Trends and Typology of Emerging Antenna Propagation Technologies Identified by Citation Network Analysis

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***Abstract*—Detection of emerging technologies is vital for R&D managers and policy makers, and bibliometric approach analyzing papers and patents has been developed. In this research, we propose Research Classification Schema (RCS), which uses citation network analysis to classify technologies into four categories: Change-Maker, Breakthrough, Matured and Incremental. Each technology is plotted on RCS based on its publication profile. A case study in the field of antenna was conducted to evaluate relevance and to evaluate effectiveness of RCS. The method can contribute to the usefulness of identification process of promising technologies, and therefore, to the convenience of target designing of research projects in universities and companies. We also discuss effect of resolution limit of clustering algorithm on RCS to improve reliability.**

I. INTRODUCTION

It is important for R&D managers and policy makers to consider latest trends of research in the world, which are rapidly causing developments and paradigm shifts in establishing and planning R&D programs and projects. Historically, academic papers and patents are used to detect emerging research front for technological forecasting [1–3] and technology roadmapping [4]–[6]. There have been two approaches to detect emerging technologies [7]. First is detection by expert who knows the research domain such as the Delphi method, but it is becoming difficult to grasp these trends comprehensively because enormous amount of papers and patents are being published.

The other approach utilizes computers in order to solve this problem, and has been an active research field. This approach aims to grasp R&D trends with help of large data processing techniques such as text mining [8–13] and link mining [14–23]. There is especially a focus on detecting actively and quickly developing fields (emerging research fronts), which have papers of a new average publication year. Some proposed methods of this approach [11, 24–26] take advantage of clustering of citation networks and text co-occurrence networks to identify emerging research fronts. Average publication year of the papers and patent information in those networks are also used in these methods in order to evaluate the level of activeness of research fields. Finally, groups of research fields are connected by citation relationship and visualized as Academic Landscape (AL) [27].

However, there are risks to miss extraction of important clusters or group of papers when we focus only on the average publication year since number of papers in some areas is not increasing or decreasing monotonously. For instance, there are clusters whose average publication years are old but the clusters have new papers which contain progressive and innovative result. Therefore, there is a strong need for tools to extract important clusters even if research trends are complicated. Such technologies will help R&D managers to grasp research trends briefly. They will also help researchers to understand their research position in the academic field, and to understand emerging technologies which they do not know about.

Existing paper search engines such as “Google scholar” or “Web of Science” help us to find important papers which are cited by many papers. However, sometimes it is difficult for researchers to find such papers, especially for those who have to study new fields where they are not familiar with. It is also hard to know the background and context of papers in those fields because it takes a lot of time and costs to understand the situation.

The objectives of this study is to propose new method called Research Classification Schema (RCS) to extract important specific research fields of antenna even if research trends are complicated. RCS classifies groups of technologies into four categories: Change-Maker, Breakthrough, Matured and Incremental. Citation network analysis is used to classify technologies, then each technology is plotted in RCS based on publication profiles of papers. It helps us to detect research fields with high possibility of epoch-making findings.

A case study in the field of antenna was conducted to evaluate the relevance and effectiveness of RCS. We selected the research field of antenna and its propagation as the target of the case study because its research achievements have a long history and many applications such as radar, radio, TV, mobile phone, and smartphone. At the same time, its research trends and R&D needs are changing rapidly. For example, antenna is used for latest technologies such as M2M [28] and IoT [29]. The LTE [30] antenna made of metamaterial [31] for smartphones has also been a popular research field.

II. METHODOLOGY

Proposed methodology is composed of the five steps as shown in Fig. 1.

A. Data collection and creating citation networks and Identifying Base-Clusters

69,965 papers including the keyword of “antenna” are retrieved and their bibliographic records were obtained from Science Citation Index by using Web of Science. Papers are connected by citations among them (step1 in Fig. 2) and divided into groups by clustering of the citation network using Newman-Girvan method [31–32] (step2 in Fig. 2).

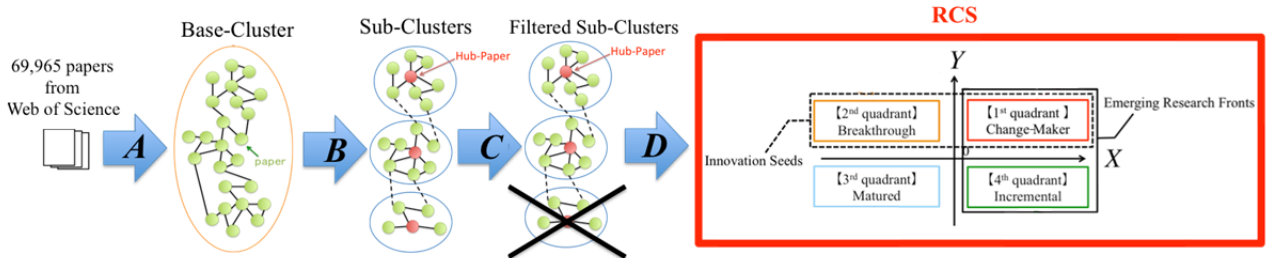

Figure 1 Methodology proposed in this paper

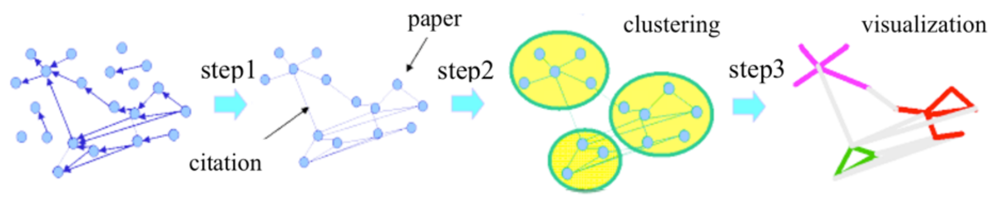

Figure 2 Steps of clustering and making AL

Those groups of papers are mapped into an AL, which helps visualize the relationship of antenna technologies (step3 in Fig. 2).

B. Creating Sub-Clusters from the Base-Cluster

Sub-Clusters are obtained by recursive clustering of the Base-Cluster (Fig. 3). Although mapping of Base-Clusters assists researchers to comprehend an entire structure and trend of a research field, it is more effective to obtain specific clusters or group of paper. For example, we found a Sub-Cluster of antenna using new material called metamaterial [31], artificial material which has a different behavior from natural substances against electromagnetic waves including light. In an interview with a researcher in this field, it was clear that the particular technology was attracting a considerable amount of attention from researchers in the entire antenna field. Hence, we set the field of metamaterial as the target of this study and tried to obtain specific research fields such as “antenna for SAR (effect of electro-magnetic exposition for a unit time on a unit volume of biological tissue) [34] reduction” in metamaterial field.

C. Filtering of Sub-Clusters for improved reliability

As noted above, the larger times clustering is executed, the more specific Sub-Clusters can be obtained and plotted on RCS. This means that the maximum modularity Q (MAXQ) [32][35] becomes small, while the density of Hub-Paper (dmax/size) becomes large (Fig. 4).

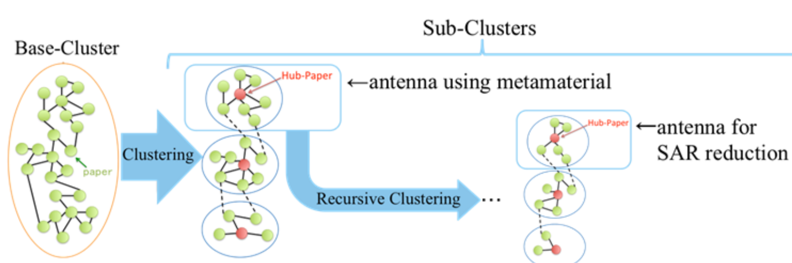

Figure 3 Obtaining Sub-Clusters from Base-Cluster

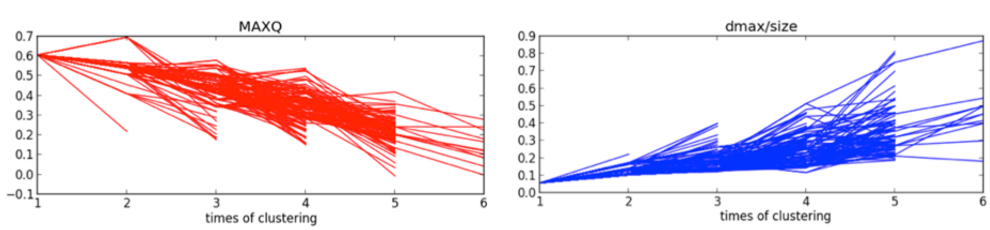

Figure 4 MAXQ and dmax/size according to times of clustering

The resolution limit of modularity gives the maximum times of clustering to Sub-Clusters [36]. The limit does not depend on particular network structures, and results only from the comparison between the number of links of interconnected communities and the total number of links of the network. The modules cannot be further resolved if the following (1) is satisfied.

$$l_S - \sqrt{2L} < 0 \tag{1}$$

where l_S and L are the number of links after and before clustering, respectively. We stop recursive clustering in such condition.

D. Plotting of the Sub-Clusters into RCS, and evaluation

To distinguish the above types of clusters, we propose the following two measures:

First, X is the novelty of Sub-Cluster *i* defined by the difference between the average publication year of the Sub-Cluster *i* and the Base-Cluster where the Sub-Cluster belonged. It is shown in (2) as follows:

$$X = x_{Sub_i} - x_{Base} \tag{2}$$

where x_{Sub_i} and x_{Base} are the average publication year of Sub-Cluster *i* and of Base-Cluster, respectively.

Second, Y is the novelty of Hub-Paper *i* defined by the difference between the publication year of the Hub-Paper *i* in the Sub-Cluster *i*, and the average year of all the papers in the Sub-Cluster *i* which the Hub-Paper belongs to. It is shown in (3) as follows:

$$Y = y_{Hub_i} - y_{Sub_i} \tag{3}$$

where y_{Hub_i} and y_{Sub_i} are the publication year of Hub-Paper *i* and the average publication year of Sub-Cluster *i*, respectively.

Sub-Clusters are plotted in accordance with the two measures, Sub-Clusters are plotted into quadrants named Change-Maker, Breakthrough, Matured and Incremental as follows:

- 1st: Change-Maker ($X > 0$, $Y > 0$)

  Average publication year of its Sub-Clusters is newer than the Base-Cluster, which means academic fields represented by the Sub-Clusters are growing. Meanwhile, the publication year of Hub-Papers is newer than the Sub-Cluster averages, which means the researches refer to forefront paper.
- 2nd: Breakthrough ($X < 0$, $Y > 0$)

  Average publication year of its Sub-Clusters is older than the Base-Cluster, which means academic fields represented by the Sub-Clusters are declining. Meanwhile, the publication year of Hub-Papers is newer than the Sub-Cluster averages, which means the researches refer to forefront paper.
- 3rd: Matured ($X < 0$, $Y < 0$)

  Average publication year of its Sub-Clusters is older than the Base-Cluster, which means academic fields represented by the Sub-Clusters are declining. Meanwhile, the publication year of Hub-Papers is older than the Sub-Cluster averages, which means the researches refer to existing paper.
- 4th: Incremental ($X > 0$, $Y < 0$)

  Average publication year of its Sub-Clusters is newer than the Base-Cluster, which means academic fields represented by the Sub-Clusters are growing. Meanwhile, the publication year of Hub-Papers is older than the Sub-Cluster averages, which means the researches refer to existing paper.

As a result, Sub-Clusters are classified and plotted on RCS. The structure of RCS is shown in Fig. 5. Here Emerging Research Fronts consists of Change-Maker plus Incremental, and are defined as Sub-Clusters which have a recent average publication year (X>0). Innovation Seeds consists of Change-Maker plus Breakthrough, and are defined as Sub-Clusters which has a recently published Hub-Papers (Y>0). Although Emerging Research Fronts are not new concept, but in this paper, we integrate it with the newly introduced concept, Innovation Seeds, to grasp better overview of research fields.

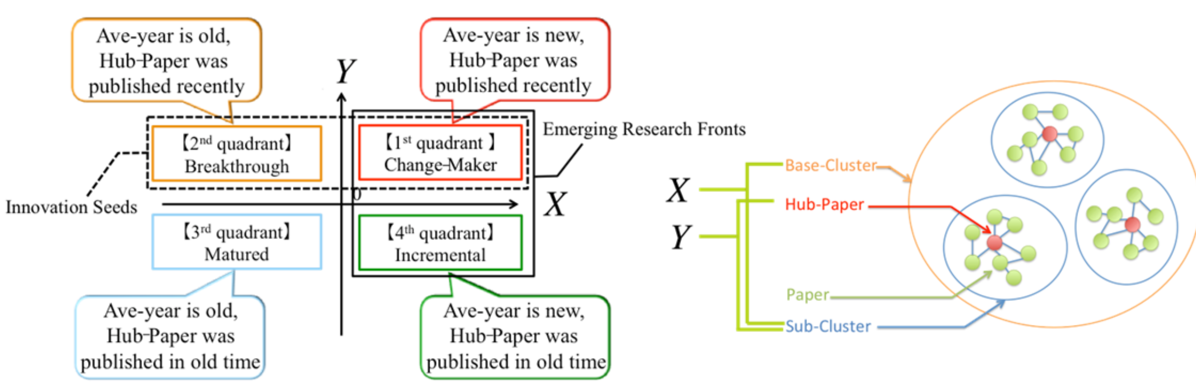

Figure 5 Structure of RCS and relation between Base-Cluster, Sub-Cluster, and Hub-Paper

As already noted, the average publication year of papers in Sub-Clusters has been used as a simple indicator to detect emerging research fronts [23]. However, this approach has a limitation in detecting important clusters.

Here, the limitation of the conventional approach and the advantages of RCS will be described. Fig. 6 illustrates the relationship between two categories of Sub-Clusters whose average publication year is newer than that of the Base-Cluster: Change-Maker and Incremental. Areas of those Sub-Clusters are actively researched. The difference between Sub-Clusters of Change-Maker and Incremental is the novelty of their Hub-Paper. A research domain in the Change-Maker quadrant means that the domain is active as a research target, and its most popular research is also relatively new. This domain's researches produce continuous progress and have high possibility of epoch-making findings. A research domain in the Incremental quadrant means that the domain is active as a research target, but its most popular research is also relatively old. This domain's researches produce continuous progress but have low possibility of epoch-making findings. In this way, RCS can add detailed information to Emerging Research Fronts, which is obtained from average publication years.

Fig. 7 illustrates the relationship between two categories of Sub-Clusters whose average publication year is older than that of the Base-Cluster: Breakthrough and Matured. Areas of those Sub-Clusters are inactively researched. The difference between Sub-Clusters of Breakthrough and Matured is the novelty of their Hub-Paper. A research domain in the Breakthrough quadrant means that the domain is inactive as a research target, but its most popular research is relatively new. This domain's researches produce slow progress but have high possibility of epoch-making findings. A research domain in the Matured quadrant means that the domain is inactive as a research target, and its most popular research is also relatively old. This domain's researches produce slow progress and have low possibility of epoch-making findings. In this way, RCS can detect Breakthrough, which is neglected in cluster characterization based only on the average publication year.

RCS supports to find Innovation Seeds (Change-Maker plus Breakthrough) which are becoming more important nowadays. Especially, Breakthrough quadrant was not paid attention in the previous approach which extracts emerging cluster by focusing on the average publication year.

The number of papers in each Sub-Cluster is then represented as bubble charts, and Sub-Clusters are plotted at the barycenters. Note that when the size of Sub-Cluster is small, there is a case that we can find some Hub-Paper receiving the same number of citations in the same cluster. For instance, Fig. 8 shows that there are two Hub-Papers whose Degree are both five. In such case, each Hub-Papers are plotted at the baycenters.

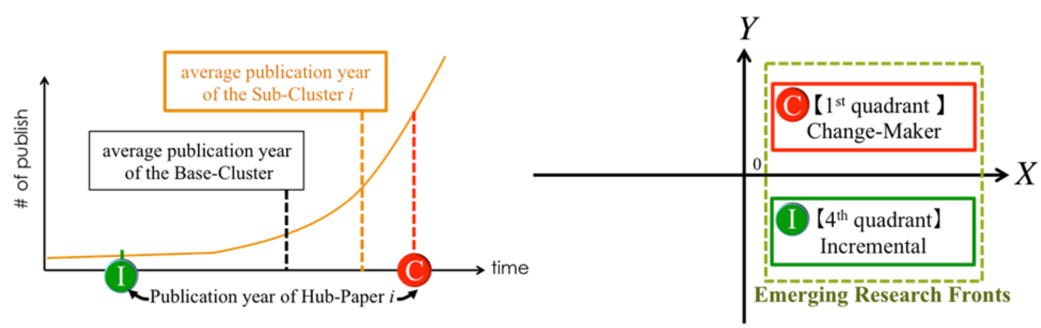

Figure 6 Overview of Sub-Cluster in growing research field and Comparison between conventional Emerging Research Fronts with quadrants of RCS

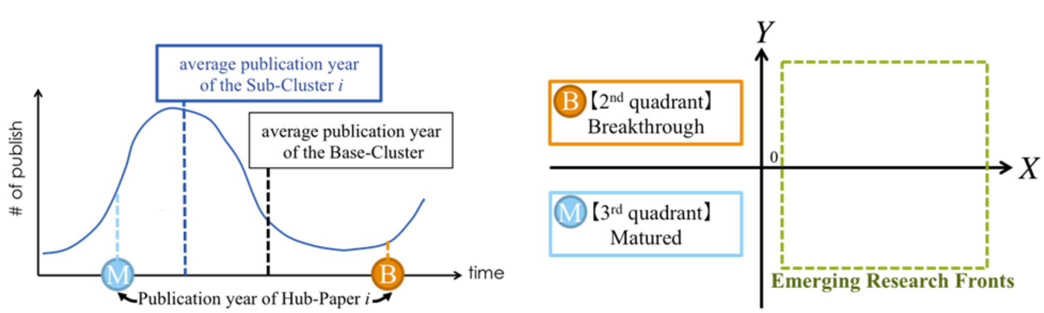

Figure 7 Overview of Sub-Cluster in declining research field and Comparison between conventional Emerging Research Fronts with quadrants of RCS

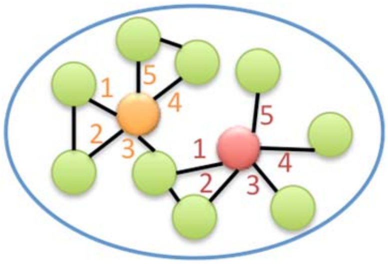

Figure 8 Hub-Papers in single Sub-Cluster.

III. RESULTS

Academic Landscape was obtained and its Base-Cluster consisted of 3877 papers of antenna new material called metamaterial is depicted in Fig. 9. Here, c1_c3 is the cluster number, and the numbering of c1_c3 means that it is third biggest Sub-Cluster obtained by clustering its Base-Cluster c1. All the clusters are numbered in this way.

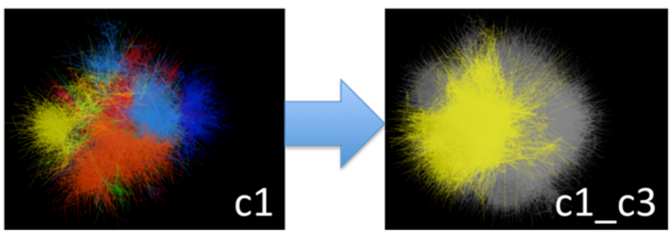

Figure 9 Base-Cluster of metamaterial.

In Fig. 10, Sub-Clusters plotted on RCS are differently colored according to their times of clustering. The larger times clustering is carried out, the larger number of Sub-Clusters are classified as Change-Maker and Breakthrough.

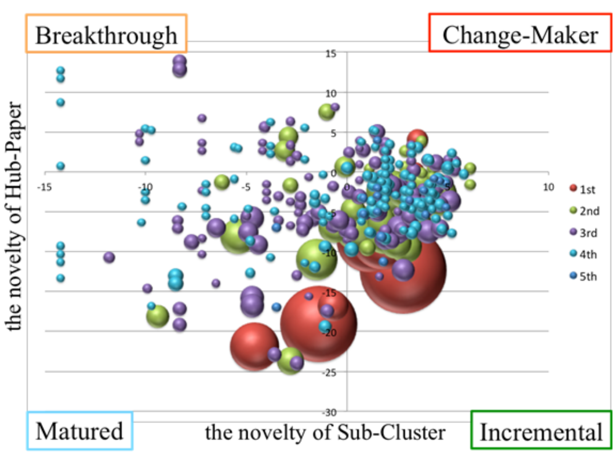

Figure 10 Sub-Clusters according to times of clustering.

We conducted an interview to an expert in the research domain without letting know the result of RCS, and asked which technologies were growing. The expert thought Specific Absorption Rate (SAR) reduction, antenna miniaturization, beam control, and Frequency Selective Surfaces (FSS) were growing and worth focusing on in the metamaterial filed. Fig.11 shows the Sub-Clusters identified by the expert as important research topic. It spans Change-Maker, Breakthrough, Matured and Incremental domain. According to the result, the expert paid attention on relatively large Sub-Clusters. There are special reasons for his focusing on the smaller Sub-Clusters. He knew the information through news website, the research field was his supervisor's research partner's, and some of the Sub-Clusters were his own research topics.

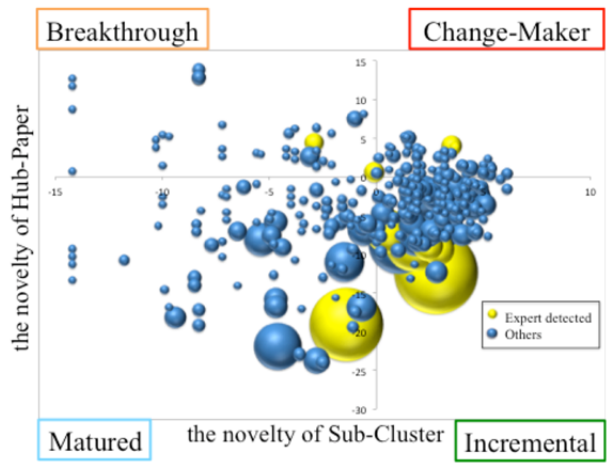

Figure11 Comparison of the Sub-Clusters obtained by RCS and detected by the expert.

Then, we made another interview to evaluate effectiveness and reliability of RCS. Several Sub-Clusters were selected for the interview as shown in Fig. 12. The novelty of Sub-Clusters (x-coordinate) is evaluated with titles of the ten most-cited papers in relation with their Base-Cluster. The novelty of Hub-Papers (y-coordinate) is evaluated with the content in relation with their Sub-Clusters at large. Here, (B-2) and (M-2) were not used for the interview since (B-2) is a Sub-Cluster cited by his research group and (M-2) overlaps with (B-2). Hence, four characteristic Sub-Clusters, (M-1), (I-1), (B-1), (C-1) are used for evaluating RCS.

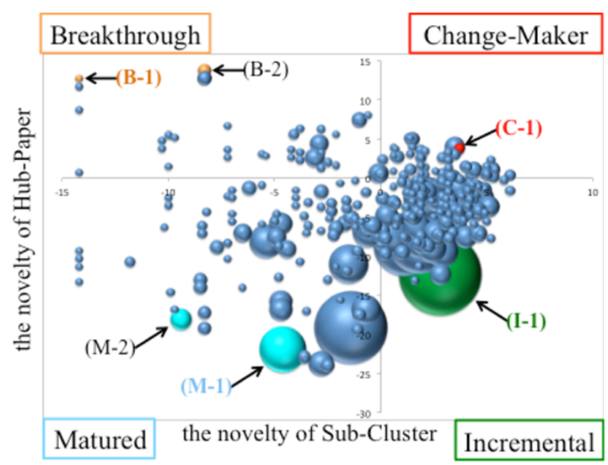

Figure 12 Extraction of Characteristic Sub-Clusters

- **Evaluation of (M-1)**
  The list of title of top-10 most cited papers in (M-1) is shown in Table 1. The Sub-Cluster number is c1_c3_c5_c1.

Judging from the list, this Sub-Cluster shows the field of microstrip antenna. Technologies of microstrip antenna have long history, and thus this Sub-Cluster has old technologies compared to Base-Cluster.

According to Hub-Paper [37], "The radiation characteristics of the first higher order mode of microstrip lines are investigated. As a result, a simple traveling wave antenna element is described, having a larger bandwidth compared with resonator antennas. A method to excite the first higher order mode is shown. A single antenna element is treated theoretically and experimentally, and an array of four antenna elements is demonstrated." This is one of the fundamental papers in microstrip antenna technologies. Given that, it is possible to say that (M-1) is located in right domain of Matured, since the Sub-Cluster is old and the result of the Hub-Paper is also old.

- **Evaluation of (I-1)**
  The list of title of top-10 most cited papers in (I-1) is shown in Table 2. The Sub-Cluster number is c1_c3_c1.

Judging from the list, this Sub-Cluster shows the field of Q factor (mechanical friction of resonator). Studies of controlling Q to realize wide band antenna are famous, and the applications of metamaterial for antenna are popular among researchers. Hence, this Sub-Cluster has relatively new technologies compared to Base-Cluster.
According to Hub-Paper [38], "An exact method, which is more straightforward than those previously published, is derived for the calculation of the minimum radiation Q of a general antenna. This expression agrees with the previously published and widely cited approximate expression in the extreme lower limit of electrical size. However, for the upper end of the range of electrical size which is considered electrically small, the exact expression given here is

TABLE 1 TOP-10 MOST CITED PAPERS IN (M-1)

	Title and Information of Papers (The first paper in the list is the Hub-Paper of the Sub-Cluster)
1	**NEW TRAVELING-WAVE ANTENNA IN MICROSTRIP** MENZEL, W, *AEU-INT J ELECTRON C*, V33, P137 (1979)
2	**Analysis and design of feeding structures for microstrip leaky wave antenna** Lin, YD et al, *IEEE T MICROW THEORY*, V44, P1540 (1996)
3	**Leakage From Higher Modes on Microstrip Line with Application to Antennas** OLINER, AA, *RADIO SCI*, V22, P907 (1987)
4	**Mode distinction and radiation-efficiency analysis of planar leaky-wave line source** Lin, YD et al, *IEEE T MICROW THEORY*, V45, P1672 (1997)
5	**Simple design of dual-beam leaky-wave antennas in microstrips** Luxey, C et al, *IEE P-MICROW ANTEN P*, V144, P397 (1997)
6	**A fixed-frequency beam-scanning microstrip leaky wave antenna array** Li, YX et al, *IEEE ANTENN WIREL PR*, V6, P616 (2007)
7	**Fixed-frequency dual-beam scanning microstrip leaky wave antenna** Li, YX et al, *IEEE ANTENN WIREL PR*, V6, P444 (2007)
8	**A novel two-beam scanning active leaky-wave antenna** Wang, CJ et al, *IEEE T ANTENN PROPAG*, V47, P1314 (1999)
9	**An aperture-coupled linear microstrip leaky-wave antenna array with two-dimensional dual-beam scanning capability** Hu, CC et al, *IEEE T ANTENN PROPAG*, V48, P909 (2000)
10	**Dual-beam array of microstrip leaky-wave antennas** Luxey, C et al, *ELECTRON LETT*, V34, P1041 (1998)

TABLE 2 TOP-10 MOST CITED PAPERS IN (I-1)

	Title and Information of Papers (The first paper in the list is the Hub-Paper of the Sub-Cluster)
1	**A re-examination of the fundamental limits on the radiation Q of electrically small antennas** McLean, JS, *IEEE T ANTENN PROPAG*, V44, P672 (1996)
2	**Impedance, bandwidth, and Q of antennas** Yaghjian, AD et al, *IEEE T ANTENN PROPAG*, V53, P1298 (2005)
3	**A metamaterial for directive emission** Enoch, S et al, *PHYS REV LETT*, V89 (2002)
4	**Infinite wavelength resonant antennas with monopolar radiation pattern based on periodic structures** Lai, A et al, *IEEE T ANTENN PROPAG*, V55, P868 (2007)
5	**Composite right/left-handed transmission line metamaterials** Lai, A et al, *IEEE MICROW MAG*, V5, P34 (2004)
6	**The radiation properties of electrically small folded spherical helix antennas** Best, SR, *IEEE T ANTENN PROPAG*, V52, P953 (2004)
7	**Metamaterial-based efficient electrically small antennas** Ziolkowski, RW et al, *IEEE T ANTENN PROPAG*, V54, P2113 (2006)
8	**New radiation Q limits for spherical wire antennas** Thal, HL, *IEEE T ANTENN PROPAG*, V54, P2757 (2006)
9	**Low Q electrically small linear and elliptical polarized spherical dipole antennas** Best, SR, *IEEE T ANTENN PROPAG*, V53, P1047 (2005)
10	**Dominant mode leaky-wave antenna with backfire-to-endfire scanning capability** Liu, L et al, *ELECTRON LETT*, V38, P1414 (2002)

significantly different from the approximate expression. This result has implications on both the bandwidth and efficiency limitations of antennas which fall into this category." This paper is famous paper for researchers in the field and the result is conventional compared to that of nowadays. Given that, it is possible to say that (I-1) is located in right domain of Incremental, since the Sub-Cluster is new but the result of the Hub-Paper is old.

- **Evaluation of (B-1)**
  The list of title of top-10 most cited papers in (B-1) is shown in Table 3. The Sub-Cluster number is c1_c3_c5_c2_c1_c1, and it means this Sub-Cluster was obtained after clustering (M-1) recursively.

Judging from the list, this Sub-Cluster shows the field of microstrip antenna, as same as (M-1). Leaky wave antenna is based on microstrip antenna. The research field has long history, and thus this Sub-Cluster has old technologies compared to Base-Cluster.

According to Hub-Paper [39], "This change in the conductivity of the silicon semiconductor produces a change in the effective width of the microstrip line, thus producing a phase shift in a high-frequency signal propagating in the line." This means the paper tried to propose new application. The proposed structure enables to control the conductivity and thus it is possible to control wavelength in waveguide. The result is new compared to the conventional works [37] even the basic technology is related old research field. Given that, it is possible to say that (B-1) is located in right domain of Breakthrough, since the Sub-Cluster is old but the result of the paper is new.

An interview with expert to evaluate this Sub-Cluster and the Hub-Paper was conducted. He knew about this research field and author via technical book, but didn't know about the author, institution, and the paper. Given that, it was new information for him since researchers including him had not been focusing on this field recently. He regarded the paper as Breakthrough, which was the same as the classification by RCS. He recognized information of the paper is useful, and regarded the achievement of the paper as progressive. He thought the result of this paper is niche and can be useful for feed antenna for beam direction control of array antenna.

- **Evaluation of (C-1)**
  The list of title of top-10 most cited papers in (C-1) is shown in Table 4 as Appendix. The Sub-Cluster number is c1_c3_c7_c1.

TABLE 3 TOP-10 MOST CITED PAPERS IN (B-1)

	Title and Information of Papers (The first paper in the list is the Hub-Paper of the Sub-Cluster)
1	**An electronically controlled transmission-line phase shifter** Shin, CS et al, *MICROW OPT TECHN LET*, V40, P402 (2004)
2	**A novel millimeter-wave beam-steering technique using a dielectric-image line-fed grating film** Rodenbeck, CT et al, *IEEE T ANTENN PROPAG*, V51, P2203 (2003)
3	**An electronically switchable leaky wave antenna** Huang, LM et al, *IEEE T ANTENN PROPAG*, V48, P1769 (2000)
4	**Integrated Image-Line Steerable Active Antennas** KIRK, AM et al, *INT J INFRARED MILLI*, V13, P841 (1992)
5	**Single-Frequency Electronic-Modulated Analog Line Scanning Using a Dielectric Antenna** HORN, RE et al, *IEEE T MICROW THEORY*, V30, P816 (1982)
6	**HORN IMAGE-GUIDE LEAKY-WAVE ANTENNA** TRINH, TN et al, *IEEE T MICROW THEORY*, V29, P1310 (1981)
7	**Electronic Modulated Beam-Steerable Silicon Wave-Guide Array Antenna** HORN, RE et al, *IEEE T MICROW THEORY*, V28, P647 (1980)
8	**Simulation Study of Electronically Scannable Antennas and Tunable Fiters Integrated in a Quasi-Planar Dielectric Waveguide** ITOH, T et al, *IEEE T MICROW THEORY*, V26, P987 (1978)
9	**A Survey of Millimeter-Wavelength Planar Antenna-Arrays for Military Applications** HENDERSON, A et al, *J I ELECTRON RAD ENG*, V52, P543 (1982)
10	**Leaky-wave antenna based on micro-electromechanical systems-loaded microstrip line** Zvolensky, T et al, *IET MICROW ANTENNA P*, V5, P357 (2011)

TABLE 4 TOP-10 MOST CITED PAPERS IN (C-1)

	Title and Information of Papers (The first paper in the list is the Hub-Paper of the Sub-Cluster)
1	**A New Design of Metamaterials for SAR Reduction** Faruque, MRI et al, *MEAS SCI REV*, V13, P70 (2013)
2	**Folded-loop antenna with a reflector for mobile handsets at 2.0 Ghz** Hirata, A et al, *MICROW OPT TECHN LET*, V40, P272 (2004)
3	**DESIGN ANALYSIS OF FERRITE SHEET ATTACHMENT FOR SAR REDUCTION IN HUMAN HEAD** Islam, MT et al, *PROG ELECTROMAGN RES*, V98, P191 (2009)
4	**A New Design of Split Ring Resonators for Electromagnetic (EM) absorption Reduction in Human Head** Faruque, MRI et al, *INFORM MIDEM*, V42, P18 (2012)
5	**EFFECT OF HUMAN HEAD SHAPES FOR MOBILE PHONE EXPOSURE ON ELECTROMAGNETIC ABSORPTION** Faruque, MRI et al, *INFORM MIDEM*, V40, P232 (2010)
6	**Reduction of the peak SAR in the human head with metamaterials** Hwang, JN et al, *IEEE T ANTENN PROPAG*, V54, P3763 (2006)
7	**Effects of Phase Difference in Dipole Phased-Array Antenna Above EBG Substrates on SAR** Chan, KH et al, *IEEE ANTENN WIREL PR*, V12, P579 (2013)
8	**Dipole Antenna Above EBG Substrate for Local SAR Reduction** Ikeuchi, R et al, *IEEE ANTENN WIREL PR*, V10, P904 (2011)
9	**Evaluation of Specific Absorption Rate (SAR) Reduction for PIFA antenna Using Metamaterials** Faruque, MRI et al, *FREQUENZ*, V64, P144 (2010)
10	**Effects of using conductive materials for SAR reduction in mobile phones** Chan, KH et al, *MICROW OPT TECHN LET*, V44, P140 (2005)

TABLE 5 SUMMARY OF THE ASSESSMENT BY EXPERT

	Characteristic Sub-Cluster	(C-1)	(B-1)	(M-1)	(I-1)
Q1	Have you focused on the research field? [Y/N]	Y	N	N	Y
Q2	Do you know the paper? [Y/N]	N	N	N	N
Q3	Do you think the information is useful for you? [Y/N]	Y	Y	N	N

Judging from the list, this Sub-Cluster shows the field of technologies for specific absorption rate (SAR) reduction. The research field is popular because of the spread of mobile phone use and thus this Sub-Cluster has new technologies compared to Base-Cluster.

According to Hub-Paper [34], "These results put forward a guideline to select various types of metamaterials with the maximum SAR reducing effect for a cellular phone." It shows that new design was proposed. Conventional antenna in mobile phone has loop antenna of simple structure [40], but in the paper author proposed the design using metamaterial which has complicated structure which is able to achieve 53.06% reduction of the initial SAR value for the case of 10 gm. Given that, it is possible to say that (C-1) is located in right domain of Change-Maker, since the Sub-Cluster is new and the result of the paper is new.

An interview by expert about this Sub-Cluster and the Hub-Paper was conducted. He knew about this research field via online news, but didn't know about the author, institution, journal, and the paper. Given that, it was not new information for him since researchers including him had been focusing on this field recently. He regarded the paper as Change-Maker, which was the same as the classification by RCS. He recognized information of the paper is useful, but regarded the achievement of the paper is not progressive because the principle of SAR reduction is widely known among researchers in the field. He thought the result of this paper is versatile and can be useful for design for reduction of unwanted radiation from wireless terminals such as mobile phone, tablet computer, Wi-Fi router, etc.

The assessed results by the expert are summarized in Table 5. You can compare the results from Q1 and Q2, and recognize that RCS is even helpful for experts to identify the Hub-Paper in research areas which they have been paying attention to.

The contribution of RCS to the perception of research trends identified by the expert was classified into three aspects, Confirmation, Misunderstanding, and New Value, as summarized below (including Table 6):

◆ Confirmation

The role of RCS is to confirm the perception of the expert in an explicit manner. When researchers paid attention to the research field since they believe it is worth paying attention, they are able to have confident to keep going. When researchers did not pay attention to the research field since they believe it is not worth paying attention, they are able to have confident to keep the state.

◆ Misunderstanding

The role of RCS is to reorganize and update understanding of the expert not clear. When researchers paid attention to the research field since they believe it is worth paying attention, and they did not know the paper, they are able to get additive information from the paper.

◆ New Value

The role of RCS is to give technological alternative which is not known before by the expert. When researchers did not pay attention to the research field since they believe it is not worth paying, and they did not know the paper, they are able to get new information from the paper.

TABLE 6 CLASSIFICATION OF THE SUB-CLUSTERS

	Paid attention to the research field	Didn't paid attention to the research field
Useful info.	Confirmation **(C-1)**	New Value **(B-1)**
Not Useful info.	Misunderstanding **(I-1)**	Confirmation **(M-1)**

IV. DISCUSSION

Conventional paper search engines such as "Google scholar" or "Web of Science" help us to find important papers which are cited by many times. They also support to list the papers in the recent order. Our proposed method adds a new function so that we can find important papers and Hub-Papers, such as (B-1), in their early stage in addition to their contexts. According to the results, RCS can be a good recommendation tool for finding progressive research fields and Sub-Clusters. Some of extracted Sub-Clusters are difficult to identify even for experts. In summary, RCS can:

- Divide emerging research fronts into Change-Maker and Incremental domain, which were both regarded as newer than average publication year in the conventional method.
- Detect Breakthrough domain, which was not paid attention in the conventional method, but has possibility of progressive technologies.
- Allow R&D manager to use as a tool to narrow down Sub-Clusters which have high potential of innovation (Innovation Seeds), instead of focusing on all of the papers in the research field.
- Allow experts to grasp their own research position in RCS because it is possible to extract specific Sub-Clusters thanks to the recursive clustering.

Of course, researchers can find those Hub-Papers in conventional ways, but RCS can reduce the costs of the Innovation Seeds identification process (studying new fields which they are not familiar with, spending a long time to find important and progressive papers, etc.).

In this paper, we propose RCS and demonstrate its effectiveness. However, the evaluation is not enough. RCS is not perfect tool to classify technologies at this point. The limitation of current RCS is listed below:

- Some papers incorrectly classified in Breakthrough and Change-Maker because RCS does not treat qualitative information of papers, but only treat quantitative information such as publication year and maximum degree. (For instance citation within the laboratories occurs misclassification)
- Interdisciplinary analysis requires adjustment in the criteria (e.g. citation number, impact factor). At this point, it is able to grasp technologies within the same research field. However it is not able to evaluate correctly when we treat different types of research fields and paper bridging different clusters have an important role in the field and thus citations distribute among clusters.
- There are biases due to:
  - ✓ Nationality of the authors
    Researchers tend to check and cite papers written in their native language because of the easiness of reading.
  - ✓ Published journals
    Researchers tend to check and cite journals they write, and they do not check others.
  - ✓ Terms ambiguity
    In this study, "metamaterial" is also represented as "photonic bandgap," "periodic boundary," and "electromagnetic bandgap" means same technologies. Researchers tend to cite papers using the same terminology and not the others even when it technologically adopts the same.

To improve the reliability of RCS, more verification researches are needed. It is also needed to investigate other technologies of antenna than metamaterial. There are some possible target options:

- Microstrip Antenna [37]

The research field has long history and famous among almost of the researchers. By studying Sub-Clusters of Microstrip Antenna it is possible to evaluate relevance and effectiveness of RCS.

- Radial Line Slot Antenna [41]

The research field is niche but has important technologies. Prior work showed that sometimes niche technologies are plotted wrong. By studying Sub-Clusters of Radial Line Slot Antenna, it may become able to extract niche but has progressive technologies.

- Post Wall Waveguide [42]

The research fields have plural terms having same technologies. For example, Post Wall Waveguides and SIW (Substrate Integrated Waveguide) are same but some researchers use the former and the others use the latter. By studying Sub-Clusters of Post Wall Waveguide, it may become able to extract technologies which have terms ambiguity.

V. CONCLUSION

In this study, we proposed a new method called Research Classification Schema (RCS) to identify researches of different stages. We used citation network analysis to extract clusters by recursive clustering while considering resolution limit of modularity maximization algorithm. RCS is especially useful for researchers in universities and companies to find Innovation Seeds, which have high possibility of epoch-making findings, in addition to Emerging Research Fronts. The advantages of RCS were confirmed through the experiment of one technical domain and interviews of the domain's expert. Future research on RCS needs the improvement of the methodology and its further verification with quantitative/qualitative approaches.

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