Internet of things: A scientometric assessment of global output, 2005–2014

B. M. Gupta*, S. M. Dhawan[1], Ritu Gupta[2]

National Institute of Science, Technology and Development Studies, [1]National Physical Laboratory, New Delhi, [2]Shri Venkateshwara University, Tirupati, Andhra Pradesh, India

ABSTRACT

The publication examines 6800 global publications on "Internet of Things" (IoT), as covered in Scopus database during 2005–2014, experiencing an annual average growth rate of 98.63% and citation impact of 1.97. The global publications on IoT came from several countries, of which the top 12 (China – 44.87%, USA – 8.04%, Germany – 6.06%, Italy – 5.19%, UK – 4.84%, Spain – 4.19%, France – 3.46%, Taiwan – 2.53%, South Korea – 2.34%, Switzerland – 2.16%, Finland – 2.03%, and India – 1.87%) together accounts for 87.57% and 89.56% share of the global publication and citations output during 2005–2014. Only 27.96% of the total global publications were cited one or more times during 2005–2014. Among subjects contributing to IoT, computer science contributed the highest publication share (64.93%), followed by engineering (43.01%), social sciences (4.65%), business, management and accounting (3.73%), physics (2.94%), and decision science (2.72%) during 2005–2014. Under broad subjects, the major priorities have been assigned to hardware (technology) with 43.87% share, followed by applications (42.93% share), architectural aspects of technology (22.69% share), security aspects (17.43% share), software (technology) (7.10% share), privacy (6.13% share), business models (0.85% share), governance (0.62% share), legal aspects and accountability (0.5% share), etc. Among the various organizations and authors contributing to IoT, the 20 most productive organizations and authors together contributed 16.78% and 6.13% publications share and 25.63% and 23.16% citation share to the cumulative global publications and citations output during 2005–2014. The top 15 most productive journals contributed 24.54% share to the total journal global publication output during 2005–2014, with largest number of papers (55) is published in Jisuanji Xuebao Chinese Journal of Computers, followed by International Journal of Distributed Sensor Network (50), Sensors Switzerland (46), China Communication (34), Wireless Personnel Communication (33), IEEE Sensors Journal (28), etc. There were only 10 highly cited papers (which came from 8 countries and involved 24 institutions and 41 authors), which had received 100 or more citations, and together got 2951 citations during 2005–2014.

Keywords: Global publications, Internet of Things, scientometrics

INTRODUCTION

Internet of Things (IoT) is about connecting world of smart things, homes, and cities of the future. This connectedness is between various things through Internet. In the future, most homes, cities, and things will be connected through the internet. This has brought a fundamental change in which physical objects are developed, worked, or utilized. According to Gartner, there will be 26 million devices on the IoT by 2020.

***Address for correspondence:**
E-mail: bmgupta1@gmail.com

Access this article online

Quick Response Code:

Website: www.jscires.org

DOI: 10.4103/2320-0057.167248

How to cite this article: Gupta BM, Dhawan SM, Gupta R. Internet of things: A scientometric assessment of global output, 2005–2014. J Sci Res 2015;4:104-14.

The term IoT was popularized by the work of the Auto-ID Center at the Massachusetts Institute of Technology (MIT), which in 1999 started to design and propagate a cross-company radio frequency identification (RFID) infrastructure.[1] In 2002, its co-founder and former head Kevin Ashton was quoted in Forbes Magazine as saying, "We need the Internet for things, a standardized way for computers to understand the real-world."[2] This article was entitled "The Internet of Things," and was the first documented use of the term in a literal sense.[3] However, already in 1999, essentially the same notion was used by Neil Gershenfeld from the MIT Media Lab in his popular book "When Things Start to Think"[1] when he wrote "in retrospect it looks like the rapid growth of the World Wide Web may have been just the trigger charge that is now setting off the real explosion, as things start to use the Net." In recent years, the term "IoT" has spread rapidly – in 2005, it could already be found in book titles, conference proceedings, numerous articles in journals, international, regional, and national research programs, and independent journals.[3-6]

The IoT usually refers to a world-wide network of interconnected heterogeneous objects (sensors, actuators, smart – devices or objects or components or products, RFID, embedded computers, etc.) uniquely addressable, based on standard communication protocols. Beyond such a definition, it is emerging a new definition of IoT seen as a loosely coupled, decentralized system of cooperating smart objects (SOs). An SO is an autonomous, physical digital object augmented with sensing/actuating, processing, storing, and networking capabilities. SOs can sense/actuate, store, and interpret information created within themselves and around the neighbouring external world where they are situated, act on their own, cooperate with each other, and exchange information with other kinds of electronic devices and human users. However, such SO-oriented IoT raises many in-the-small and in-the-large issues involving SO programming, IoT system architecture/middleware, and methods/methodologies for the development of SO-based applications.[7]

"Smart" products play a key role in the IoT vision. Smart products have three core elements: physical components, "smart" elements, and connectivity elements. Smart components amplify the capabilities and value of the physical elements, while connectivity amplifies the capabilities and value of the smart components and enable some of them to exist outside the physical product itself. Physical components comprise the mechanical and electrical parts, whereas smart components comprise the sensors, microprocessors, data storage, controls, software, and typically, an embedded operating system and enhanced user interface. Connectivity components comprise the ports, antennae, and protocols enabling wired or wireless connections with the product. Connectivity takes three forms, which can be present together: (i) One-to-one, (ii) one-to-many, and (iii) many-to-many. Connectivity serves a dual purpose. First, it allows information to be exchanged between the product and its operating environment, its maker, its users, and other products and systems. Second, connectivity enables some functions of the product to exist outside the physical device, in what is known as the product cloud. "Digitally upgrading" conventional object in this way enhances their physical function by adding the capabilities of digital objects, thus generating substantial added value.[8]

Forerunners of this development are already apparent today – more and more devices such as sewing machines, exercise bikes, electric toothbrushes, washing machines, electricity meters, and photocopiers are being "computerized" and equipped with network interfaces. In other application domains, Internet connectivity of everyday objects can be used to remotely determine their state so that information systems can collect up-to-date information on physical objects and processes. This enables many aspects of the real world to be "observed" at a previously unattained level of detail and at negligible cost. This would not only allow for a better understanding of the underlying processes, but also for more efficient control and management.[9] The ability to react to events in the physical world in an automatic, rapid, and informed manner not only opens up new opportunities for dealing with complex or critical situations, but also enables a wide variety of business processes to be optimized. The real-time interpretation of data from the physical world will most likely lead to the introduction of various novel business services and may deliver substantial economic and social benefits.

From a technical point of view, the IoT is not the result of a single novel technology; instead, several complementary technical developments provide capabilities that taken together help to bridge the gap between the virtual and physical world. These capabilities include: (i) Communication and cooperation: Objects have the ability to network with Internet resources or even with each other, to make use of data and services and update their state. Wireless technologies such as GSM and UMTS, Wi-Fi, Bluetooth, ZigBee, and various other wireless networking standards currently under development, particularly those relating to Wireless Personal Area Networks, are of primary relevance here; (ii) addressability: Within an IoT, objects can be located and addressed via discovery, look-up or name services, and hence remotely interrogated or configured; (iii) identification: Objects are uniquely identifiable. RFID, near-field communication (NFC), and optically readable bar codes are examples of technologies with which even passive objects that do not have built-in energy resources can be identified (with the aid of a "mediator" such as an RFID reader or mobile phone). Identification enables objects to be linked to information associated with the particular object and that can be retrieved from a server, provided the mediator is connected to the network; (iv) Sensing: Objects collect information about their surroundings with sensors, record it, forward it, or react directly to it; (v) actuation: Objects contain actuators to manipulate their environment (for example, by converting electrical signals into mechanical movement). Such actuators can be used to remotely control real-world processes via the Internet; (vi) embedded information processing: SOs feature a processor or micro-controller, plus storage capacity. These resources can be used, for example, to process and interpret sensor information, or to give products a "memory" of how they have been used; (vii) localization: Smart things are aware of their physical location, or can be located. GPS or the mobile phone network are suitable technologies to achieve this, as well as ultrasound time measurements, ultra-wideband, radio beacons (e.g. neighbouring Wireless Local Area Networks base stations or RFID readers with known coordinates) and optical technologies; and (viii) User interfaces: SOs can communicate with people in an appropriate manner (either directly or indirectly, for example, via a smartphone). Innovative interaction paradigms are relevant here, such as tangible user interfaces, flexible polymer-based displays and voice, image or gesture recognition methods.[10]

Literature Review

In the past, very few scientometric studies have been carried on publication and patent data on IoT both at global and national levels. Whitmore *et al.*[11] reported on the current state of research, based on the analysis of 127 publications on the IoT. They examined the literature, identified current trends, described challenges that threaten IoT diffusion, and presented open research questions and future directions. The literature was classified according to its content into major categories: Technology, applications, challenges, business models, future directions, and overview/survey. Some of these top-level categories were further broken down into sub-categories, and some of the sub-categories were broken into sub-sub-categories.

A report by World Intellectual Property Organization[12] analyzed the global patents filed on IoT during 2003–2012, focusing on the geographical distribution of patents, distribution of patent filing across top assignees, and broad subject-wise distribution. The patent subject portfolio has been divided into four broad categories: Networking, computing, infrastructure, and application areas; (i) networking – resource management, computing protocols, topology, and management, (ii) computing has been subdivided into information retrieval, imaging processes, and data security, (iii) infrastructure – control system, circuits, and sensors and (iv) applications – E-commerce, home security, health care, etc. Another report from Intellectual Office of UK[13] analyzed 22,000 published patents (which belongs to 9860 patent families, involving 7238 patent assignees and 17,756 inventors from 42 countries on IoT during 2004–2013. The main analysis provides break-up of patents data by period, distribution across countries, identification of top assignees, technology break down by IPC Group, and the extent of international collaboration involved.

OBJECTIVES

The main objectives of this study are to study the performance of global research on IoT during 2005–2014, based on publications output, as indexed in Scopus database. In particular, the study focuses on the following objectives:

- To study the growth of world literature and study its distribution by type of documents and sources;
- To study the citation pattern of the global research output;
- To study the contribution, global share, and citation impact of top 12 most productive countries;
- To study the distribution of global research output by broad subject areas and by narrow subfields and identification of significant keywords;
- To study the publication productivity and citation impact of most productive top 20 organizations and authors;
- To study the leading media of communication; and
- To study the characteristics of highly cited papers.

METHODOLOGY

The study retrieved and downloaded the publication data of the world and of 12 most productive countries on IoT from the Scopus database (http://www.scopus.com) for 10 years during 2005–2014. The keyword IoT was used in "title, abstract, and keyword" tag and restricting it to the period 2005–2014 in "date range tag" for searching the global publication data and this become the main search string. When the main search string is restricted to 12 most productive countries in the "country tag," as shown below, the publication data on these individual most productive countries were obtained. When the main search string is further restricted to "subject area tag," "country tag," "source title tag," "journal title name," and "affiliation tag," we got information on distribution of publications by subject, collaborating countries, organization-wise and journal-wise, etc. The citation data were collected from the date of publication until the end of April 2015. There are a number of quantitative and qualitative indicators used for measuring the research activity. Among such indicators, Relative Citation Index (RCI) is defined as the ratio of global share of citations to global share of papers.

ANALYSIS

World Output

The cumulative research output on IoT reached 6800 publications in 10 years during 2005–2014. The cumulative annual average growth was 72.74%. The cumulative output increased from 186 global publications on IoT during 2005–2009 to 6614 during 2010–2014, averaging 5 yearly growth rate of 3455.19%. The average citation per paper averaged to 1.97 during 2005–2014 [Table 1 and Figure 1].

Distribution of Citations

The global publications output of 6800 papers on IoT during 2005–2014 received 13,397 citations until 20 April 2015. The average citation per publication was 1.97. Around 69% of the total publications did not get any citations (zero citation) in 11 years and the rest 31.02% publications were cited one or more times. Of the total cited publications, 27.96% publications (receiving 1–10 citations) accounted for 37.98% citations share, 2.00% publications (receiving 11–30 citations) contributed 16.89% citations share, 0.51% publications each (receiving 31–50 citations) contributed 10.31% citation share, 0.40% publications (receiving 51–100 citations) contributed 13.82% citation share, and the rest 0.14% publications (receiving >100) contributed 21.00% citations share [Table 2 and Figure 2].

Global Publication Share of Top 12 Most Productive Countries

The top 12 most productive countries on IoT contributed individually from 127 to 3051 papers and together contributed 5955 papers and 11,988 citations, accounting for 87.57% global publications share and 89.56% citations share of the total output during 2004–2013. The largest global publication share (44.87%) came from China, followed by USA (8.04%), Germany (6.06%), Italy (5.19%), UK (4.84%), Spain (4.19%), France (3.46%), Taiwan (2.53%), South Korea (2.34%), Switzerland (2.16%), Finland (2.03%), and India (1.87%) during 2005–2014. The highest average citation per paper impact (6.44) was made by Italy from among the top 12 most productive countries, followed by Switzerland (6.02), Finland (4.31), UK (3.71), Spain (2.99), USA (2.14), Germany (2.09), France (1.94),

Table 1: Annual average growth of publications on "Internet of Things" and their average citation per paper impact during 2005-2014

Period	TP	TC	ACPP
2005	10	12	1.2
2006	17	148	8.706
2007	21	71	3.381
2008	50	219	4.38
2009	88	999	11.35
2010	388	3933	10.14
2011	819	2678	3.27
2012	1271	2542	2.00
2013	1771	1991	1.124
2014	2365	784	0.332
2005-2009	186	1449	7.79
2010-2014	6614	11,928	1.80
2005-2014	6800	13,377	1.97

TP=Total papers, TC=Total citations, ACPP=Average citations per paper

Table 2: Citations received by global publications on "Internet of Things" during 2005-2014

Citation range	Number of papers	Number of citations	Share of papers	Share of citations
0	4691	0	68.98	0.00
1-10	1901	5088	27.96	37.98
11-30	136	2263	2.00	16.89
31-50	35	1381	0.51	10.31
51-100	27	1851	0.40	13.82
101-200	7	1134	0.10	8.465
201-300	2	483	0.03	3.605
>300	1	1197	0.01	8.935
	2109	13,397	31.02	100
	6800	13,397		

Taiwan (1.40), South Korea (1.38), India (1.33), and China (1.00) during 2005–2014. In terms of RCI, above the world average value of 1 was achieved by Italy (3.28), Switzerland (3.06), Finland (2.19), UK (1.89), Spain (1.52), USA (1.09), and Germany (1.06). The other countries that averaged RCI value below 1 were France (0.99), Taiwan (0.71), South Korea (0.70), India (0.68), and China (0.51) during 2005–2014 [Table 3 and Figure 3].

Subject-wise distribution of papers

As per Scopus database classification, computer science accounted for the highest publications share (64.93%) of the global publications on IoT during 2005–2014, followed by engineering (43.01%), social sciences (4.65%), business, management and accounting (3.73%), physics (2.94%), and decision science (2.72%) during 2005–2014 [Table 4].

Among these six subjects, decision sciences registered the highest average citation per paper impact (3.72), followed by physics (2.78), computer science (2.41), business, management and accounting (2.11), engineering (1.81), and social sciences (1.61) during 2005–2014.

Subfield-wise break-up of publications

Under the IoT, major emphasis has been placed on technology. The hardware aspects of technology accounted for 2983 papers (43.87%): RFID (1394 papers), NFC (82 papers), sensor network (1296 papers), actuators (211 papers), and internet protocol including IPv6 (649 papers) during 2005–2014. The software aspects of technology accounted for 483 papers (7.10%): Middleware (321 papers) and searching/browsing (172 papers) during 2005–2014. The architectural aspects of technology accounted for 1543 (22.69%) papers during 2005–2014. The second important area is the applications that accounted for 2919 (42.93%) papers: Industry, factory, and manufacturing (1050 papers), transportation and

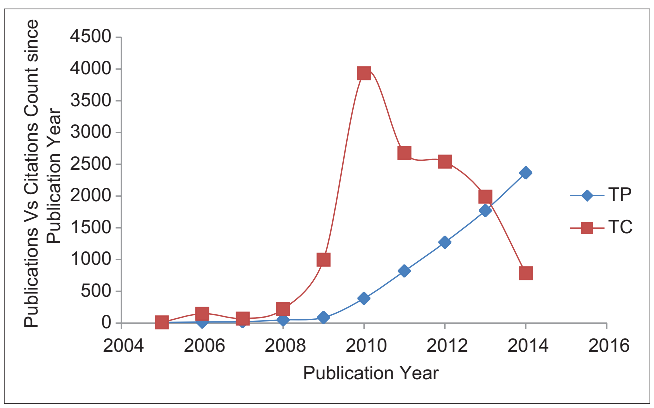

Figure 1: Distribution of publications output on Internet of Things by publication year: 2005–2014

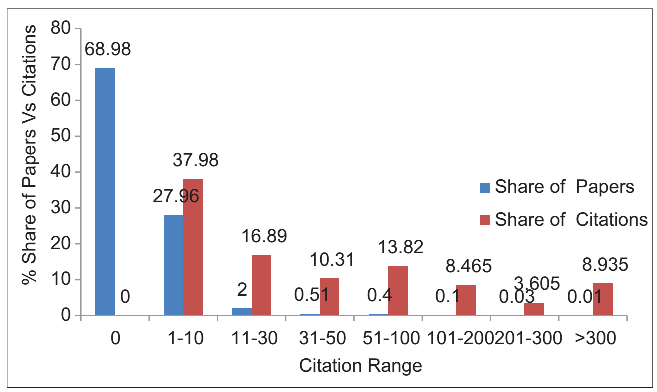

Figure 2: Distribution of publications on Internet of Things by citation range: 2005–2014

Table 3: Global publication output, global publication share, and citation impact of top 12 countries on "Internet of Things" during 2005-2014

Country	TP	TC	ACPP	Percentage of TP	Percentage of TC	RCI	ICP	Percentage of ICP
China	3051	3056	1.00	44.87	22.85	0.51	277	9.079
USA	547	1170	2.14	8.044	8.746	1.09	259	47.35
Germany	412	861	2.09	6.059	6.436	1.06	137	33.25
Italy	353	2275	6.44	5.191	17.01	3.28	103	29.18
UK	329	1221	3.71	4.838	9.128	1.89	173	52.58
Spain	285	851	2.99	4.191	6.362	1.52	109	38.25
France	235	456	1.94	3.456	3.409	0.99	104	44.26
Taiwan	172	240	1.40	2.529	1.794	0.71	37	21.51
South Korea	159	219	1.38	2.338	1.637	0.70	32	20.13
Switzerland	147	885	6.02	2.162	6.616	3.06	73	49.66
Finland	138	595	4.31	2.029	4.448	2.19	66	47.83
India	127	169	1.33	1.868	1.263	0.68	22	17.32
World	6800	13,377	1.97					

TP=Total papers, TC=Total citations, ICP=International collaborative papers, RCI=Relative citation index vehicles (517 papers), health (450 papers), smart home (430 papers), social media and networking (308 papers), logistics (270 papers), smart city (325 papers), environment monitoring (306 papers), smart power grid (300 papers), supply chain (281 papers), smart buildings (243 papers), education (213 papers), agriculture including irrigation and farming (181 papers), water (155 papers), energy monitoring (87 papers) during 2005–2014. The third form for the challenges faced: Security (1185 papers, 17.43%), privacy (417 papers, 6.13%), legal aspects and accountability (34 papers, 0.5%), and governance (42 papers, 0.62%), and among other areas include business models (58 papers, 0.85%) during 2005–2014. The priorities given to these subfields in terms of output in top 12 most productive countries are shown in Table 5.

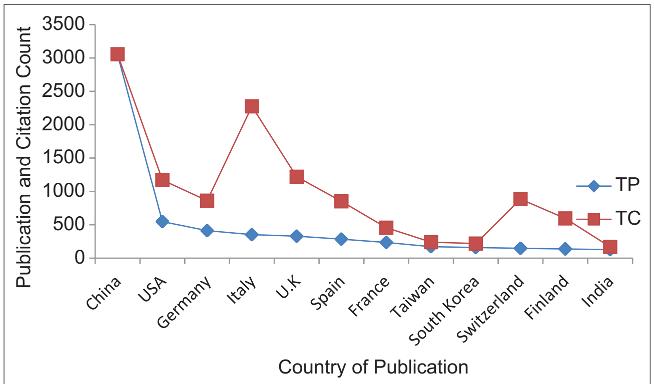

Figure 3: Distribution of publications on Internet of Things by country of publication: 2005–2014

Table 4: Subject-wise break-up of global publications on "Internet of Things" during 2005-2014

Name of the subject	TP	TC	ACPP	Percentage of TP
Computer science	4415	10643	2.41	64.93
Engineering	2925	5296	1.81	43.01
Social science	316	508	1.61	4.647
Business, management and accounting	254	535	2.11	3.735
Physics	200	555	2.78	2.941
Decision sciences	185	688	3.72	2.721
	6800			

TP=Total papers, TC=Total citations, ACPP=Average citations per paper

Significant keywords

A list of top 86 most frequently used keywords on global literature on IoT is shown in Table 6, along with frequency of their occurrence as shown in Table 5. The largest frequency of occurrence (5657) was for IoT, followed by internet (3112), architecture (1538), RFID (1394), sensor network (1295), security (1185), wireless sensor network (722), etc.

Profile of top 20 most productive organizations

The productivity of 20 most productive organizations in IoT varied from 37 to 194 publications and together they contributed 16.781% (1141) publications share and 25.63% (3429) citation share in the cumulative global publications output in IoT research during 2005–2014. The scientometric profile of these 20 organizations is presented in Table 7.

Six organizations registered higher publications output than the group average of 57.05: Beijing University of Posts and Telecommunications, China (194 publications), Beijing Jiatong Daxue, China (69 publications), Universidad de Murcia, Spain (66 publications), Institute of Computing Research, Chinese Academy of Sciences, China (63 publications), Nanjing University of Posts and Telecommunications, China (62 publications), and Tsinghua University, China (62 publications). Six organizations have registered more than the average citation per publication (3.00) of 20 organizations: Eidgenossische Technische Hochschute, Zurich, Switzerland (13.10),

Table 5: Subfield-wise break-up of global publications on "Internet of Things" during 2005-2014

Subfields	Number of papers											
	China	USA	Germ	Italy	UK	Spain	France	Taiwan	South Korea	Switzerland	Finland	India
Tech-hardware	1269	242	176	170	123	141	105	90	68	77	53	62
Tech-software	183	31	32	40	11	14	30	20	8	9	11	9
Tech-architect	585	101	110	117	86	95	71	39	43	45	40	26
Applications	1302	234	197	145	138	130	83	62	47	68	46	53
Security	531	85	66	37	54	54	34	18	31	23	23	42
Privacy	147	39	32	15	24	22	18	2	10	13	8	15
Legal/account	8	2	4	1	1	1	3	0	0	5	0	1
Governance	8	3	4	2	5	0	2	0	0	0	0	0
Business models	21	5	8	7	2	4	3	2	0	3	2	0
Total of the country	3051	547	412	353	329	285	235	172	159	147	138	127

University of Surrey, UK (6.72), Tsinghua University, China (5.71), Huazhong University of Science and Technology, China (5.17), NIPER-Mohali Institute of Computing Research, Chinese Academy of Sciences, China (4.24), and Shanghai Jiatong University, China (4.09) during 2005–2014. Eight organizations have registered more than the average h-index (5.80) of all 20 organizations: University of Surrey, UK (10), Eidgenossische Technische Hochschute, Zurich, Switzerland (9), Institute of Computing Research, Chinese Academy of Sciences, China and Nanjing University of Posts and Telecommunications, China (8 each), Tsinghua University, China, Huazhong University of Science and Technology, China, Shanghai Jiatong University, China and Beijing University of Posts and Telecommunications, China (7 each) during 2005–14. Eight organizations have achieved more than the average share of international collaborative publications (21.60%) of all 20 organizations: University of Surrey, UK (73.90%), Shanghai Jiatong University, China (52.80%), Aalto University, Finland (46.80%), Eidgenossische Technische Hochschute, Zurich, Switzerland (46.20%), Institute of Computing Research, Chinese Academy of Sciences, China (36.50%), Huazhong University of Science and Technology, China (35.00%), Universidad de Murcia, Spain (27.30%), and Tsinghua University, China (24.20%) during 2004–2013.

Profile of the top 20 most productive authors

The top 20 most productive authors published 14–60 publications each in 10 years and together contributed 6.13% publication share and 23.16% citation share to the cumulative global publications output in IoT during 2005–2014. The scientometric profile of these 20 authors is presented in Table 8. Six authors have registered higher publications per author than the group average (20.85): A. J. Jara (60 publications), A. F. Skarmeta (54 publications), L. D. Xu (26 publications), R. Prasad (22)

Table 6: Frequency distribution of most significant keywords in global literature on IoT used during 2005-2014

Name of keyword	Frequency	Name of keyword	Frequency	Name of keyword	Frequency
IoT	5657	Intelligent building	240	RFID tags	86
Internet	3112	Energy utilization	218	Near field communication	82
Architecture	1538	Smart objects	218	System architecture	68
RFID	1394	Supply chain	213	Security systems	66
Sensor network	1295	Smart city	214	Software engineering	64
Security	1185	RFID technology	211	IPv6	63
Wireless sensor networks	722	Network security	203	Environment monitoring	62
Sensor	572	Healthcare	201	Factory automation	59
Internet protocols	649	Electronic commerce	192	Energy conservation	50
Building	624	Social network	184	Traffic management	49
Home	426	Industry	182	Computer architecture	48
Manufacturing	430	Cryptography	181	Vehicles	47
Privacy	417	Energy efficiency	178	Energy harvesting	46
Home	426	Smart home	177	Industrial management	44
Ubiquitous computing	405	Security data	156	Software architecture	42
City	384	Wireless sensor	154	Actuators	40
Telecommunication networks	383	Artificial intelligence	141	Commerce	40
Smart power grid	350	Smart devices	124	Agricultural production	35
Information management	347	Authentication	122	Industrial applications	32
Middleware	321	Data privacy	121	Intelligent transport system	25
Network architecture	313	Smart home	119	Irrigation	24
Cloud computing	321	Digital storage	116	Environment monitoring	24
Algorithms	320	Cryptography	103	Smart meters	20
Wireless telecommunication networks	318	Healthcare	102	Greenhouse	15
Network architecture	314	Service oriented architecture	96	Farming	15
Sensor networks	302	Smart environment	94	Temperature monitoring	15
Transportation	275	Mobile telecommunications	91	Humidity control	11
Smart phone	262	Logistics	90	Water management	11
Automation	260	Agriculture	89		

RFID=Radio frequency identification, IoT=Internet of Things

Table 7: Scientometric profile of the 20 top most productive organizations on "Internet of Things" during 2005-2014

Name of organization	TP	TC	ACPP	ICP	Percentage of ICP	HI
Beijing University of Posts and Telecommunications, China	194	325	1.675	18	9.28	7
Beijing Jiatong Daxue, China	69	42	0.609	5	7.25	4
University of Murcia, Spain	66	187	2.833	18	27.3	6
Institute of Computing Research, Chinese Academy of Sciences, China	63	267	4.238	23	36.5	8
Nanjing University of Posts and Telecommunications, China	62	171	2.758	5	8.06	8
Tsinghua University, China	62	354	5.71	15	24.2	7
Shanghai Jiao tong University, China	53	217	4.094	28	52.8	7
Eidgenossische Technische Hochschute, Zurich, Switzerland	52	681	13.1	24	46.2	9
Wuhan University of Technology, China	51	67	1.314	4	7.84	4
Wuhan University, China	51	68	1.333	11	21.6	4
Aalto University, Finland	47	99	2.106	22	46.8	5
University of Surrey, UK	46	309	6.717	34	73.9	10
University of Science and Technology, Beijing, China	45	72	1.6	5	11.1	5
Jilin University, China	44	77	1.75	2	4.55	5
South China University of Technology, China	42	113	2.69	4	9.52	5
Huazhong University of Science and Technology, China	40	207	5.175	14	35	7
Hunan First Normal University, China	40	25	0.625	4	10	3
Northwestern Polytechnic University, China	39	72	1.846	5	12.8	5
Tongji University, China	38	37	0.974	4	10.5	4
Harbin Institute of Technology, China	37	39	1.054	1	2.7	3
Total of 20 top organizations	1141	3429	3.005	246	21.6	5.8
Total of the world	6800	13,377				
Share of top 20 organizations in global output	16.78	25.63				

TP=Total papers, TC=Total citations, ACPP=Average citations per paper, ICP=International collaborative papers; HI=H-index

I. Moermon (18), and M. A. Zamora (18). Four authors have registered more than the average citation per publication (7.43) of all 20 authors: L. Atzori (90.33), L. D. Xu (10.81), A. Gluhak (10.25), and M. Zorzi (9.14) during 2005–2014. Five authors have registered more than the average h-index (4.10) of all authors during 2003–2012: L. D. Xu (8), A. Zaslavsky (7), A. J. Jara (6), L. Atzori (5), and A. F. Skarmeta (5) during 2005–2014. Ten authors have achieved more than the average share of international collaborative publications (36.69%) of all 19 authors: N. Bessis (80.00%), Q. Z. Sheng (75.00%), A. Gluhak and S. Krco (68.75% each), K. Moessner (64.29%), P. Barnaghi (62.50%), L. D. Xu and R. Prasad (50% each), W. Wang (40.00%), and A. J. Jara (38.33%) during 2005–2014.

Medium of communication

Of the 6800 papers on IoT, 3357 had appeared in conference proceedings, 1801 in Journals, 1488 in book series, 111 in trade publications, and 43 as books during 2005–2014. The 15 most productive journals contributed from 18 to 55 papers and together contributed 24.54% share (442 papers) to the total journal publication output in 2005–2014. The largest number of papers (55) were published in *Jisuanji Xuebao Chinese Journal of Computers*, followed by *International Journal of Distributed Sensor Network* (50), *Sensors Switzerland* (46), *China Communication* (34), *Wireless Personnel Communication* (33), *IEEE Sensors Journal* (28), *IEEE Transactions on Industrial Informatics* (27), *Ad-Hoc Networks* (26), and *Jisuanji Jicheng Zhizao Xitong. Computer Integrated Manufacturing System* and *Personal and Ubiquitous Computing* (22 each), *Advances in Information Sciences and Service Sciences*, *Jisuanji Yanju Yu Fazhan Computer Research and Development* and *Journal of Convergence Information Technology* (20 each) and *Tongxin Xuebao Journal of Communications* (18) during 2005–2014.

Highly cited papers

In all, there were 10 highly cited papers with 100 or more citations since their publications until April 2015. Their citation distribution is skewed. Six papers out of 10 have registered citations from 124 to 199, 3 papers from 204 to 264, and 1 paper 1259 citations during 2005–2014. These 10 papers together have registered 2951 citations, with average citations per paper of 295.1 during 2005–2014. The 10 highly cited papers involve 8 countries, 24 institutions, and 41 authors, with 2 papers each from USA, Italy, Germany, and Switzerland and 1 paper each from China,

Table 8: Scientometric profile of the top 20 authors on "Internet of Things," 2005-2014

Name	Affiliation	TP	TC	ACPP	ICP	Percentage of ICP	HI
A. J. Jara	University of Murcia, Spain	60	184	3.067	23	38.33	6
A. F. Skarmeta	University of Murcia, Spain	54	168	3.111	13	24.07	5
L. D. Xu	Dominion University, USA and Institute of Computing Technology, China	26	281	10.81	13	50	8
M A. Zamora	University of Murcia, Spain	24	123	5.125	1	4.167	4
R. Prasad	Aalborg University, Denmark	22	41	1.864	11	50	3
I. Moermon	Ghent University, Belgium	18	22	1.222	2	11.11	3
P. Demeester	Ghent University, Belgium	17	20	1.176	2	11.76	3
S. Krco	Ericcson Serbia, Serbia	16	65	4.063	11	68.75	2
A. Zaslavsky	Commonwealth Scientific and Industrial Research Organization, Canberra, Australia	16	95	5.938	3	18.75	7
A. Gluhak	University of Surrey, UK	16	164	10.25	11	68.75	4
Q. Z. Sheng	University of District of Columbia, Washington, D.C., USA	16	59	3.688	12	75	4
W. Wang	University of Surrey, UK; Southeast University, Nanjing, China	15	64	4.267	6	40	4
P. Barnaghi	University of Surrey, UK	16	93	5.813	10	62.5	4
L. Atzori	University of Cagliari, Italy	15	1355	90.33	1	6.667	5
N. Bessis	University of Derby, UK	15	19	1.267	12	80	3
K. Framling	Helsinki University of Technology, Finland	15	56	3.733	4	26.67	4
M. Zorzi	University of Padova, Italy	14	128	9.143	4	28.57	4
K. Moessner	University of Surrey, UK	14	58	4.143	9	64.29	3
J. Haupert	German Research Center for Artificial Intelligence, Saarbricken, Germany	14	32	2.286	4	28.57	3
Z. Cheng	University of Aizu, Japan	14	71	5.071	1	7.143	3
Total output		417	3098	7.429	153	36.69	4.1
Total global output		6800	13,377				
Share of 20 authors in global output		6.13	23.16				

TP=Total publications, TC=Total citations, ACPP=Average citation per publication, ICP=International collaborative publications, HI=H-index

UK, Australia, and Finland during 2005–2014. Eight out of 10 publications were research articles, and 1 each was a review paper and one published as a book. Of the 10 highly cited papers, 2 were without any collaborative activity, 6 were national collaborative, and 2 international collaborative papers. The list of 10 highly cited papers is given in Table 9.

SUMMARY AND CONCLUSION

The IoT is a computing concept where all things, including every physical object, can be connected to the Internet, making those objects intelligent, programmable, and capable of interacting with each other and with humans. The term IoT is used to refer to "things" such as environments, buildings, vehicles, clothing, portable devices, and other objects that will have the ability to sense, analyze, communicate, network, and produce new information. Most of the physical objects in future will be connected with smart devices, networks, and infrastructure through the Internet. This sort of connectedness between various things has the potential to bring about the fundamental change in which they work, are developed, and are used. A widespread IoT will revolutionize consumer habits and the way we do business. As more and more information is revealed each day, IoT will transform how we communicate with machines and each other can change the world. The IoT demonstrates how the communication and connection have moved from machine-to-machine (M2M), machine-to-human (M2H), machine-to-things (M2T), things-to-things (T2T), etc. IoT is more about smart devices and smart services that will change forever our personal and professional lives, how we live in our cities, how we travel, how we manage our lives sustainably, how we age, and how services and entertainment accompany us and adapt as our surroundings change.

The IoT research is multi-disciplinary in nature combining the study of electronic engineering and computer science, with an emphasis on internet technologies, wireless communications, sensor devices, and cloud computing. Research and development in this area are still in its infant stage of growth. The first research paper on IoT

Table 9: Top 10 highly cited papers on IoT during 2005-2014

Name of authors	Affiliation of authors	Title of paper	Source	Number of citations
L. Atzori, A. Iera, G. Morabito	University of Cagliari, DIEE, Italy; University Mediterranean of Reggio Calabria, Italy and University of Catania, Italy	The IoT: A survey (article)	Computer Networks 2010;54 (15):2787-805	1259
B. H. Li, L. Zhang, S. L. Wang, F. Tao, J. W. Cao, X. D. Jiang, X. Song, X. D. Chai	Beihang University, Engineering Research Center of Advanced Manufacturing System of Complex Product, Beijing, China; Beijing Simulation Center, China; College of Mechanical Engineering, Chongqing University of Chongqing, China; Research Institute of Information Technology, Tsinghua University, Beijing China and Smartdot Technologies Co. Ltd., Beijing, China	Cloud manufacturing: A new service-oriented networked manufacturing model (article)	Jisuanji Jicheng Zhizao Xitong/CIMS 2010;16 (1):1-7, 16	264
G. Kortuem, F. Kawsar, V. Sundramoorthy, D. Fitton	Lancaster University, UK, University of Central Lancashire, UK and University of Salford, UK	Smart objects as building blocks for the IoT (Article)	IEEE Internet Computing 2010;14 (1):44-51	241
E. Welbourne, L. Battle, G. Cole, K. Gould, K. Rector, S. Raymer, M. Balazinska, G. Borriello	University of Washington, Department of Computer Science and Engineering Seattle, WA, USA; Microsoft Research, USA; Western Oregon University, Monmouth, OR, USA and Oregon State University, Corvallis, OR, USA	Building the IoT using RFID: The RFID ecosystem experience (article)	IEEE Internet Computing 2009;813 (3): 48-55	204
D. Guinard, V. Trifa, S. Karnouskos, P. Spiess, D. Savio	SAP Research and Institute for Pervasive Computing, ETH Zurich, Switzerland and SAP Research Karlsruhe, Germany	Interacting with the SOA-based IoT: Discovery, query, selection, and on-demand provisioning of web services (article)	IEEE Transactions on Services Computing 2010;3 (3): 223-35	199
D. Miorandi, S. Sicari, F. De Pellegrini, I. Chlamtac	CREATE-NET, via Alla Cascata 56/D, IT-38123 Povo, Trento, Italy and Dipartimento di Informatica e Comunicazione, Università Degli Studi Del, Varese, Italy	IoT: Vision, applications and research challenges (Review)	*Ad-Hoc* Networks 2012;10 (7):1497-516	198
J. Gubbi, R. Buyya, S. Marusic, M. Palaniswami	Department of Electrical and Electronic Engineering, University of Melbourne, Australia and Department of Computing and Information Systems, University of Melbourne, Australia	IoT: A vision, architectural elements, and future directions (Article)	Future Generation Computer Systems 2013;29 (7):1645-60	166
Z. Shelby, C. Bormann	Sensinode, Finland and Universität Bremen TZI, Germany	6LoWPAN: The Wireless Embedded Internet (Book)	Book 2009. p. 223	163
R. K. Ganti, F. Ye, H. Lei	IBM T. J. Watson Research Center, USA	Mobile crowd-sensing: Current state and future challenges (article)	IEEE Communications Magazine 2011;49 (11):32-9	133
R. H. Weber	University of Zurich, Zurich, Switzerland	IoT: New security and privacy challenges (article)	Computer Law and Security Review 2010;26 (1):23-30	124

CIMS=Computer Integrated Manufacturing Systems, RFID=Radio frequency identification, IoT=Internet of Things

topic had appeared 10 years ago in 2005. Until 2014, the total world output in IOT research had reached only to a small figure of 6800 publications, 72.74% growth per annum. China ranks at the top among 12 leading world countries for its highest global publication share (44.8%) in IoT. The remaining 11 countries are distant cousins; their combined global publication share (42.7%) is less than that of China. Their global share is in single digit varying from USA (8.04%), Germany (6.06%), Italy (5.19%), UK (4.84%), Spain (4.19%), France (3.46%), Taiwan (2.53%), South Korea (2.34%), Switzerland (2.16%), Finland (2.03%), and India (1.87%) during 2005–2013.

Citation profile of IoT publications is not very exciting. Only 4% output in IoT received citations in the range 11–300+ during 2005–2014. Sixty-nine percent papers received 0 citation in 10 years and 27% between 1 and 10 citations in 10 years. Citation density of IoT publications averaged at 0.84 citations per paper per citation window-year. Both the indicators-citation distribution and citation density confirm that citation profile of IoT publications is indeed not very exciting.

At country level, Italy registered the highest citation impact per paper (average citations per paper [ACPP] 6.44) among the 12 most productive countries, followed by Switzerland (6.02), Finland (4.31), UK (3.71), Spain (2.99), USA (2.14), Germany (2.09), France (1.94), Taiwan (1.40), South Korea (1.38), and India (1.33). Though China appeared as the most productive country in IoT output, its ACPP was the lowest (1.00) during 2005–2014. Citation analysis on RCI also reveals a very similar picture. Italy tops the ranking with an RCI score of 3.28, followed by

Switzerland (3.06), Finland (2.19), UK (1.89), Spain (1.52), USA (1.09), and Germany (1.06) during 2005–2014.

IoT combines research studies in computer science, engineering, social sciences, management, physics, and decision sciences. But their respective shares in IoT research differ significantly. Computer science contributed the highest publication share of 64.93%, followed by engineering (43.01%), social sciences (4.65%), business, management and accounting (3.73%), physics (2.94%), and decision science (2.72%) during 2005–2014.

These multi-disciplinary areas differ in terms of their citation impact. Decision sciences registered the highest citation impact per paper (3.72), followed by physics (2.78), computer science (2.41), business, management and accounting (2.11), engineering (1.81), and social sciences (1.61) during 2005–2014.

Subfields analysis reveals that the major emphasis in IoT has been on hardware (technology) with 43.87% share, followed by applications (42.93% share), architectural aspects of technology (22.69% share), security aspects (17.43% share), software (technology) (7.10% share), privacy (6.13% share), business models (0.85% share), governance (0.62% share) and legal aspects, and accountability (0.5% share).

Among significant keywords identified, the largest number of papers (5657) was on IoT, followed by Internet (3112), architecture (1538), RFID (1394), sensor network (1295), security (1185), wireless sensor network (722), sensor (572), internet protocol (649), etc.

The top 20 most productive organizations contributed 16.78% publications share, 25.63% citation share, registered an average productivity of 57.05 papers, average citations per paper of 3.0, average h-index of 5.80, and average share of international collaborative papers of 21.60% during 2005–2014.

In contrast, the top 20 most productive authors together contributed 6.13% publications share, 23.16% citation share, registered an average productivity of 20.85 papers, average citations per paper of 7.43, average h-index of 4.10, and average share of international collaborative papers of 36.69% during 2005–2014.

The 15 most productive journals together contributed 24.54% share to the total journal publication output in during 2005–2014, with the largest number of papers (55) published in *Jisuanji Xuebao Chinese Journal of Computers*, followed by *International Journal of Distributed Sensor Network* (50), *Sensors Switzerland* (46), *China Communication* (34), *Wireless Personnel Communication* (33), *IEEE Sensors Journal* (28), *IEEE Transactions on Industrial Informatics* (27), *Ad-Hoc Networks* (26), etc., during 2005–2014.

In all, there were 10 highly cited papers with citations from 124 to 1259 per paper, and together they got 2951 citations. These highly cited papers came from 8 countries and had seen participation by 24 institutions and 41 authors during 2005–2014.

Financial Support and Sponsorship

Nil.

Conflicts of Interest

There are no conflicts of interest.

REFERENCES

1. Schoenberger CR. The Internet of Things. Forbes Magazine; March 18, 2002.
2. Gershenfeld N. When Things Start to Think. New York: Henry Holt and Company; 1999.
3. European Commission. Internet of Things – An Action Plan for Europe. COM; 2009. p. 278. Available from: http://www.eur-lex.europa.eu/LexUriServ/site/en/com/2009/com2009_0278en01.pdf.2009. [Last accessed on 2015 Jul 11].
4. Fleisch E, Mattern F, editors. Das Internet der Dinge. Springer; 2005. Available from: http://www.link.springer.com/book/10.1007/3-540-28299-8. [Last accessed on 2015 Jul 11].
5. Floerkemeier C, Langheinrich M, Fleisch E, Mattern F, Sarma SE, editors. First International Conference, IOT 2008, Zurich, Switzerland, March 26-28, 2008, Springer; 2008. Available from: https://www.books.google.co.jp/books/about/The_Internet_of_Things.html. [Last accessed on 2015 Jul 12].
6. International Telecommunication Union: The Internet of Things; 2009. Available from: http://www.eur-lex.europa.eu/LexUriServ/site/en/com/2009/com2009_0278en01.pdf. [Last accessed on 2015 Jul 11].
7. Fortino G, Trunfio P, editors. Internet of Things Based on Smart Objects. Technology, Middleware and Applications. Springer International; 2014. Available from: http://www.springer.com/gp/book/9783319004907. [Last accessed on 2015 Jul 11].
8. Porter MF, Heppelmann A. How Smart, Connected Products Transferring Competition. Harvard Business Review; November, 2014. Available from: https://www.hbr.org/2014/11/how-smart-connected-products-are-transforming-competition. [Last accessed on 2015 Jul 11].
9. What is the internet of things? When things add value. In: Auto-ID Labs White Paper WP-BIZAPP-053, Auto-ID Lab. Switzerland: ETH Zurich/University of St. Gallen; 2010.
10. Mattern F, Floerkemeier C. From the Internet of Computers to the Internet of Things. Available from: http://www.vs.inf.ethz.ch/publ/papers/Internet-of-things.pdf. [Last accessed on 2015 Jul 11].
11. Whitmore A, Agarwal A, Li DX. The Internet of things – A survey of topics and trends. Inf Syst Front 2015;17:261-74.
12. WIPO. Internet of Things Patent Landscape Analysis. Available from: http://www.wipo.int/patentscope/en/programs/patent_landscapes/documents/internet-of-things.pdf. [Last accessed on 2015 Jul 11].
13. Eight Great Technologies. The Internet of Things; A Patent Overview. Newport, UK: Intellectual Property Office; 2014.