

## Research output on cryptography: A bibliometric study

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### Abstract

To-day periodical evaluation of scientific outputs of research has been given high priority specifically on subject domain. Bibliographic method has been adopted to analyse the research output. In this paper Cryptography research output has been taken up for the study. Cryptography is the science of writing in secret code and is an ancient art. To analyse the growth of cryptography research output 40 years publications data from 1976 to 2015 collected from scopus database has been taken up for the study. A total of 1,21,697 records were identified in the field of "Cryptography", of which 1,18,873 research literatures (97.68%) are directly related to Cryptography. The Bibliometric tools such as Relative Growth Rate, doubling time were used beside percentile composition. The study identifies the core journals on cryptography. Further frequently used keywords for cryptographic research output has also been identified. China contributes more on cryptographic research output.

**Keywords:** Cryptographic research output, Bibliometric study, Research Output, Cryptography, Growth of literature.

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### Introduction

Recently, high priority is being given to regular evaluation of scientific outputs of research groups, institutions, universities, and research institutes and centers to know about their current status.<sup>(1,2)</sup> The measure of research output has been carried out using bibliometric method. In this study, the research output on Cryptography has been analysed.

### Cryptography

Cryptography is the science of writing in secret code and is an ancient art; the first documented use of cryptography in writing dates back to circa 1900 B.C. when an Egyptian scribe used non-standard hieroglyphs in an inscription. Some experts argue that cryptography appeared spontaneously sometime after writing was invented, with applications ranging from diplomatic missives to war-time battle plans. It is no surprise, then, that new forms of cryptography came soon after the widespread development of computer communications. In data and telecommunications, cryptography is necessary when communicating over any untrusted medium, which includes just about *any* network, particularly the Internet.

### Review of related Literature

The majority of articles of bibliometric study contain bibliometric references to journal, books, conference proceedings, dissertations etc. The quantitative study of patterns in the scientific literature approach can be applied, to examine trends in the number of publications on a certain topic,<sup>(3-5)</sup> to investigate the spatial distribution of the research attention given to a certain topic,<sup>(6-8)</sup> to study the relative number of papers dealing with various research areas,<sup>(9-11)</sup> to analyze the reception of papers (or items

therein, e.g., anecdotes) by posterity,<sup>(12-14)</sup> to assess the productivity of researchers and its likely quality,<sup>(15-17)</sup> to compare the research performance and diversity of institutions and countries,<sup>(18-20)</sup> to document patterns and determinants of the length of peer review processes,<sup>(21-23)</sup> and to study interdisciplinary collaboration activities.<sup>(24-26)</sup> A quantitative measurement of research contributions is an innovative way of correlating numerous gestures of research revealing trends and is considered as an aid to map research productivity.<sup>(27)</sup>

### Objectives

The objectives of the study are

1. To identify the chronological growth of literature on Cryptography.
2. To identify the related growth rate on Cryptography.
3. To identify the country wise and language wise distribution on Cryptography.
4. To identify the preferred bibliographic form for the research output for Cryptography.
5. To identify the predominant organisation on Cryptography.
6. To identify the primary journal on Cryptography.
7. To identify the highly contributed authors in Cryptography.

### Hypotheses

The hypotheses formulated for the study are

1. There exists substantial growth output on Cryptography research.
2. There exists more contribution by developed nations on Cryptography.

3. Among various bibliographical forms, periodicals seems to be most preferred for publication of Cryptographic research.
4. English language dominates in Cryptographic research.

**Data Collection:** The study uses 40 years publications data from 1976 to 2015 on Cryptography collected from Scopus database. A total of 1,21,697 records were identified in the field of "Cryptography", of which 1,18,873 research literatures (97.68%) are directly related to Cryptography. The following search strategy has been used to retrieve data. The search term used for retrieving the bibliographic records as follows:  
(TITLE-ABS-KEY ("Cryptography" OR "cryptography") AND PUBYEAR > 1975 AND PUBYEAR < 2016.

These bibliographic records were downloaded for further analysis.

**Scope:** This study covers a period of 40 years only spanning between 1976 and 2015. The present study was confined to only cryptography research output.

Records for the analysis of this investigation have been downloaded from the SCOPUS database.

**Analysis:** The analysis has been carried out based on Chronological growth, Country wise Distribution, bibliographic form, Language Wise Publications, Organisation wise distribution, Major Sources, Highest number of Contributors and Frequently used keywords were analysed.

#### Chronological Growth

The growth of literature has been identified using

- Year wise Growth
- Rate of Growth (RoG)
- Compound Annual Growth Rate (CAGR)
- Relative growth rate (RGR)
- Doubling time (Dt)

#### Year Wise Growth

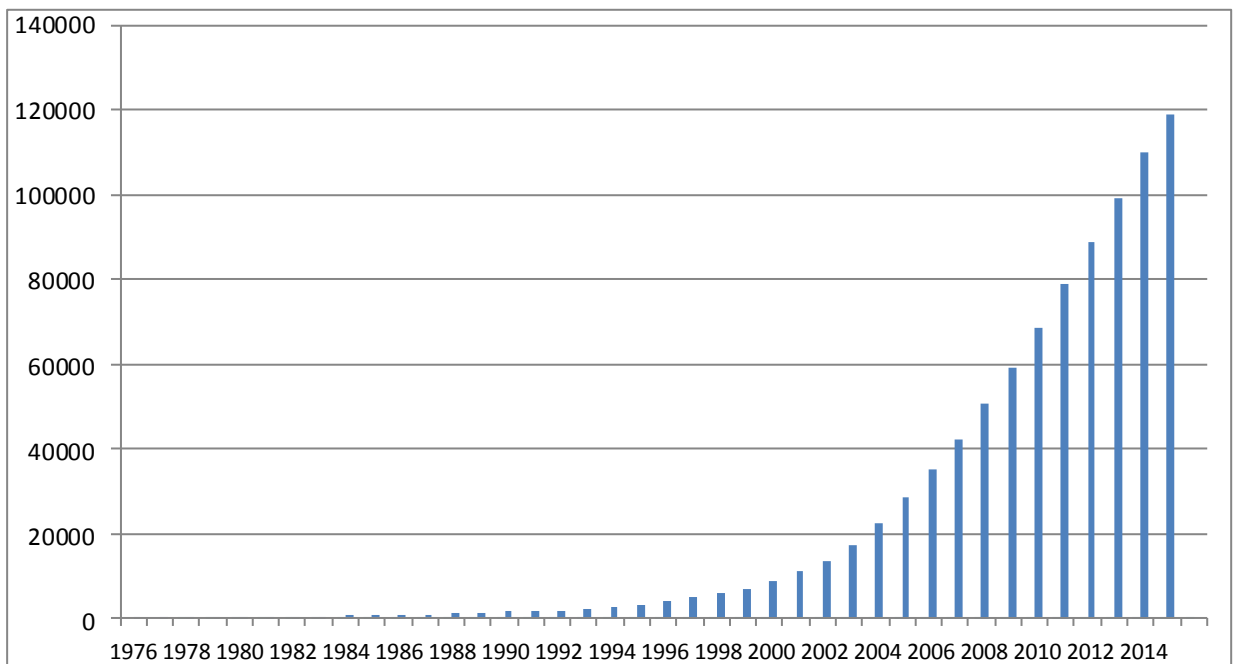
Year of wise distribution of cryptographic research output during the period of study has been shown in Table 1.

**Table 1: Year wise Distribution**

S. No.	Year	No. of Papers	Cumulative Papers	Percentage	Cumulative Percentage	RoG
1	1976	6	6	0.01	0.01	
2	1977	24	30	0.02	0.03	4.00
3	1978	33	63	0.03	0.06	1.38
4	1979	41	104	0.03	0.09	1.24
5	1980	54	158	0.05	0.14	1.32
6	1981	53	211	0.04	0.18	0.98
7	1982	82	293	0.07	0.25	1.55
8	1983	174	467	0.15	0.40	2.12
9	1984	136	603	0.11	0.51	0.78
10	1985	127	730	0.11	0.62	0.93
11	1986	138	868	0.12	0.74	1.09
12	1987	140	1008	0.12	0.85	1.01
13	1988	176	1184	0.15	1.00	1.26
14	1989	161	1345	0.14	1.14	0.91
15	1990	180	1525	0.15	1.29	1.12
16	1991	165	1690	0.14	1.43	0.92
17	1992	200	1890	0.17	1.59	1.21
18	1993	333	2223	0.28	1.88	1.67
19	1994	422	2645	0.36	2.23	1.27
20	1995	602	3247	0.51	2.74	1.43
21	1996	741	3988	0.62	3.36	1.23
22	1997	917	4905	0.77	4.13	1.24
23	1998	1095	6000	0.92	5.05	1.19
24	1999	1154	7154	0.97	6.02	1.05
25	2000	1644	8798	1.38	7.41	1.42
26	2001	2206	11004	1.86	9.26	1.34
27	2002	2498	13502	2.10	11.36	1.13
28	2003	3939	17441	3.31	14.68	1.58
29	2004	5030	22471	4.23	18.91	1.28
30	2005	6247	28718	5.26	24.16	1.24

31	2006	6410	35128	5.39	29.56	1.03
32	2007	7278	42406	6.12	35.68	1.14
33	2008	8078	50484	6.80	42.47	1.11
34	2009	8864	59348	7.46	49.93	1.10
35	2010	9434	68782	7.94	57.87	1.06
36	2011	10190	78972	8.57	66.44	1.08
37	2012	9722	88694	8.18	74.62	0.95
38	2013	10214	98908	8.59	83.21	1.05
39	2014	11013	109921	9.26	92.47	1.08
40	2015	8952	118873	7.53	100.00	0.81

A total of 1,18,873 publications were published during the study period of 1976-2015. It can be seen from Table 1 that during the year 1976 there were six publications. A total of 1000 publications were published during the period of 1976-1987. Afterwards there exists study growth of publications every year. Maximum 11,013 publications were published during the year 2014. More than 10000 articles per year can be seen during 2013 (10214) and 2011 (10214). Substantial growth can be seen from the year 2002 onwards. Nearly 90% of publications were appeared during the period of 2002 and 2015.



It can be seen from figure that the growth seems to be parabolic in nature.

**RGR and Doubling Time**

**Relative Growth Rate (RGR):** The mean Relative Growth Rate (R) over the specific period of interval can be calculated from the following equation:

$$1-2 \bar{R} = \frac{\text{Log}_e 2W - \text{log}_e 1W}{2^T - 1^T}$$

whereas

- 1-2  $\bar{R}$  = mean relative growth rate over the specific period of interval
- $\text{log}_e 1W$  = log of initial number of articles/pages
- $\text{log}_e 2W$  = log of final number of articles/pages after a specific period of interval
- $2^T - 1^T$  = the unit difference between the initial time and the final time

The year can be taken here as the unit of time. The RGR for both articles and pages can be calculated separately.

Therefore

$1 - 2^{\bar{R}(aa-1 \text{ year} -1)}$  can represent the mean relative growth rate per unit of articles per unit of year over a specific period of interval and

$1 - 2^{\bar{R}(pp-1 \text{ year} -1)}$  can represent the mean relative growth rate per unit of pages per unit of year over a specific period of interval.

**Doubling Time (Dt):** There exists a direct equivalence between the relative growth rate and the doubling time.<sup>(21)</sup> If the number of articles/pages of a subject doubles during a given period then the difference between the logarithms of numbers at the beginning and end of this period must be the logarithms of number 2. If natural logarithm is used this difference has a value of 0.693. Thus the corresponding doubling time for each specific period of interval and for both articles and pages can be calculated by the following formula:

$$\text{Doubling time (Dt)} = \frac{0.693}{R}$$

Therefore

$$\text{Doubling time for articles Dt (a)} = \frac{0.693}{1 - 2^{\bar{R}(aa-1 \text{ year} -1)}}$$

and

$$\text{Doubling time for pages Dt (p)} = \frac{0.693}{1 - 2^{\bar{R}(pp-1 \text{ year} -1)}}$$

The relative growth rate (RGR) and doubling time (Dt) has been calculated and the same is shown in Table 2.

**Table 2: RGR and doubling time**

S. No.	Year	Papers	Cum papers	%	w1	w2	RGR	Dt
1	1976	6	6	0.01		1.79	1.79	0.39
2	1977	24	30	0.02	1.79	3.40	1.61	0.43
3	1978	33	63	0.03	3.40	4.14	0.74	0.93
4	1979	41	104	0.03	4.14	4.64	0.50	1.38
5	1980	54	158	0.05	4.64	5.06	0.42	1.66
6	1981	53	211	0.04	5.06	5.35	0.29	2.40
7	1982	82	293	0.07	5.35	5.68	0.33	2.11
8	1983	174	467	0.15	5.68	6.15	0.47	1.49
9	1984	136	603	0.11	6.15	6.40	0.26	2.71
10	1985	127	730	0.11	6.40	6.59	0.19	3.63
11	1986	138	868	0.12	6.59	6.77	0.17	4.00
12	1987	140	1008	0.12	6.77	6.92	0.15	4.63
13	1988	176	1184	0.15	6.92	7.08	0.16	4.31
14	1989	161	1345	0.14	7.08	7.20	0.13	5.44
15	1990	180	1525	0.15	7.20	7.33	0.13	5.52
16	1991	165	1690	0.14	7.33	7.43	0.10	6.75
17	1992	200	1890	0.17	7.43	7.54	0.11	6.20
18	1993	333	2223	0.28	7.54	7.71	0.16	4.27
19	1994	422	2645	0.36	7.71	7.88	0.17	3.99
20	1995	602	3247	0.51	7.88	8.09	0.21	3.38
21	1996	741	3988	0.62	8.09	8.29	0.21	3.37
22	1997	917	4905	0.77	8.29	8.50	0.21	3.35
23	1998	1095	6000	0.92	8.50	8.70	0.20	3.44
24	1999	1154	7154	0.97	8.70	8.88	0.18	3.94
25	2000	1644	8798	1.38	8.88	9.08	0.21	3.35
26	2001	2206	11004	1.86	9.08	9.31	0.22	3.10

27	2002	2498	13502	2.10	9.31	9.51	0.20	3.39
28	2003	3939	17441	3.31	9.51	9.77	0.26	2.71
29	2004	5030	22471	4.23	9.77	10.02	0.25	2.73
30	2005	6247	28718	5.26	10.02	10.27	0.25	2.83
31	2006	6410	35128	5.39	10.27	10.47	0.20	3.44
32	2007	7278	42406	6.12	10.47	10.66	0.19	3.68
33	2008	8078	50484	6.80	10.66	10.83	0.17	3.97
34	2009	8864	59348	7.46	10.83	10.99	0.16	4.28
35	2010	9434	68782	7.94	10.99	11.14	0.15	4.70
36	2011	10190	78972	8.57	11.14	11.28	0.14	5.02
37	2012	9722	88694	8.18	11.28	11.39	0.12	5.97
38	2013	10214	98908	8.59	11.39	11.50	0.11	6.36
39	2014	11013	109921	9.26	11.50	11.61	0.11	6.56
40	2015	8952	118873	7.53	11.61	11.69	0.08	8.85

The RGR ranges between 0.08 and 0.74 except the initial years the growth rate is 1.79 during the year 1976 and 1.61 during the year 1977. The growth rate during first 10 years is decreasing in nature. From the year 2000 onwards the growth rate is almost stable. However during this period also it is decreasing in nature.

The doubling time during the study period ranges between 0.09 and 8.85 during the last 2 years the doubling time ranges between 6.36 and 8.85 which indicates the growth of Lung Cancer research doubles in 7 to 8 years.

### Country Wise Distribution

The country wise distribution of cryptography publication was identified and the same has been shown in Table 3.

**Table 3: Country Wise Distribution**

S. No.	Name of the Country	Number of Publications	Percentage
1	China	25935	18.62
2	United States	23099	16.58
3	India	7372	5.29
4	Germany	6424	4.61
5	Japan	6407	4.60
6	United Kingdom	6058	4.35
7	France	5536	3.97
8	Taiwan	4791	3.44
9	Canada	4717	3.39
10	South Korea	4412	3.17
11	Italy	3494	2.51
12	Australia	3416	2.45
13	Spain	2701	1.94
14	Singapore	2226	1.60
15	Switzerland	2069	1.49
16	Belgium	1905	1.37
17	Israel	1759	1.26
18	Netherlands	1512	1.09
19	Austria	1450	1.04
20	Hong Kong	1352	0.97
21	Malaysia	1340	0.96
22	Iran	1301	0.93
23	Greece	1248	0.90
24	Russian Federation	1247	0.90
25	Brazil	1075	0.77
26	Poland	1029	0.74
27	others	15405	11.06
Total		139280	100.00

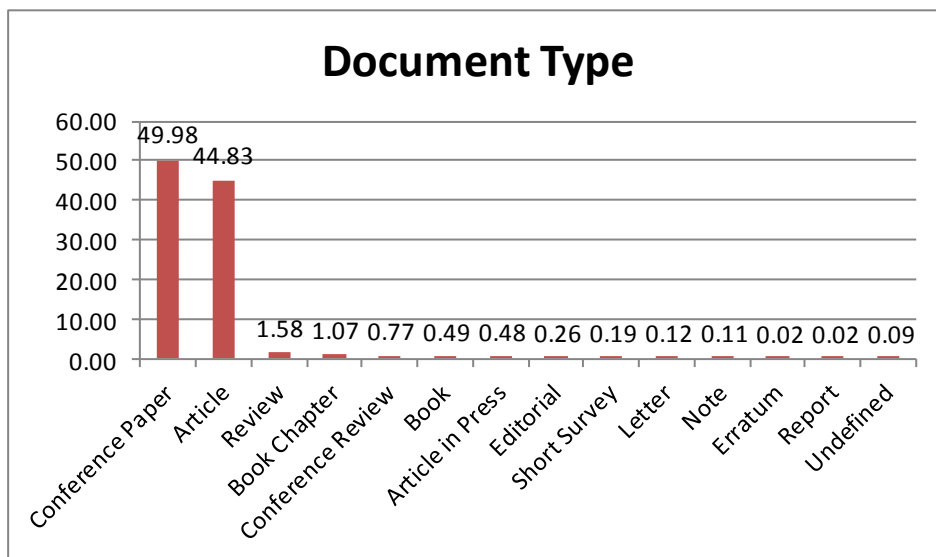
A total of 1,18,873 publications on cryptography were contributed by 1,39,280 persons from 144 countries. China (18.62%) has highest contribution. It is followed by United States (16.58%) and India (5.29%). Nearly 50% of publications were contributed by China (25935); United States (23099), India (7372); Germany (6424) and Japan (6407). India occupies third place in total number of publications.

**Bibliographic Form**

The bibliographic form preferred by the cryptography researchers were identified and the same has been shown in Table 4.

**Table 4: Type of Document**

S. No.	Type of Document	Papers	Percentage
1	Conference Papers	59415	49.98
2	Articles	53288	44.83
3	Reviews	1876	1.58
4	Book Chapters	1275	1.07
5	Conference Reviews	914	0.77
6	Books	585	0.49
7	Article in Press	570	0.48
8	Editorials	310	0.26
9	Short Surveys	222	0.19
10	Letters	139	0.12
11	Notes	128	0.11
12	Erratum	24	0.02
13	Reports	20	0.02
14	Undefined (others)	107	0.08
Total		118873	100



Conference paper constitutes 49.98% of publications. It is followed by journal articles (44.83%); review (1.58%) and book chapter (1.07%).

**Language Wise Publications**

Language wise publications were shown in Table 5.

**Table 5: Language wise distribution**

S. No.	Language	No. of Publications	Percentage
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1	English	113977	95.88
2	Chinese	4292	3.61
3	German	95	0.08
4	Japanese	90	0.08
5	Russian	78	0.07
6	Turkish	71	0.06
7	French	70	0.06
8	Spanish	64	0.05
9	Portuguese	37	0.03
10	Polish	25	0.02
11	Italian	23	0.02
12	Slovene	12	0.01
13	Korean	10	0.01
14	Other Languages	29	0.02
Total		118873	100

As like that of every domain, in cryptography also predominates were given for English languages. Nearly 96% of publications were belongs to English. It is followed by Chinese (4,292) language.

#### Organisation Wise Distribution

The organisation that has more 500 publications were identified and the same has been shown in Table 6.

**Table 6: Top Organisation has more than 500 publications**

S. No.	Name of the Organisation	No. of Publications
1	Xidian University	1732
2	Beijing University of Posts and Telecommunications	1276
3	Shanghai Jiaotong University	1192
4	Chinese Academy of Sciences	1104
5	University of Waterloo	1065
6	Tsinghua University	1030
7	Nippon Telegraph & Telephone	898
8	KU Leuven	794
9	University of Science and Technology of China	763
10	Massachusetts Institute of Technology	732
11	Institute of Software Chinese Academy of Sciences	711
12	Nanyang Technological University	671
13	Technische Universitat Darmstadt	651
14	IEEE	625
15	University of Bristol	617
16	Royal Holloway University of London	613
17	Eidgenossische Technische Hochschule Zurich	596
18	National University of Singapore	582
19	Graduate University of Chinese Academy of Sciences	577
20	Korea University	566
21	Universitat Bochum	566
22	University of Wollongong	565
23	University of California, Los Angeles	562
24	Microsoft Research	561
25	Huazhong University of Science and Technology	560
26	Harbin Institute of Technology	550
27	University of Electronic Science and Technology of China	546
28	Institute for Infocomm Research, A-Star, Singapore	542
29	University of Tokyo	527

30	University of Maryland	526
31	City University of Hong Kong	515
32	Wuhan University	505
33	Ecole Normale Superieure	500
34	Other organisations	95053
Total		118873

33 organisations contributed more than 500 publications. Among the 33 organisations, Xidian University has 1732 publications. It is followed by Beijing University of Posts and Telecommunications (1276); Shanghai Jiaotong University (1192); Chinese Academy of Sciences (1104); University of Waterloo (1065) and Tsinghua University (1030).

### Preferred sources of Publications

Major source title which has more than 500 publications were identified and same is shown in Table 7.

**Table 7: Top sources has more than 500 publications**

S. No.	Source Title	No. of Publications	Percentage
1	Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	15273	12.85
2	Physical Review A Atomic Molecular and Optical Physics	2424	2.04
3	Proceedings of SPIE the International Society for Optical Engineering	2053	1.73
4	Designs Codes and Cryptography	2011	1.69
5	IEEE Transactions on Information Theory	1241	1.04
6	IEICE Transactions on Fundamentals of Electronics Communications and Computer Sciences	1111	0.93
7	Communications in Computer and Information Science	823	0.69
8	Proceedings of the ACM Conference on Computer and Communications Security	759	0.64
9	Lecture Notes in Computer Science	753	0.63
10	Physical Review Letters	733	0.62
11	IEEE International Symposium on Information Theory Proceedings	633	0.53
12	Optics Communications	526	0.44
13	Computers and Security	506	0.43
14	Other sources	90027	75.74
Total		118873	100

13 source titles publishers nearly 25% of the total cryptographic publications. "Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics" has maximum number 15273 (12.85%) of publications. It is followed by "Physical Review A Atomic Molecular and Optical Physics" (2424, 2.04%) and "Proceedings of SPIE the International Society for Optical Engineering" (2053, 1.73%). These 13 sources can be considered as primary sources.

### Highest number of Contributors

The authors who have contributed more than 150 publications were identified and the same is shown in Table 8.

**Table 8: Top Authors has more than 150 publications**

S. No.	Name of the Author	No. of Publications
1	Chang, C.C.	410
2	Susilo, W.	282
3	Preneel, B.	272
4	Yoo, K.Y.	214
5	Guo, G.C.	211
6	Wen, Q.Y.	202
7	Gisin, N.	201
8	Mu, Y.	199
9	Verbawhede, I.	194
10	Hwang, M.S.	190
11	Cao, Z.	186



12	Takagi, T.	174
13	Sakurai, K.	171
14	Yung, M.	170
15	Paar, C.	155
16	Gong, G.	155
17	Hwang, T.	151
18	Other authors	115336
Total		118873

“Chang, C.C” has contributed nearly 410 publications. It is followed by “Susilo, W” (282); “Preneel, B” (272) and “Yoo, K.Y” (214).

### Frequently Used Keywords

Frequently used keywords for 118873 publications were identified. The keywords which has represented more than 2500 times alone were given in Table 9.

**Table 9: Frequently used keywords**

S. No.	Keywords	No. of Publications
1	Cryptography	50724
2	Security of data	19953
3	Algorithms	12669
4	Authentication	11434
5	Public key cryptography	11211
6	Network security	10903
7	Network protocols	8604
8	Security	5865
9	Data privacy	5357
10	Quantum cryptography	4889
11	Internet	4797
12	Electronic document identification systems	4045
13	Security systems	3610
14	Access control	3564
15	Quantum theory	3443
16	Wireless telecommunication systems	3433
17	Photons	3292
18	Computer crime	3103
19	Mathematical models	3092
20	Computer simulation	2963
21	Information theory	2962
22	Codes (symbols)	2893
23	Communication	2883
24	Problem solving	2842
25	Computational complexity	2808
26	Wireless sensor networks	2673
27	Information technology	2615
28	Computer science	2590

Besides the word “Cryptography” (50724); the other words that has represented more than 10,000 times were “Security of data” (19953); “Algorithms” (12669); “Authentication” (11434); “Public key

“cryptography” (11211) and “Network security” (10903).

### Findings

The findings of the study are;

- A total of 1,18,873 publications were published during the study period of 1976-2015. A total of 1000 publications were published during the period of 1976-1987. Afterwards there exists study growth of publications every year. Maximum 11,013 publications were published during the year 2014. More than 10000 articles per year can be seen during 2013 (10214) and 2011 (10214). Substantial growth can be seen from the year 2002 onwards. Nearly 90% of publications were appeared during the period of 2002 and 2015. (Table 1)
- The RGR ranges between 0.08 and 0.74 except the initial years the growth rate is 1.79 during the year 1976 and 1.61 during the year 1977. The growth rate during first 10 years is decreasing in nature. From the year 2000 onwards the growth rate is almost stable. However during this period also it is decreasing in nature. The doubling time during the study period ranges between 0.09 and 8.85. During the last 2 years the doubling time ranges between 6.36 and 8.85 which indicates the growth of Lung Cancer research doubles in 7 to 8 years. (Table 2)
- A total of 1,18,873 publications on cryptography were contributed by 139280 persons from 144 countries. China (18.62%) has highest contribution. It is followed by United States (16.58%) and India (5.29%). Nearly 50% of publications were contributed by China (25935); United States (23099), India (7372); Germany (6424) and Japan (6407). India occupies third place in total number of publications. (Table 3)
- Conference paper constitutes 49.98% of publications. It is followed by journal articles (44.83%); review (1.58%) and book chapter (1.07%). (Table 4)
- As like that of every domain, in cryptography also predominates were given for English languages. Nearly 96% of publications were belongs to English. It is followed by Chinese (4,292) language. (Table 5)
- 33 organisations contributed more than 500 publications. Among the 33 organisations, Xidian University has 1732 publications. It is followed by Beijing University of Posts and Telecommunications (1276); Shanghai Jiaotong University (1192); Chinese Academy of Sciences (1104); University of Waterloo (1065) and Tsinghua University (1030). (Table 6)
- “Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics” has maximum number 15273 (12.85%) of publications.

It is followed by “Physical Review A Atomic Molecular and Optical Physics” (2424, 2.04%) and “Proceedings of SPIE the International Society for Optical Engineering” (2053, 1.73%). (Table 7)

- “Chang, C.C” has contributed nearly 410 publications. It is followed by “Susilo, W” (282); “Preneel, B” (272) and “Yoo, K.Y” (214). (Table 8)
- The word “Cryptography” (50724); the other words that has represented more than 10,000 times were “Security of data” (19953); “Algorithms” (12669); “Authentication” (11434); “Public key cryptography” (11211) and “Network security” (10903). (Table 9)

## Conclusion

The dynamic nature of growth of the domain primarily depends on quality of research. The quality and quantity of research were measured using bibliographic study. In this study the cryptographic domain has been taken up for the study. In the Scopus data base there were nearly 1,18,873 research output. The study uses 40 years publications data from 1976 to 2015 on Cryptography collected from Scopus database. A total of 1,18,873 publications on cryptography were contributed by 1,39,280 persons from 144 countries. It is interesting to China (18.62%) has highest contribution. It is followed by United States (16.58%) and India (5.29%). This study enables to identify the core journals in cryptography.

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