS 1; Ait Austrian Inst Technol Gmbh 1; Tampere Univ Technol 1; Ctr Invest Tecnol Software & Sistemas Multimedia 1; Univ Salento 1; Univ Kashan 1; Ericsson Res 1; Natl Inst Informat & Commun Technol 1; Univ Macau 1; Natl Univ Tainan 1; Atos Origin Sae 1; Fraunhofer Inst Optron Syst Technol & Image Explo 1; Waterford Inst Technol 1; Inst Environm & Sustainabil 1; Univ Complutense Madrid 1; Hsch Angew Wissensch 1; San Jose State Univ 1; Indian Inst Technol 1; Hunan Univ 1; Nanyang Technol Univ 1; Univ Helsinki 1; Imperial Coll London 1; Beijing Inst Technol 1; Univ Murcia 1
3	I11	Review paper and developments from the paper (***applications: platform for multiple unmanned vehicles with WSNs navigation and cyber-transportation systems in the form of Cyber-Physical Systems, medication control, smart home/smart grid/healthcare using M2M, material and production tracking in toy manufacturing,* etc.** Technologies: agent serivce platform to solve heterogeneity issue, security architecture, etc.)	23	23	2012.87	China 9; Canada 2; Romania 2; Portugal 2; Germany 2; South Korea 2	S China Univ Technol 4; Jiangxi Univ Sci & Technol 3; Huazhong Univ Sci & Technol 2; Univ Minho 2; Guangdong Jidian Polytech 2
4	I6	***Future IoT***	66	76	2012.79	China 19; Taiwan 8; Germany 7; South Korea 7; England 6	Natl Taiwan Univ Sci & Technol 3; Natl Chung Cheng Univ 2; Dongguk Univ 2; Univ London 2; Chia Nan Univ Pharm & Sci 2; Tech Univ Berlin 2; Univ Adelaide 2; Huazhong Univ Sci & Technol 2; UCL 2; Univ Politecn Valencia 2; Soongsil Univ 2; Tata Consultancy Serv 2
5	I10	Review paper and developments from the paper (***applications: smart community, smart garbage system, electric vehicle charging-swap networks operation, environmental condition monitoring,* etc.** Technologies: cyberentity security, autonomic protocol and architecture for devices, etc.)	31	34	2012.74	China 12; Canada 5; Italy 5; Taiwan 4; US 3	Univ Waterloo 3; Huazhong Univ Sci & Technol 2; Univ Ottawa 2; Huzhou Univ 2; Queens Univ 1; Univ Valencia 1; Selex Elsag 1; Jntu Hyderabad 1; Keio Univ 1; Chung Ang Univ 1; Acad Sinica 1; Natl Kaohsiung Univ Appl Sci 1; ETH 1; Tohoku Univ 1; Beihang Univ 1; MIT 1; Hunan Univ Arts & Sci 1; Wuxi Profess Coll Sci & Technol 1; Georgia Inst Technol 1; Univ Carlos Iii Madrid 1; Massey Univ 1; Natl Taiwan Univ 1; Beijing Univ Posts & Telecommun 1; Southeast Univ Seu 1; Univ Calif Los Angeles 1; Univ Lille 1 1; Zhejiang Univ 1; Univ Bern 1; Nanjng Univ Posts & Telecommun 1; CNRS 1; Natl Ilan Univ 1; Univ Bologna 1; Fdn Ugo Bordoni 1; Univ Fed Parana 1; Univ Genova Unige 1; Fed Univ Para 1; Lille Nord Europe Inria Res Ctr 1; Univ Ontario Inst Technol 1; Univ Oulu 1; St Francis Xavier Univ 1; Univ Mediterranea Reggio Calabria 1; S China Univ Technol 1; Nanjing Univ Posts & Telecommun 1; Int Islamic Univ Malaysia 1; King Saud Univ 1; Nanyang Technol Univ 1; Natl Formosa Univ 1
6	I13	***Environmental IoT***	21	24	2012.71	China 14; US 6; South Korea 2; Romania 1; Italy 1; India 1; France 1; Greece 1; Taiwan 1	Chinese Acad Sci 8; Univ Chinese Acad Sci 5; Purdue Univ 3; Mokpo Natl Univ 2; Beijing Univ Posts & Telecommun 2; Hebei Normal Univ Sci & Technol 2
7	I5	Security for IoT	81	102	2012.59	China 28; Germany 8; England 8; Spain 7; Italy 6	Beijing Univ Posts & Telecommun 5; Univ Malaga 3; Univ Zurich 3; Univ Surrey 3; Univ Lubeck 3; Univ Lancaster 3

(continued on next page)

Table 8 (*continued*)

Rank	ID	Research field	# N	# E	Ave. year	Top 5 countries	Top 5 organizations
8	I3	Review paper and developments from the paper (***applications: Internet of civil infrastructure framework, expert system for vehicle sensor tracking and managing application generation, multi-objective decision making-based evaluation model of service quality, etc.*** Technology: scalable multi-agent architecture for managing IoT data, etc.)	93	114	2012.58	China 28; Spain 11; Italy 8; Germany 6; South Korea 6	Nanjing Univ Posts & Telecommun 4; Create Net 3; Vienna Univ Technol 3; Kyung Hee Univ 2; Univ Oviedo 2; Polytech Inst Leiria 2; Tech Univ Munich 2; Wuhan Univ Technol 2; United Arab Emirates Univ 2; Elect & Telecommun Res Inst 2; Univ Piraeus 2; Univ Politecn Cataluna 2; Lulea Univ Technol 2; Nw Polytech Univ 2; Islamic Azad Univ 2; West Univ Timisoara 2; Beijing Univ Posts & Telecommun 2; Univ Politecn Valencia 2; Jilin Univ 2
9	I12	Integration of WSNs and IoT (IP-based WSN, minimum hops constraint, etc.)	22	21	2012.27	South Korea 5; China 4; Spain 4; US 3; Portugal 2; Finland 2	Korea Adv Inst Sci & Technol 4; Texas A&M Univ 2; Beijing Univ Posts & Telecommun 2; Univ Oulu 2; Univ Aveiro 2
10	I8	Paper describing new concept and developments from the paper (***applications: water environment monitoring, smart product, food quality safety, etc.*** Technologies: 6LoWPAN, ipv6, etc.)	61	66	2012.05	China 17; US 6; Portugal 6; Spain 5; Finland 5	Univ Beira Interior 6; Aalto Univ 4; Cicese Res Ctr 3; Beijing Univ Posts & Telecommun 3; Univ Cyprus 2; Beijing Normal Univ 2; Polytech Inst Tomar 2; Northeastern Univ 2; Univ Aveiro 2

et al., 2012; Morak et al., 2007; Izumi et al., 2014), medication adherence monitoring (Morak et al., 2012), etc.). A number of studies utilize mobile phones and wireless communication technologies as body area network (BAN) and personal area network (PAN) to monitor health-related parameters (e.g., blood pressure, body weight, glucose, oxygen saturation, electrocardiogram signals) (Su et al., 2010; Mindikoglu & Van Der Veen, 2008; Nie et al., 2012) and to record and reminder a patient's medication intake based on smart blisters and mobile phones with NFC functionality (Morak et al., 2012).

- N7: Ambient Assisted Living (ALL) (monitoring of elderly people (Jara et al., 2014), supporting chronic disease (Bravo et al., 2008b), etc.). ALL "fosters the provision of equipment and services for the independent or more autonomous living of elderly people, via the seamless integration of info-communication technologies within homes and residences" (López-de-Ipiña et al., 2010). NFC enables ALL because it is intuitive/easy to use, has understandable user interface, is implemented to personal devices (e.g., tablets, smart phones), and allows the linkage of the data captured from smart objects with the context and situation of user (Jara et al., 2014).
- N9: context-awareness system (mobile payment (Liu & Shen, 2012), smart home (Chang et al., 2010; Chang et al., 2013), loyalty service (Ozdenizci et al., 2013), etc.). Middleware must be aware of their contexts and automatically adapt to the changing environment as context-awareness to avoid increasing applications and services complexity for users (Liu & Shen, 2012). Using NFC, the efficient support for acquiring, interpreting and accessing contexts is provided. NFC also "enables the long awaited Internet-of-Things, (IoT), changing our interactions with the world in subtle but pervasive ways providing digitally immersive experience" (Katiyar et al., 2014).

3.3. Emerging SN clusters

Table 7 shows top 10 SN clusters with opportunities for commercialization in the near future. In the field of SN, 1 out of 10 clusters was categorized as application level, and the other 9 as technology level.

9 technology level SN clusters were:

- S1-4-5: distributed particle filtering (DPF). One of the goals in sensor network is to detect and track changes, and DFP is widely used tracking algorithm (Gu, 2007). DPF algorithms are "sequential state estimation algorithms that are executed by a set of agents. Some or all of the agents perform local particle filtering and interact with other agents in order to calculate a global state estimate" (Hlinka et al., 2013).
- S1-4-9: speech enhancement with wireless acoustic sensor networks. There are several speech processing applications such as mobile telephony, hearing aids, and human-machine communication systems. In such applications, speech quality and intelligibility get severely degraded in noisy environments. To improve the quality and intelligibility of noisy speech and to reduce or eliminate the acoustical noise in speech communication systems, a large number of speech enhancement algorithms have been developed (Zeng & Hendriks, 2014).
- S1-8: radio tomography for device free localization. When there is object in wireless networks, the links pass through the object attenuate. Radio tomographic imaging (RTI) is an emerging technology for imaging the shadowing losses. "RTI may be useful in emergencies, rescue operations, and security breaches, since the objects being imaged need not carry an electronic device" (Wilson & Patwari, 2010). The applications include security system and smart building since the images can track humans moving through/inside a building (Nannuru et al., 2013).
- S2-3-7: handover mechanism and mobility support. Current standardization of Internet Protocol version 6 (IPv6) over Low-power

Personal Area Network (6LoWPANs) allows WSN nodes to communicate using IP protocol. In the IP-based WSNs scenario, to achieve a continuous connectivity with body nodes with mobility support, it is important to develop self-configuration (handover) mechanisms that can handle the link transitions between different access points (Caldeira et al., 2012). Mobility in the sensor network with special attention to energy efficiency is a major issue to be addressed (Islam & Huh, 2011).

- S2-4-6: two-factor user authentication. User authentication in WSN is a critical security issue because of their unattended and hostile deployment in the field. “Since sensor nodes are equipped with limited computing power, storage, and communication modules; authenticating remote users in such resource-constrained environments is a paramount security concern” (Khan & Alghathbar, 2010). Hence two-factor user authentication (Das, 2009) has been proposed. It is a concept used to describe an authentication mechanism, where more than one factor (e.g., password and chip card) is required to authenticate the communicating party. It provides strong authentication, session key establishment, and achieves efficiency.
- S2-4-9: detecting and preventing intrusions in wireless sensor networks. The core weakness of sensor nodes lies in the limited-resource devices (i.e. power and processing units), and thus, vulnerability to various security threats is notably high due to the distributed nature of Denial-of-Service attacks (Shamshirband et al., 2014a). Some studies introduced artificial immune system, that is bio-inspired and a modular-based defense strategy derived from the danger theory of the human immune system (Shamshirband et al., 2014a). The other studies cooperative game theory and the proposed model's attack detection and defense accuracy yield a greater improvement than existing machine learning methods (e.g., compared with fuzzy logic controller, Q-learning, and fuzzy Q-learning) both in terms of detection accuracy and its efficiency and viability (Shamshirband et al., 2014b).
- S2-9: cognitive radio sensor networks (CRSN). Radio spectrum has “largely been managed under a licensed approach that has led to the current day scarcity in spectrum,” and “licensed spectrum is underutilized and that there exist spectrum portions unused over space and time” (Maleki et al., 2011). CRSN has been proposed to promote utilization of such spectrum portions. CRSN can be defined as “a distributed network of wireless cognitive radio sensor nodes, which sense event signals and collaboratively communicate their readings dynamically over available spectrum bands in a multihop manner to ultimately satisfy the application-specific requirements” (Akan et al., 2009).
- S4-2-10: efficient massive processing method (top-k query, skyline query, skeleton extraction, etc.). For massive processing, a number of studies proposed the method of effective information extraction. Top-k (Wu et al., 2007) and skyline (Chen et al., 2007) are two popular optimal data query approaches that have common features, and both return the representative or special results to users (Zhang et al., 2014a). On the other hand, the performance of sensor network depends on the distribution of the sensors and the overall network topology. For instance, the global topology of a wireless sensor network has a fundamental influence on data gathering/processing scheme. Utilizing skeleton (or medial axis) enables to discover topology, and thus, greatly improve the performance (Jiang et al., 2010).
- S5-17: underground/water sensor networks. New communication technique for challenging environment such as underground (Sun & Akyildiz, 2010; Sun et al., 2011) and underwater (R-Moreno et al., 2014) have been proposed. Underground/water has strong attenuation, delay and multi-path fading since the propagation medium is no longer air but soil, rock and water. In such environment, well established wireless signal propagation techniques using electromagnetic waves do not work, but new technique using magnetic induction can create constant channel condition with small size of coils.

1 application level SN cluster was:

- S2-3-8: wireless sensor networks for healthcare. A number of review papers summarized applications and challenges in the healthcare domain (Grgić et al., 2012; Ko et al., 2010). Some representative applications are monitoring in mass-casualty disasters, vital sign monitoring in hospitals, at-home and mobile aging, assistance with motor and sensory decline, large-scale in-field medical and behavioral studies (Ko et al., 2010).

3.4. Emerging IoT clusters

Table 8 shows top 10 IoT clusters with opportunities for commercialization in the near future. In the field of IoT, 3 out of 10 clusters were categorized as technology level, 3 as application level, and the others as mix of technology and application. For most clusters, it is quite difficult to provide concise character because their research was quite broad and still had an emerging status. It might reflect broad coverage of IoT research and immature nature of it. Hence, the clusters were described only by showing some keywords in them. The 10 IoT clusters were:

3 technology level IoT clusters were:

- I5: security for the IoT. Security and privacy are important factors that will influence the adoption of the IoT paradigm (Roman et al., 2013). A study showed possible solutions for “the problem of establishing a session key between a client and a server in the context of the Internet of Things, where one or more peers are sensor nodes from a wireless sensor network” (Roman et al., 2011a). And a number of studies summarize the security challenges as survey or review papers (Roman et al., 2011b; Gluhak et al., 2011; Yan et al., 2014).
- I9 was at the technology level for various researches. It consists of resource-constrained systems (Sehgal et al., 2012; Jianming et al., 2014), cognitive management framework (Magazine, 2013), Wi-Fi enabled sensors (Tozlu et al., 2012), knowledge-aware and service-oriented middleware (Corredor et al., 2012), distributed service-based approach for sensor data fusion (Rodriguez-Valenzuela et al., 2014), cloud-based IoT (Cubo et al., 2014), web-of-objects (Ara et al., 2014), fiber-wireless (Maier & Lévesque, 2014), observations on economics, pricing, and penetration of IoT (Bohli et al., 2009), etc., and the review paper of this research (Kawamoto et al., 2014).
- I12: integration of WSNs and IoT (IP-based WSN (Hong et al., 2010), minimum hop constraint (Ouyang & Chen, 2014), etc.) In the IoT era, it becomes essential how to compose and integrate different web services efficiently to provide complicated services (Ouyang & Chen, 2014). Nonstandard or non-IP WSNs tailored to specific applications seem inappropriate for building a global infrastructure (Hong et al., 2010). However, “if trillions of things are connected through a single open standard interface such as IP, TCP, and HTTP,

Table 9
The number and percentage of all of clusters and top 10 emerging paper clusters for each levels.

Domain	All of paper clusters		All of patent clusters		Top 10 emerging paper clusters		
	Area A	Area B	Area A	Area C	Application level	Technology level	Mixed level
RFID	20 (7.7%)	19 (7.3%)	23 (8.9%)	197 (76.1%)	4 (40.0%)	6 (60.0%)	0 (0.0%)
NFC	4 (11.8%)	6 (17.6%)	5 (14.7%)	19 (55.9%)	4 (66.7%)	2 (33.3%)	0 (0.0%)
SN	22 (9.7%)	199 (88.1%)	5 (2.2%)	0 (0.0%)	1 (10.0%)	9 (90.0%)	0 (0.0%)
IoT	2 (9.1%)	11 (50.0%)	3 (13.6%)	6 (27.3%)	3 (30.0%)	3 (30.0%)	4 (40.0%)

Table 10
Comparison between extracted clusters of application level and the 11 systems of CSTI.

	11 systems	Extracted clusters
1	Optimizing the energy value chain	● ***I10 (electric vehicle charging-swap networks operation)*** ● ***I11 (smart grid using M2M)***
2	Building a global environment information platform	● ***I8 (water environment monitoring)*** ● ***I10 (environmental condition monitoring)*** ● ***I13 (environmental IoT)***
3	Maintenance and upgrade of an efficient and effective infrastructure	● ***R2-4 (construction applications: concrete processing and handling, cost coding for labor and equipment, materials/tools control and tracking,*** **etc.*****)*** ● ***I3 (Internet of civil infrastructure framework)*** ● ***I10 (smart community, smart garbage system)***
4	Attaining a resilient society against natural disasters	● ***S2-3-8 (WSNs for healthcare: monitoring in mass-casualty disasters)***
5	Intelligent transportation systems	● ***I3 (expert system for vehicle sensor tracking and managing application generation)*** ● ***I11 (platform for multiple unmanned vehicles with WSNs navigation and cyber-transportation systems in the form of Cyber-Physical Systems)***
6	New manufacturing systems	● ***R2-3 (RFID-based wireless manufacturing)*** ● ***I4 (IoT in industry: cloud manufacturing, supply chain management, compliance checking,*** **etc.*****)*** ● ***I11 (material and production tracking in toy manufacturing)***
7	Integrated material development systems	–
8	Promoting integrated community care systems	● ***S2-3-8 (WSNss for healthcare: vital sign monitoring in hospitals, at-home and mobile aging, assistance with motor and sensory decline, large-scale in-field medical and behavioral studies,*** **etc.*****)*** ● ***N7 (Ambient Assisted Living: monitoring of elderly people, supporting chronic disease,*** **etc.*****)*** ● ***N6 (telemonitoring: blood pressure, body weight, glucose, oxygen saturation, ECG signals,*** **etc.*****)*** ● ***I11 (medication control, healthcare using M2M)***
9	Hospitality systems	● ***R2-7 (location awareness in indoor environment in house)*** ● ***N3 (ambient intelligence: touristic-cultural field*** **e.g.*****, mobile guide for museum visitors, city navigation, access to bibliographic sources,*** **etc.*****)*** ● ***N9 (context-awareness system: mobile payment, smart home, loyalty applications,*** **etc.*****)*** ● ***I3 (multi-objective decision making-based evaluation model of service quality)*** ● ***I11 (smart home using M2M)***
10	Smart food chain systems	● ***R2-7 (location awareness in indoor environment in warehouse)*** ● ***I8 (food quality safety)***
11	Smart production systems	● ***I8 (smart product)***
	Others	● ***R2-6 (ubiquitous learning, auto-scoring system for billiards games, anti-swindle mahjong leisure system,*** **etc.*****)*** ● ***R2-7 (location awareness in indoor environment in library)*** ● ***I6 (future IoT)***

they can transparently support seamless connectivity, unique addressability, and rich applicability" (Bae et al., 2011). In order to achieve this objective, IP-based WSN has recently gained worldwide attention, and that is why the Internet Engineering Task Force 6LoWPAN and ROLL Working Groups are actively performing standardization in this area.

3 application level IoT clusters were:

- I4 was the application level for IoT in industry. Some applications have been proposed, such as cloud manufacturing (Tao et al., 2014a; Zhang et al., 2014b; Tao et al., 2014b), supply chain management (Li, 2013), and compliance checking (Viriyasitavat et al., 2014).
- I6 was the application level for future IoT. Several innovative techniques have been developed gradually and incorporated into the IoT, which is referred to as the Future Internet of Things (FIoT) because the requirements of the IoT are quite different from what the Internet today can offer (Tsai et al., 2014).
- I13: environmental Internet of Things (EIoT). The construction of sustainable cities is crucial, and EIoT has been introduced to meet the needs of urban environment comparative analysis. "EIoT can be used to monitor some water, atmosphere, soil, sound, and wind environmental indicators to realize the collection, transportation, treatment, modeling, forecasting and early warning, and application of environmental information with online, real-time in situ and long-distance approaches" (Zhao et al., 2013).

4 IoT clusters were mix of technology and application:

- I3 was a mix of application and technology levels for a review paper and developments from the paper. The review paper summarized the vision, applications, and research challenges (Miorandi et al., 2012). Research has been conducted to solve the challenges shown in the review paper. Several applications have been proposed, such as an internet of civil infrastructure framework (Liaw & Lin, 2013), expert system for vehicle sensor tracking and managing application generation (Cueva-Fernandez et al., 2014), and multi-objective decision making-based evaluation model of service quality (Shaoshuai et al., 2011). For technology level, some research has been conducted, such as scalable multi-agent architecture for managing IoT data (Manate et al., 2013).

– I8 was a mix of application and technology levels for a paper describing a new concept and developments from the paper. The paper described the new concept of "Internet-Zero." This is almost the same as the IoT, and is "giving everyday objects the ability to connect to a data network," which would have a range of benefits (Gershenfeld et al., 2004). Research has been conducted to solve the issues shown in the review paper. Several applications have been proposed, such as water environment monitoring (Cao et al., 2014), smart product (N.J. et al., 2008), and food quality safety (Ying & Fengquan, 2013). For technology level, some research has been conducted, such as 6LoWPAN (Oliveira et al., 2013a), ipv6 (Oliveira et al., 2013b).
– I10 tends to study at allocation level but was a mix of application and technology levels for a review paper and developments from the paper. The review paper provided an overview of IoT and some research issues (Antonio et al., 2010). Research has been conducted to solve the issues shown in the review paper. Several applications have been proposed, such as smart community (Li et al., 2011), smart garbage system (Hong et al., 2014), electric vehicle charging-swap networks operation (Gao et al., 2012), environmental condition monitoring (Kelly et al., 2013), etc. For technology level, some research has been conducted, such as cyberentity security (Ning et al., 2013), autonomic protocol and architecture for devices (Ashraf et al., 2014), etc.
– I11 was a mix of application and technology levels for a review paper and developments from the paper. The review paper summarized applications and challenges in technology and standardization (Bandyopadhyay & Sen, 2011). Research has been conducted to solve the challenges shown in the review papers. Several applications have been proposed, such as platforms for multiple unmanned vehicles with Wireless Sensor Network (WSN) navigation and cyber-transportation systems in the form of cyber-physical systems (Wan et al., 2013), medication control (Laranjo et al., 2012), smart home/smart grid/healthcare using machine to machine (M2M) (Chen et al., 2012), material and production tracking in toy manufacturing (Cao et al., 2013), etc. For the technology level, some research has been conducted, such as an agent service platform to solve heterogeneity issues (Jing et al., 2014; Jung et al., 2014), security architecture (Gonçalves et al., 2013), etc.

4. Discussion

4.1. Comparison among IoT-related technologies

We compared the feature of IoT-related technologies. The number and percentage of all of clusters, and top 10 emerging paper clusters for each level were summarized to investigate difference among IoT, RFID, NFC, and SN (Table 9). As can be seen in Table 9, there are two different patterns especially in paper clusters, i.e., RFID and NFC appear equally at area A and area B but SN and IoT at area B of Fig. 5.

In case of RFID, patent clusters classified as area C are the majority, which was 76.1%. Meanwhile, the percentage of emerging paper clusters of technology level is 60.0%. Thus, RFID as a whole could be already commercialized but still the technologies are developing. In case of NFC, patent clusters classified as area C are the majority, which was 55.9%. Meanwhile, the percentage of emerging paper clusters of application level is 66.7%. Thus, NFC as a whole could be already commercialized but still the applications are developing. In case of SN, paper clusters classified as area B are the majority, which was 88.1%. Meanwhile, the percentage of emerging paper clusters of technology level is 90.0%. Thus, SN as a whole could be commercialized in the future and the technologies are developing. In case of IoT, paper clusters classified as area B are the majority, which was 50.0%. Meanwhile, the percentage of emerging paper clusters of mixed level is 40.0%. Thus, IoT as a whole could be commercialized in the future but still the development is not established. This implies that in RFID and NFC, science (papers) and technology (patents) co-evolve but SN and IoT there might exist opportunities of technological seeds (papers) missed in the current technology (patents).

4.2. Potential link between technology and application level

In order to investigate role of IoT-related technology and future applications further, extracted clusters of application level clusters, as shown in Tables 5, 6, 7, and 8, were compared with a public government document. In the 5th Science and Technology Basic Plan, IoT is one of top priorities as the main development path to resolve social issues and develop future society. The public document of the Council for Science, Technology, and Innovation (CSTI), the Cabinet Office of Japan Government, proposed an ideal form of future society: a "super smart society" or "Society 5.0." A super smart society is characterized as that in which "the various needs of society are finely differentiated and met by providing the necessary products and services in the required amounts to the people who need them when they need them, and in which all the people can receive high-quality services and live a comfortable, vigorous life that makes allowances for their various differences such as age, sex, region, or language" (C. Office, 2015). To achieve this goal, "11 systems were identified and given priority for development in the 2015 Comprehensive Strategy, based on the economic and social issues that require the strongest national efforts" (C. Office, 2015). The extracted clusters of application level were validated by comparing the 11 systems. The comparison is shown in Table 10. There was good agreement between the extracted clusters and the systems except for "integrated material development systems." In addition, some clusters (R2-6, R2-7, I6) had no correspondence with the 11 systems, as they were missed in the CSTI public document. In other word, the clusters could be emerging applications.

Extracted emerging clusters of technology level were compared with the 11 systems' enabling technologies in more details, and summarized as Appendix iv. Here, I3, I8, I9, I10, and I11 were omitted because they are clusters which were mix of technology and application and thus not suitable for this analysis. 14 out of 19 clusters contributed for at least one of the 11 systems. We found some clusters can cover a wide range of applications. Especially, R1-5 (chipless RFID), R1-4 (passive tag and improvements of backscattering communication) and S2-9 (cognitive radio sensor networks) have possibility to be applied for all of the 11 systems. As Table 9 shows, these clusters are the technologies to enable applications, but they were not listed up as enabling technologies for 11 systems in CSTI report. This could be because they are emerging technologies, and thus, they were not recognized by CSTI. R1-5 and R1-4 are technologies how to communicate without battery. They are

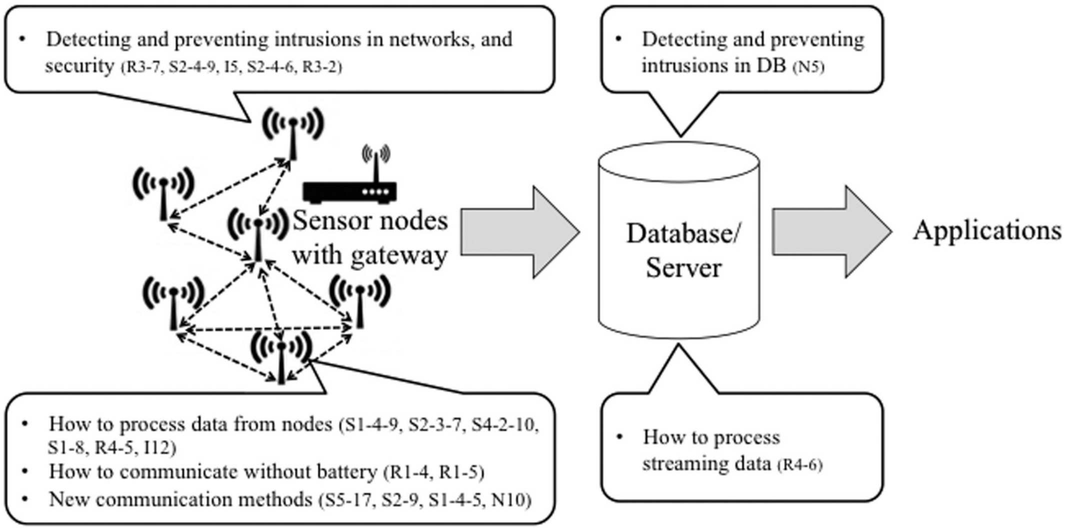

Fig. 8. Relationship among extracted IoT-related technologies.

essential for era of trillion sensors since it will be impossible to change batteries for such huge amount of devices. S2-9 is technology of cognitive radio sensor network, which can select appropriate bandwidth or communication system according to communication environment. It will be crucial because applications will be quite diverse. Here, we could detect that the public document lacked some important technologies compared with extracted clusters of IoT technology level. On the other hands, the 11 system's enabling technologies listed in in CSTI report include not concrete technologies. For an example, they just mentioned that AI can contribute to applications of these systems. Our analysis can elucidate more concrete options.

4.3. Toward further development of IoT and related technologies

In order to discuss further room for technological development, we summarized extracted clusters of technology level in Tables 5–8 as Fig. 8. They could be divided into two parts: sensor nodes with gateway, and database/server. Once the data were extracted from sensor nodes, and they go thorough database/server, and at last they were converted into applications. In the sensor nodes with gateway part, technologies how to process data from large amount of nodes, technologies how to communicate without battery, technologies for new communication methods, and technologies for detecting and preventing intrusions in networks, and security were detected. In database/server part, following after the sensor nodes, technology how to process streaming data from sensor nodes, and technology for detecting and preventing intrusions in database were detected. We consider that the appearance of emerging research field reflects the existence of unresolved technological issues on those points and thus further research is necessary for IoT and related technologies to be implemented in wider scope of industry and society.

4.4. Conclusion

In this study, we investigated the research areas of IoT-related technologies to explore opportunities for commercialization and social implementation in the near future. To discover potential opportunities for industrial commercialization, patents clusters and papers clusters were compared in terms of their topics. To validate usefulness of the result, they were compared to a public government document that contained IoT technology policy. There was good agreement between extracted clusters of IoT application level and the public document. And we demonstrated that it can extract technological options which were lacked in the document.

The limitations of this study are four folds. First, we mainly analyzed only on top 10 emerging clusters. Therefore, there is a possibility that we missed important clusters. Especially, clusters whose sizes were quite small but contain important information were neglected. Second, types of methodology for forecasting should be improved. Even though the accuracy of citation analysis is good, other methodologies might be useful because there have not been sufficient citations in this early stage for emerging technologies, such as IoT, and thus, it is difficult to obtain density network. Possible candidates are integrating concepts by adding other queries, expanding reference path (Von Wartburg et al., 2005; Takano et al., 2016), and text-based analysis such as topic modeling (Yau et al., 2014). Third, there is a room for improvement in data retrieval strategy. We used the same queries used in the previous literature but it can be revised by query expansion and related technology using natural language processing, topic model, and expert judgement. In terms of type of data, not only papers or patents, news magazines (Kataoka et al., 2016), SNS (Bian et al., 2016) could be considered. Fourth, average value of text similarity was utilized in this study. However, the results and outputs of proposed integrated methods highly depend on the text similarity threshold. Instead of the average, another more optimized threshold may exist, and thus, it is needed to discuss how to figure out such threshold in the future.

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Appendix A

Here, we show from top 11 to top 20 clusters for each IoT-related technology, except NFC because the number of clusters in area B is 6. We simplify the contents compared to the Tables 5, 6, 7, and 8: only show number of node, number of edge, average publication year, and reference of the hub-paper (the most connected paper in the cluster).

i. RFID cluster (we list up from top 11 to top 19 clusters because the number of cluster in area B is 19)

Rank	ID	#N	#E	Ave. year	Reference of the hub-paper
11	R3-3	254	361	2009.96	A. Juels, "RFID security and privacy: A research survey," *IEEE journal on selected areas in communications*, vol. 24, no. 2, pp. 381–394, 2006.
12	R10	80	159	2009.94	I. Kwon et al., "A single-chip CMOS transceiver for UHF mobile RFID reader," *IEEE Journal of Solid-State Circuits*, vol. 43, no. 3, pp. 729–738, 2008.
13	R3-4	249	715	2009.73	M. Feldhofer et al., "Strong authentication for RFID systems using the AES algorithm," *CHES*, vol. 4, pp. 357–370, 2004.
14	R3-1	318	936	2009.58	S. Vaudenay, "On privacy models for RFID," *Advances in Cryptology–ASIACRYPT 2007,* vol. 4833, pp. 68–87, 2007.
15	R7	108	179	2009.56	E. J. H. Robinson et al., "Radio tagging reveals the roles of corpulence, experience and social information in ant decision making," *Behavioral ecology and sociobiology,* vol. 63, no. 5, pp. 627–636, 2009.
16	R2-1	530	2281	2009.34	E. W. T. Ngai et al., "RFID research: An academic literature review (1995–2005) and future research directions," *International Journal of Production Economics,* vol. 112, no. 2, pp. 510–520, 2008.
17	R4-8	106	133	2009.23	B. Jiang et al., "Unobtrusive long-range detection of passive RFID tag motion," *IEEE transactions on instrumentation and measurement,* vol. 55, no. 1, pp. 187–196, 2006.
18	R4-9	47	50	2008.83	J. Zhai and G. N. Wang, "An anti-collision algorithm using two-functioned estimation for RFID tags," *Computational Science and Its Applications–ICCSA 2005,* vol. 3483, pp. 147–151, 2005.
19	R3-5	122	147	2008.62	S. A. Weis et al., "Security and privacy aspects of low-cost radio frequency identification systems," *Security in pervasive computing.* Springer, Berlin, Heidelberg, vol. 2802, pp. 201–212, 2004.

ii. IoT cluster (we list up only top 11 cluster because the number of cluster in area B is 11)

Rank	ID	#N	#E	Ave. year	Reference of the hub-paper
11	I7	65	70	2012.00	D. Bandyopadhyay and J. Sen, "Internet of things: Applications and challenges in technology and standardization," *Wireless Personal Communications*, vol. 58, no. 1, pp. 49–69, 2011.

iii. SN cluster (we list up from top 11 to top 20 clusters out of 199 clusters)

Rank	ID	#N	#E	Ave. year	Reference of the hub-paper
11	SN2-4-3	140	150	2011.76	J. Yick et al., "Wireless sensor network survey," *Computer networks,* vol. 52, no. 12, pp. 2292–2330, 2008.
12	SN2-2-2	326	808	2011.72	V. C. Gungor and G. P. Hancke, "Industrial wireless sensor networks: Challenges, design principles, and technical approaches," *IEEE Transactions on industrial electronics,* vol. 56, no. 10, pp. 4258–4265, 2009.
13	SN1-4-3	242	666	2011.56	B. Sinopoli et al., "Kalman filtering with intermittent observations," *IEEE transactions on Automatic Control,* vol. 49, no. 9, pp. 1453–1464, 2004.
14	SN6-12	19	21	2011.53	C. Y. Chong et al., "Sensor networks: evolution, opportunities, and challenges," *Proceedings of the IEEE,* vol. 91, no. 8, pp. 1247–1256, 2003.
15	SN5-22	14	13	2011.50	W. Hu et al., "A survey on visual surveillance of object motion and behaviors," *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews),* vol. 34, no. 3, pp. 334–352, 2004.
16	SN3-3-7	56	83	2011.46	Y. T. Hou et al., "Rate allocation and network lifetime problems for wireless sensor networks," *IEEE/ACM Transactions on Networking (TON),* vol. 16, no. 2, pp. 321–334, 2008.
17	SN1-1-6	88	259	2011.44	X Cheng et al., "Silent positioning in underwater acoustic sensor networks," *IEEE Transactions on vehicular technology,* vol. 57, no. 3, pp. 1756–1766, 2008.
18	SN4-4-13	12	11	2011.40	W. S. Jang et al., "Wireless sensor networks as part of a web-based building environmental monitoring system," *Automation in Construction,* vol. 17, no. 6, pp. 729–736, 2008.
18	SN2-3-1	273	705	2011.40	M. Chen et al., "Body area networks: A survey," *Mobile networks and applications,* vol. 16, no. 2, pp. 171–193, 2011.
20	SN1-3-6	38	79	2011.37	P Braca et al., "Asymptotic optimality of running consensus in testing binary hypotheses," *IEEE Transactions on Signal Processing,* vol. 58, no. 2, pp. 814–825, 2010.

iv. Comparison between extracted clusters of technology level and the 11 systems' enabling technologies. When there is correspondence between extracted cluster and enabling technology, the reason with the ID number of enabling technologies is shown in the cross section. If the extracted cluster could be applied but not listed up as enabling technology, it shows as check mark. The coverage of each technological cluster to the 11 systems is shown in the percentage

The 11 systems			System 1	System 2	System 3	System 4
			Optimizing the energy value chain	Building a global environment information platform	Maintenance and upgrade of an efficient and effective infrastructure	Attaining a resilient society against natural disasters
The 11 systems' enabling technologies			1-1. Renewable energy 1-2. Nuclear power generation 1-3. Biomass utilization 1-4. Electronic device 1-5. Structural material 1-6. Energy carriers 1-7. Next-generation rechargeable battery 1-8. Big data analysis, AI 1-9. Information Security 1-10. Energy network systems	2-1. Improvement of the performance of satellite-borne sensors 2-2. Launch and operation of Earth observation satellite 2-3. Development of observation technology of marine and polar 2-4. Predictive model/simulation of the global environment 2-5. Prediction of the amount of power generated by renewable energy 2-6. Global environmental information platform	3-1. Robot/sensors 3-2. Inspection technology of non-destructive inspection, etc. 3-3. Evaluation technology (soundness evaluation, remaining life cycle prediction, etc.) 3-4. Repair and reinforcement technology 3-5. Long life material 3-6. Communication technologies to collect and transmit the measurement data with high reliability and ultra low power consumption 3-7. Data utilization technology (removal of misdetect, efficient accumulation of data, classification and analysis of similar pattern) 3-8. Asset management system (optimization of maintenance management plan that takes into account the characteristics of the target infrastructure)	4-1. Earthquake-proof countermeasure of the structure 4-2. Countermeasure of the disaster and accident of the important facilities, fire-fighting technology 4-3. Details observation technology and early prediction techniques (for earthquakes, tsunamis, heavy rain, tornadoes, volcanic, etc) 4-4. New type weather radar 4-5. Earth observation satellite 4-6. Synthetic Aperture Radar 4-7. Robot for disaster countermeasure 4-8. Technology to collect/use/retrieve/process/distribute information related to the disaster in real time 4-9. Disaster prediction/simulation 4-10. Real-time damage estimation techniques 4-11. Decision support system by real-time sharing of disaster-related information
R1-5	Chipless RFID	**0/11 (0%)**	✓	✓	✓	✓
R1-4	Passive tag and improvements of backscattering communication	**0/11 (0%)**	✓	✓	✓	✓
R4-6	Data stream processing (data cleaning, supporting big volume data, handing new types of queries, event processing, data interpretation and compression, etc.)	7/11 (64%)	Big data analysis@1-8	✓	Data utilization technology @3-7	Real time@4-8, 4-10, 4-11
R3-7	Distance bounding protocols to prevent relay attacks	5/11 (45%)	Security@1-9	✓	High reliability@3-6	✓
R3-2	Authentication protocol for security and privacy	5/11 (45%)	Security@1-9	✓	High reliability@3-6	✓
R4-5	Separation and grouping of RFID signals (anti-collision algorithm, antenna array solution, etc.)	5/11 (45%)	✓	✓	High reliability@3-6	Detail observation@4-3
N5	Relay attack and security	5/11 (45%)	Security@1-9	✓	High reliability@3-6	✓

N10	Integration or comparison with conventional technologies (RFID, Blootooth, barcodes, etc.) for touching interaction	4/4 (100%)			Communication technology to collect data @ 3-6	
S1-8	Radio tomography for device free localization	3/5 (60%)			✓	
S2-4-9	Detecting and preventing intrusions in wireless sensor networks	5/11 (45%)	Security@1-9	✓	High reliability@3-6	✓
S1-4-9	Speech enhancement with wireless acoustic sensor networks	0/4 (0%)				
S5-17	Underground/ water sensor networks	0/6 (0%)	✓	✓	✓	✓
S2-9	Cognitive radio sensor networks	**0/11 (0%)**	✓	✓	✓	✓
S1-4-5	Distributed particle filtering	3/5 (60%)			✓	
S2-4-6	Two-factor user authentication	5/11 (45%)	Security@1-9	✓	High reliability@3-6	✓
S2-3-7	Handover mechanism and mobility support	7/11 (64%)	Big data analysis@1-8	✓	Data utilization technology @3-7	Real time@4-8, 4-10, 4-11
S4-2-10	Efficient massive processing method (top-k query, skyline query, skeleton extraction, etc.)	7/11 (64%)	Big data analysis@1-8	✓	Data utilization technology @3-7	Real time@4-8, 4-10, 4-11
I5	Security for IoT	5/11 (45%)	Security@1-9	✓	High reliability@3-6	✓
I12	Integratin of Wireless Sensor Networks and IoT (Collaborative WSN, IP-based WSN, minimum hops constraint, etc.)	1/11 (9%)	✓	✓	✓	✓

The 11 systems	System 5	System 6	System 7	System 8	System 9	System 10	System 11
	Intelligent transportation systems	New manufacturing systems	Integrated material development systems	Promoting integrated community care systems	Hospitality systems	Smart food chain systems	Smart production systems
The 11 systems' enabling technologies	5-1. Communication system (communication protocol, vehicle-to-vehicle communication, communication interface, modeling of the load, security) 5-2. Map	6-1. Technology for investigating potential needs, high precision and high-speed simulation, the optimum design 6-2.	7-1. Measurement and evaluation 7-2. High-speed, high-efficiency material prototype 7-3. Big data analysis	8-1. Independence behavior support technology and autonomous mobility (wheelchair, robot care equipment)	9-1. Ultra-realistic communication by the three-dimensional image, etc. 9-2. Device that enables innovative video display	10-1. Technology for improving storable duration, processing and distribution 10-2. Development of long storable	11-1. Weeding robotic 11-2. Assist suit (high capacity battery, lighter suit) 11-3. Water management automation 11-4. High precision ploughing and irrigating the fields/

		information sophistication (dynamic map) 5-3. Human Machine Interface 5-4. Traffic data utilization 5-5. Autonomous driving system 5-6. Small autonomous driving system for local community 5-7. Next-generation urban transportation system (Advanced Rapid Transit) 5-8. Accident reduction simulation system	Measurement technology of brain activity 6-3. Human - robot coordination line 6-4. IoT· Big data analysis 6-5. AI 6-6. Conversion of tacit techniques of artisan into explicit knowledge 6-7. Platform construction of the supply chain system	7-4. Big data mining 7-5. Materials database 7-6. Material characteristics and performance prediction 7-7. Material development meets the demands 7-8. Integrated material development system (Materials Integration System)	8-2. Sensing 8-3. Indoor and outdoor positioning 8-4. Three-dimensional map 8-5. Ultra high-speed/safe/stable innovative network infrastructure technology 8-6. Next-generation analysis technology 8-7. Construction of next-generation medical ICT infrastructure	9-3. AI 9-4. Big data analysis 9-5. IoT real-time sensing 9-6. Information cybersecurity (encryption, anonymity, authentication, etc) 9-7. Enhancement of the corpus 9-8. Shooting/compression/recording, transmission/display of multi-view video 9-9. Platform that centralizes data collection and utilization	duration breeds 10-3.Development and dissemination and cultivation of new varieties 10-4.Next-generation functional elements 10-5. Production meets the demands 10-6.Sensing technology (image analysis, etc.) by the sensor of the satellite 10-7. Closed/solar-type plant factory, breeding & nursery system 10-8. High-value-added products production and supply system (next generation facility horticulture) 10-9. Providing information platform (traceability system, ensuring the safety and reliability of food)	seeding/fertilization based on sensing information 11-5. Field map (collected by the sensor) 11-6. Data mining 11-7.Conversion of tacit techniques of artisan into explicit knowledge 11-8. Automatic travel system with a high precision GPS (nighttime operation of agricultural machinery, multiple operation, automatic operation) 11-9. Management and decision making support system
R1-5	Chipless RFID	✓	✓	✓	✓	✓	✓	✓
R1-4	Passive tag and improvements of backscattering communication	✓	✓	✓	✓	✓	✓	✓
R4-6	Data stream processing (data cleaning, supporting big volume data, handing new types of queries, event processing, data interpretation and compression, etc.)	✓	Big data analysis@6-4	Big data analysis@7-3, 7-4	✓	Big data analysis@9-4 Real time@9-5	✓	Big data analysis@11-6
R3-7	Distance bounding protocols to prevent relay attacks	Security@5-1	✓	✓	Safe network@8-5	Cybersecurity@9-6	✓	✓
R3-2	Authentication protocol for security and privacy	Security@5-1	✓	✓	Safe network@8-5	Cybersecurity@9-6	✓	✓
R4-5			✓	✓		✓	✓	

	Separation and grouping of RFID signals (anti-collision algorithm, antenna array solution, etc.)	Communication protocol @5-1			Positioning@8-3			Human tracking and extract tacit techniques@11-7
N5	Relay attack and security	Security@5-1	✓	✓	Safe network@8-5	Cybersecurity@9-6	✓	✓
N10	Integration or comparison with conventional technologies (RFID, Blootooth, barcodes, etc.) for touching interaction				Positioning@8-3	Enhancement of corpus@9-7		Human tracking and extract tacit techniques@11-7
S1-8	Radio tomography for device free localization	✓	Human tracking and extract tacit techniques@6-6		Positioning@8-3			Human tracking and extract tacit techniques@11-7
S2-4-9	Detecting and preventing intrusions in wireless sensor networks	Security@5-1	✓	✓	Safe network@8-5	Cybersecurity@9-6	✓	✓
S1-4-9	Speech enhancement with wireless acoustic sensor networks		✓		✓	✓		✓
S5-17	Underground/water sensor networks	✓						✓
S2-9	Cognitive radio sensor networks	✓	✓	✓	✓	✓	✓	✓
S1-4-5	Distributed particle filtering	✓	Human tracking and extract tacit techniques@6-6		Positioning@8-3			Human tracking and extract tacit techniques@11-7
S2-4-6	Two-factor user authentication	Security@5-1	✓	✓	Safe network@8-5	Cybersecurity@9-6	✓	✓
S2-3-7	Handover mechanism and mobility support	✓	Big data analysis@6-4	Big data analysis@7-3, 7-4	✓	Big data analysis@9-4 Real time@9-5	✓	Big data analysis@11-6
S4-2-10	Efficient massive processing method (top-k query, skyline query, skeleton extraction, etc.)	✓	Big data analysis@6-4	Big data analysis@7-3, 7-4	✓	Big data analysis@9-4 Real time@9-5	✓	Big data analysis@11-6
I5	Security for IoT	Security@5-1	✓	✓	Safe network@8-5	Cybersecurity@9-6	✓	✓
I12	Integratin of Wireless Sensor Networks and IoT (Collaborative WSN, IP-based WSN, minimum hops constraint, etc.)	Communication protocol @5-1	✓	✓	✓	✓	✓	✓

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