COLLABORATION PATTERN IN CRYPTOGRAPHY RESEARCH OUTPUT (1976 – 2015): A SCIENTOMETRIC STUDY

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ABSTRACT

The Collaboration authorship pattern of research has been given high priority specifically on scientific subject domain. Scientometric analysis has been adopted to quantify 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 authorship pattern of research output, 40 years publications data from 1976 to 2015 collected from Scopus database. A total of 1,21,697 records were identified in the field of “Cryptography”, of which 1,18,873 records (97.68%) are directly related to Cryptography. The solo research paper can be seen only 14.7%. The collaborative research works out to 84.3% and only 1.0% of papers from anonymous. 1,18,873 papers were contributed by 3, 44,703 authors. Nearly 90% of publications were appeared during the period of 2002 and 2015. On an average 2972 articles were published per year during the study period of 40 year i.e. 1976-2015. 50.2% of articles were conference papers and nearly 45.2% of publications were Journal articles. In general this paper enumerates the patterns of authorship, intensity of research-collaboration and measures the collaboration-index in this particular domain by using various authorship pattern indicators.

Key words: Cryptography, Research Output, Authorship Pattern, Collaboration Indicators, Research-Collaboration, Collaboration-index

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1. INTRODUCTION

Cryptography is an academic discipline and primarily used for secure communication. It is the practice and study of techniques in the presence of third parties. The first use of the term *cryptograph* (as opposed to *cryptogram*) dates back to the 19th century - it originated in *The Gold-Bug*, a novel by Edgar Allan Poe (1843)¹. Extensive academic research on cryptography is relatively recent and it began only in the mid-1970s. In the early 20th century, cryptography was chiefly concerned with linguistic and lexicographic patterns. Since then, the emphasis has been shifted, and cryptography now makes extensive use of mathematics, including aspects of information theory, computational complexity, statistics, combinatorics, abstract algebra, number theory, and finite mathematics. It is also a branch of engineering, but an unusual one since it deals with active, intelligent, and malevolent opposition (e.g. cryptographic engineering and security engineering); other kinds of engineering (e.g., civil or chemical engineering) need deal only with neutral natural forces. There is also active research examining the relationship between cryptographic problems and quantum physics. This paper analyses quantitatively the research output of cryptography by using various scientometric indicators especially authorship pattern indicators.

2. REVIEW OF RELATED LITERATURE

During the last few years a large number of bibliometric/scientometric studies of collaborative authorship patterns have been reported. In this review only a few studies have been covered. Elango and Rajendran (2012)² analysed the authorship collection pattern and the trends in the subject of marine science published in the Indian Journal of Marine Science for the period from 2001 to 2010. A study by Dutt, Bharvi and Nikam (2014)³ about the collaborative authorship pattern in the subject of solar cell research in India covered in the Web of Science for the period 1991-2010, which reported that almost half of the total output has both domestic and international collaboration. Natarajan and Kaliyaperumal (2016)⁴ have analysed the bio electrical research output for the period 1989-2014. The study found that most of the authors of different countries collaborated with USA authors. This study also focused the research talents in India on the subject of study as well as the collaborative pattern of Indian authors who have teamed up US, Japanese and South Korea authors. Sharma and Gaurav (2017)⁵ have made attempt of analysing comparatively the research contribution and collaboration pattern of two universities namely Assam University and Tezpur University by using Web of Science covering the period from 1997-2016. It was found that there is noticeable difference between the US under study in terms of productivity. Garg, Kumar and Beb (2018)⁶ analysed the publication output of Indian Scientists in the field of organic chemistry during 2004 and 2013 covered in the Web of Science. The study indicates that collaboration coefficient has increased during 2011 and 2013. Among the institutional collaboration countries, India has published the highest number of papers with USA followed by Germany.

3. OBJECTIVES

The objectives of the study

- To analyse the quantum of publications in the field of cryptography during the study period from 1976 to 2015.
- To study the authorship pattern of cryptographic research output.
- To quantify the DC, CI, CC and MCC in the field of cryptographic research output.
- To arrive at Collaborative Author Index (CAI) for the subject of the study.

4. SOURCE DATABASE - SCOPUS: A BRIEF NOTE

Scopus is the largest abstract and citation database of peer-reviewed literature covering scientific journals, books and conference proceedings. It is comprehensive overview of the world's research output in the fields of science, technology, medicine, social sciences, and arts and humanities, Scopus features smart tools to track, analyze and visualize research. As research becomes increasingly global, interdisciplinary and collaborative, one can make sure that critical research from around the world is not missed by using Scopus. To keep track of what's happening in the research world. Scopus delivers the broadest overview of global, interdisciplinary scientific information. Content on Scopus comes from over 5,000 publishers and must be reviewed and selected by an independent Content Selection and Advisory Board (CSAB) to be, and continue to be, indexed on Scopus. (www.scopus.com)⁷

Data Collection

The study uses 40 years publications data covering 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 records (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.

5. COLLABORATION INDICATORS

Collaboration pattern for the literature in Cryptography has also been administered. The study of collaboration trend or productivity is one of the important aspects in the scientometric analysis. In order to identify collaboration trend and authorship pattern, the researcher has attempted to analyse the following aspects:.

Collaboration pattern has been analysed through in the following indicators:

- Authorship pattern i.e. Single, Multiple authors Frequency
- Collaboration Index (CI) – Ajiferuke, Burrell and Tague (1988)⁸
- Degree of collaboration (DC) - Subramaniam (1983)⁹
- Collaborative Coefficient (CC) - Ajiferuke, Burrell and Tague (1988)⁸
- Modified Collaborative Coefficient (MCC) - Price and Beaver (1996)¹⁰; Ajiferuke, Burrell and Tague (1988)⁸
- Pattern of Co-authorship Index (CAI) Garg & Padhi (2002)¹¹; Guan & Ma (2007)¹²

6. DATA ANALYSIS

Authorship Pattern

Table 1 presents the quantum of publications on cryptography from 1976 to 2015. The author productivity and collaboration in nature were classified as single, two, three, four, five, more than five and anonymous authors.

Table 1 Quantum of Publication by Year *Vs.* Authorship Pattern

S. No.	Year of Publication	Anonymous	Single Author	Two Authors	Three Authors	Four Authors	Five Authors	Six and Above Authors	Total
1	1976	0 (0.0)	3 (0.0)	1 (0.0)	1 (0.0)	0 (0.0)	1 (0.0)	0 (0.0)	6 (0.0)
2	1977	1 (0.0)	19 (0.0)	3 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	24 (0.0)
3	1978	3 (0.0)	21 (0.0)	6 (0.0)	1 (0.0)	1 (0.0)	0 (0.0)	1 (0.0)	33 (0.0)
4	1979	0 (0.0)	21 (0.0)	14 (0.0)	5 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)	41 (0.0)
5	1980	5 (0.0)	38 (0.0)	7 (0.0)	3 (0.0)	0 (0.0)	1 (0.0)	0 (0.0)	54 (0.0)
6	1981	2 (0.0)	32 (0.0)	13 (0.0)	5 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)	53 (0.0)
7	1982	5 (0.0)	45 (0.0)	21 (0.0)	10 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)	82 (0.1)
8	1983	10 (0.0)	104 (0.1)	42 (0.0)	15 (0.0)	2 (0.0)	1 (0.0)	0 (0.0)	174 (0.1)
9	1984	5 (0.0)	68 (0.1)	37 (0.0)	22 (0.0)	3 (0.0)	0 (0.0)	1 (0.0)	136 (0.1)
10	1985	16 (0.0)	61 (0.1)	26 (0.0)	15 (0.0)	5 (0.0)	1 (0.0)	3 (0.0)	127 (0.1)
11	1986	13 (0.0)	63 (0.1)	40 (0.0)	18 (0.0)	1 (0.0)	3 (0.0)	0 (0.0)	138 (0.1)
12	1987	5 (0.0)	81 (0.1)	29 (0.0)	18 (0.0)	4 (0.0)	2 (0.0)	1 (0.0)	140 (0.1)
13	1988	5 (0.0)	80 (0.1)	57 (0.0)	22 (0.0)	10 (0.0)	2 (0.0)	0 (0.0)	176 (0.1)
14	1989	3 (0.0)	62 (0.1)	57 (0.0)	30 (0.0)	6 (0.0)	2 (0.0)	1 (0.0)	161 (0.1)
15	1990	7 (0.0)	82 (0.1)	57 (0.0)	24 (0.0)	8 (0.0)	1 (0.0)	1 (0.0)	180 (0.2)
16	1991	7 (0.0)	64 (0.1)	54 (0.0)	30 (0.0)	7 (0.0)	2 (0.0)	1 (0.0)	165 (0.1)
17	1992	5 (0.0)	70 (0.1)	87 (0.1)	25 (0.0)	10 (0.0)	1 (0.0)	2 (0.0)	200 (0.2)
18	1993	6 (0.0)	109 (0.1)	132 (0.1)	59 (0.0)	19 (0.0)	4 (0.0)	4 (0.0)	333 (0.3)
19	1994	7 (0.0)	151 (0.1)	157 (0.1)	77 (0.1)	23 (0.0)	4 (0.0)	3 (0.0)	422 (0.4)
20	1995	13 (0.0)	274 (0.2)	189 (0.2)	83 (0.1)	31 (0.0)	5 (0.0)	7 (0.0)	602 (0.5)
21	1996	11 (0.0)	292 (0.2)	240 (0.2)	135 (0.1)	47 (0.0)	10 (0.0)	6 (0.0)	741 (0.6)
22	1997	21 (0.0)	324 (0.3)	329 (0.3)	151 (0.1)	61 (0.1)	19 (0.0)	12 (0.0)	917 (0.8)
23	1998	26 (0.0)	358 (0.3)	375 (0.3)	205 (0.2)	75 (0.1)	31 (0.0)	25 (0.0)	1095 (0.9)
24	1999	9 (0.0)	320 (0.3)	411 (0.3)	237 (0.2)	108 (0.1)	43 (0.0)	26 (0.0)	1154 (1.0)
25	2000	25 (0.0)	426 (0.4)	563 (0.5)	332 (0.3)	184 (0.2)	60 (0.1)	54 (0.0)	1644 (1.4)
26	2001	42 (0.0)	523 (0.4)	702 (0.6)	548 (0.5)	247 (0.2)	80 (0.1)	64 (0.1)	2206 (1.9)
27	2002	37 (0.0)	539 (0.5)	773 (0.7)	622 (0.5)	308 (0.3)	108 (0.1)	111 (0.1)	2498 (2.1)
28	2003	80 (0.1)	830 (0.7)	1279 (1.1)	932 (0.8)	464 (0.4)	209 (0.2)	145 (0.1)	3939 (3.3)
29	2004	98 (0.1)	953 (0.8)	1555 (1.3)	1331 (1.1)	660 (0.6)	231 (0.2)	202 (0.2)	5030 (4.2)
30	2005	104 (0.1)	1048 (0.9)	1898 (1.6)	1798 (1.5)	834 (0.7)	313 (0.3)	252 (0.2)	6247 (5.3)
31	2006	93 (0.1)	948 (0.8)	1912 (1.6)	1843 (1.6)	961 (0.8)	386 (0.3)	267 (0.2)	6410 (5.4)
32	2007	86 (0.1)	947 (0.8)	2192 (1.8)	2039 (1.7)	1196 (1.0)	437 (0.4)	381 (0.3)	7278 (6.1)
33	2008	47 (0.0)	979 (0.8)	2373 (2.0)	2340 (2.0)	1401 (1.2)	550 (0.5)	388 (0.3)	8078 (6.8)
34	2009	61 (0.1)	1071 (0.9)	2603 (2.2)	2545 (2.1)	1542 (1.3)	632 (0.5)	410 (0.3)	8864 (7.5)
35	2010	44 (0.0)	1085 (0.9)	2794 (2.4)	2708 (2.3)	1618 (1.4)	703 (0.6)	482 (0.4)	9434 (7.9)
36	2011	40 (0.0)	1199 (1.0)	2894 (2.4)	2820 (2.4)	1850 (1.6)	808 (0.7)	579 (0.5)	10190 (8.6)
37	2012	55 (0.0)	1090 (0.9)	2732 (2.3)	2754 (2.3)	1775 (1.5)	767 (0.6)	549 (0.5)	9722 (8.2)
38	2013	46 (0.0)	1071 (0.9)	2790 (2.3)	2857 (2.4)	1934 (1.6)	880 (0.7)	636 (0.5)	10214 (8.6)
39	2014	56 (0.0)	1073 (0.9)	3137 (2.6)	2983 (2.5)	2064 (1.7)	948 (0.8)	752 (0.6)	11013 (9.3)
40	2015	47 (0.0)	893 (0.8)	2515 (2.1)	2363 (2.0)	1636 (1.4)	825 (0.7)	673 (0.6)	8952 (7.5)
Total		1146 (1.0)	1741 (14.7)	3509 (29.5)	3200 (26.9)	1909 (16.1)	807 (6.8)	603 (5.1)	1188 (100)

Percentage given in Parenthesis

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 of 11,013 publications were published during the year 2014. More than 10000 articles per year can be seen during 2013 (10214) and 2011 (10190). Substantial growth can be seen from the year 2002 onwards. Nearly 90% of publications were appeared during the period of 2002 and 2015. There are 1146 anonymous publications. There is a gradual growth of multiple authorship since 1976 the beginning of the study period. It is interesting to note that two and three authors' contributions are more in this study. The reason may be cryptography is a subject of interdisciplinary subject nature wherein collaborative pattern is possible for research productivity and scholarly communication.

Table 2 Authorship Pattern Vs. Number of Papers

S. No.	Authorship Pattern	Number of Papers	Percentage	Number of Authors	Percentage
1	Single Author	17417	14.7	17417	5.05
2	Two Authors	35096	29.5	70192	20.36
3	Three Authors	32007	26.9	96021	27.86
4	Four Authors	19098	16.1	76392	22.16
5	Five Authors	8070	6.8	40350	11.71
6	Six and above Authors	6039	5.0	43185	12.53
7	Anonymous	1146	1.0	1146	0.33
Total		118873	100	344703	100

It is noticed from Table 2, that the solo research paper can be seen only 14.7%. The collaborated research works out to 84.3% and only 1.0% of papers forms Anonymous authors. Further it can be seen that two authors have contributed more publications (29.5%), followed by three authors (26.9%) and four authors (16.1%). All these 1,18,873 papers were contributed by 3,44,703 authors.

Table 3 Authorship Pattern – Average Publications per Year

Description	Anonymous	Single Author	Two Authors	Three Authors	Four Authors	Five Authors	Six and above Authors	Total
Total publications over 40 years	1146	17417	35096	32007	19098	8070	6039	118873
Average paper per year	28.65	435.425	877.4	800.175	477.45	201.75	150.975	2971.825
Rounded Off	29	435	877	800	477	202	151	2971
Ratio of collaboration	435 : 2516 = 1:6							

The number of collaborated publications and number of authors were also analysed in Table 3. The average number of authors works out to 2.90 which enable us to infer that there are three authors per paper on an average. As seen in Table 3 that on an average 2972 articles were published during the study period of 40 year i.e. 1976-2015. On an average, 435 papers of single author publications, followed by 877 two authors papers; 800 three authors papers; 477 four authors papers; 202 five authors papers and 151 six and above authors papers published per year. The ratio of collaboration works out to 1:6, which means that of six collaborated papers appears, there will be one solo research paper. The highest numbers of average papers per year (877.4) were by two authors' publications, followed by three authors

(800.175). The lowest numbers of papers (150.975) have been noticed by six and above authors.

Table 4 Authorship Pattern Vs. Block Year of Publication

S. No.	Authorship Pattern	Between 1976 and 1985	Between 1986 and 1995	Between 1996 and 2005	Between 2006 and 2015	Total
1	Single Author	412 (0.3)	1036 (0.9)	5613 (4.7)	10356 (8.7)	17417 (14.7)
2	Two Authors	170 (0.1)	859 (0.7)	8125 (6.8)	25942 (21.8)	35096 (29.5)
3	Three Authors	78 (0.1)	386 (0.3)	6291 (5.3)	25252 (21.2)	32007 (26.9)
4	Four Authors	14 (0.0)	119 (0.1)	2988 (2.5)	15977 (13.4)	19098 (16.1)
5	Five Authors	4 (0.0)	26 (0.0)	1104 (0.9)	6936 (5.8)	8070 (6.8)
6	Six and above Authors	5 (0.0)	20 (0.0)	897 (0.8)	5117 (4.3)	6039 (5.1)
7	Anonymous	47 (0.0)	71 (0.1)	453 (0.4)	575 (0.5)	1146 (1.0)
Total		730 (0.6)	2517 (2.1)	25471 (21.4)	90155 (75.8)	118873 (100)

The entire period of study has been grouped in four block years such as 1976-1985, 1986-1995, 1996-2005 and 2006 and 2015. The authorship pattern has been calculated based on block year wise and the same has been shown in Table 4. Almost 75.8% of the publications were published in the fourth block year (2006-2015). This also reveals that 56.4% of the total publications belong to two and three authors of which almost 43% were published in the fourth block year period (2006-2015). Solo research was evident during the first two block years i.e. between 1976 and 1985 & between 1986 and 1995. From the block year 1996-2005 and 2006 -2015 onwards, collaborative research was evident. Further it is observed that cryptography research trend gaining momentum after 2006. It is also inferred that there is an increasing trend of growth of research output from first block year period to the succeeding block year period groups.

Table 5 Authorship Pattern Vs. Bibliographic Form

S. No.	Bibliographic Form	Single Author	Two Authors	Three Authors	Four Authors	Five Authors	Six and above Authors	Anonymous	Total
1	Articles	8649 (7.3)	15671 (13.2)	14059 (11.8)	8555 (7.2)	3770 (3.2)	2923 (2.5)	114 (0.1)	53741 (45.2)
2	Books	314 (0.3)	169 (0.1)	58 (0.0)	18 (0.0)	14 (0.0)	8 (0.0)	1 (0.0)	582 (0.5)
3	Book Chapters	353 (0.3)	398 (0.3)	265 (0.2)	148 (0.1)	57 (0.0)	53 (0.0)	1 (0.0)	1275 (1.1)
4	Conference Papers	6869 (5.8)	18276 (15.4)	17194 (14.5)	10168 (8.6)	4130 (3.5)	2962 (2.5)	47 (0.0)	59646 (50.2)
5	Conference Reviews	4 (0.0)	7 (0.0)	2 (0.0)	4 (0.0)	1 (0.0)	0 (0.0)	893 (0.8)	911 (0.8)
6	Editorials	95 (0.1)	117 (0.1)	50 (0.0)	20 (0.0)	11 (0.0)	6 (0.0)	11 (0.0)	310 (0.3)
7	Erratum	7 (0.0)	8 (0.0)	4 (0.0)	1 (0.0)	1 (0.0)	0 (0.0)	3 (0.0)	24 (0.0)
8	Letters	33 (0.0)	42 (0.0)	30 (0.0)	17 (0.0)	11 (0.0)	5 (0.0)	0 (0.0)	138 (0.1)
9	Notes	85	10	8	2	1	2	20	128

		(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)
10	Reports	13 (0.0)	3 (0.0)	2 (0.0)	1 (0.0)	2 (0.0)	0 (0.0)	0 (0.0)	21 (0.0)
11	Reviews	815 (0.7)	380 (0.3)	331 (0.3)	162 (0.1)	70 (0.1)	75 (0.1)	42 (0.0)	1875 (1.6)
12	Short Surveys	180 (0.2)	15 (0.0)	4 (0.0)	2 (0.0)	2 (0.0)	5 (0.0)	14 (0.0)	222 (0.2)
Total		17417 (14.7)	35096 (29.5)	32007 (26.9)	19098 (16.1)	8070 (6.8)	6039 (5.1)	1146 (1.0)	118873 (100.0)

Percentage given in Parenthesis

Table 5 shows the bibliographic form of publications in the study. Conference proceedings (59646) amounts to the most preferred bibliographic form for publishing the cryptographic research. This is followed by journal articles (53741) and only 1275 publications represent book chapters. The other forms of publications are less significant and less preferred channels of publications. Out of 53,741 (45.2%) journal articles, nearly 29,730 articles were by two authors and three authors. Similarly out of 59,646 (50.2%) conference papers, 35470 articles were by two authors and three authors. Conference papers were more than journal articles. In the cryptography conferences were given due importance by the scientists.

The authorship pattern also analysed based on various indicators such as Degree of Collaboration (DC), Collaborative Index (CI), Collaborative Coefficient (CC) and Modified Collaborative Coefficient (MCC) which is shown in Table 6.

Table 6 Authorship Pattern Indicators Vs Quantum of Publications Per Year

S. No.	Year of Publication	Number of Papers	DC	CI	CC	MCC
1	1976	6	0.50	2.17	0.33	0.34
2	1977	24	0.21	1.17	0.13	0.14
3	1978	33	0.36	1.39	0.25	0.26
4	1979	41	0.49	1.66	0.27	0.28
5	1980	54	0.30	1.22	0.21	0.21
6	1981	53	0.40	1.45	0.24	0.24
7	1982	82	0.45	1.48	0.28	0.29
8	1983	174	0.40	1.41	0.25	0.26
9	1984	136	0.50	1.66	0.30	0.31
10	1985	127	0.52	1.58	0.36	0.37
11	1986	138	0.54	1.57	0.35	0.36
12	1987	140	0.42	1.61	0.26	0.27
13	1988	176	0.55	1.76	0.33	0.33
14	1989	161	0.61	1.90	0.36	0.37
15	1990	180	0.54	1.73	0.33	0.34
16	1991	165	0.61	1.85	0.37	0.38
17	1992	200	0.65	1.88	0.38	0.39
18	1993	333	0.67	2.01	0.40	0.41
19	1994	422	0.64	1.96	0.38	0.39
20	1995	602	0.54	1.81	0.33	0.33
21	1996	741	0.61	1.96	0.36	0.37
22	1997	917	0.65	2.01	0.39	0.40
23	1998	1095	0.67	2.13	0.41	0.42
24	1999	1154	0.72	2.30	0.44	0.45
25	2000	1644	0.74	2.38	0.46	0.47
26	2001	2206	0.76	2.42	0.48	0.49
27	2002	2498	0.78	2.56	0.50	0.51
28	2003	3939	0.79	2.53	0.50	0.51

29	2004	5030	0.81	2.60	0.52	0.53
30	2005	6247	0.83	2.67	0.53	0.55
31	2006	6410	0.85	2.76	0.55	0.56
32	2007	7278	0.87	2.84	0.56	0.58
33	2008	8078	0.88	2.90	0.57	0.59
34	2009	8864	0.88	2.90	0.57	0.59
35	2010	9434	0.88	2.93	0.57	0.59
36	2011	10190	0.88	2.98	0.58	0.59
37	2012	9722	0.89	2.99	0.58	0.60
38	2013	10214	0.90	3.05	0.59	0.61
39	2014	11013	0.90	3.07	0.59	0.61
40	2015	8952	0.90	3.10	0.60	0.61
Total		118873	0.85	2.83	0.55	0.57

The degree of collaboration of cryptographic research during the study period ranges between 0.21 and 0.90. The DC for any subject ranges from 0.01 to 0.99 and it is always below 1.00. The average degree of collaboration in this study is 0.85. The CI ranges between 1.17 and 3.10 with an average of 2.83. The value of CC is between 0.13 and 0.60 and the average is 0.55. During the study period the MCC is between 0.14 and 0.61 and the average is 0.57. Further it is observed that there is a fluctuation trends in the values of DC, CI, CC and MCC during the study period. However, on the other hand one can notice an increasing trend during the study period in all the values of DC, CI, CC and MCC.

Further the authorship pattern for block years were also analysed based on degree of collaboration (DC), Collaborative Index (CI), Collaborative coefficient (CC) and MCC which is shown in Table 7.

Table 7 Authorship Pattern Indicators Vs Block Year of Publications

S. No.	Block Year	Total	DC	CI	CC	MCC
1	Between 1976 and 1985	730	0.44	1.50	0.28	0.28
2	Between 1986 and 1995	2517	0.59	1.84	0.35	0.36
3	Between 1996 and 2005	25471	0.78	2.50	0.49	0.51
4	Between 2006 and 2015	90155	0.89	2.96	0.58	0.59
Total		118873	0.85	2.83	0.55	0.57

The degree of collaboration for block years ranges between 0.44 and 0.89 and the average is 0.85. This indicates that there is existence of collaborative research in the field of Cryptography. The CI is between 1.50 and 2.96 and average of CI is 2.83. Similarly the Collaborative coefficient is between 0.28 and 0.58 and the average is 0.55. The MCC value ranges between 0.28 and 0.59 and the average is 0.57.

The co-authorship index for single, two, three, four, five, more than five and anonymous authors were calculated on year wise and the same is shown in the Table 8.

Table 8 Authorship Pattern Vs. Collaborative Authorship Index (CAI)

S. No.	Year	Single Author	CAI	Two Authors	CAI	Three Author	CAI	Four Authors	CAI	Five Authors	CAI	Six and above Authors	CAI	Total
1	1976	3	341.26	1	56.45	1	61.90	0	0.00	1	245.50	0	0.00	6
2	1977	19	540.32	3	42.34	1	15.47	0	0.00	0	0.00	0	0.00	24
3	1978	21	434.33	6	61.58	1	11.25	1	18.86	0	0.00	1	59.65	33
4	1979	21	349.58	14	115.66	5	45.29	1	15.18	0	0.00	0	0.00	41
5	1980	38	480.29	7	43.91	3	20.63	0	0.00	1	27.28	0	0.00	54
6	1981	32	412.08	13	83.08	5	35.04	1	11.74	0	0.00	0	0.00	53
7	1982	45	374.55	21	86.74	10	45.29	1	7.59	0	0.00	0	0.00	82
8	1983	104	407.94	42	81.76	15	32.02	2	7.15	1	8.47	0	0.00	174
9	1984	68	341.26	37	92.15	22	60.08	3	13.73	0	0.00	1	14.47	136
10	1985	61	327.82	26	69.34	15	43.87	5	24.51	1	11.60	3	46.50	127
11	1986	63	311.58	40	98.18	18	48.44	1	4.51	3	32.02	0	0.00	138
12	1987	81	394.88	29	70.16	18	47.75	4	17.78	2	21.04	1	14.06	140
13	1988	80	310.23	57	109.70	22	46.42	10	35.37	2	16.74	0	0.00	176
14	1989	62	262.83	57	119.92	30	69.20	6	23.20	2	18.30	1	12.23	161
15	1990	82	310.92	57	107.26	24	49.52	8	27.66	1	8.18	1	10.94	180
16	1991	64	264.73	54	110.85	30	67.53	7	26.41	2	17.85	1	11.93	165
17	1992	70	238.88	87	147.34	25	46.42	10	31.12	1	7.37	2	19.68	200
18	1993	109	223.40	132	134.26	59	65.80	19	35.51	4	17.69	4	23.64	333
19	1994	151	244.22	157	126.01	77	67.77	23	33.92	4	13.96	3	13.99	422
20	1995	274	310.64	189	106.34	83	51.21	31	32.05	5	12.23	7	22.89	602
21	1996	292	268.95	240	109.70	135	67.66	47	39.48	10	19.88	6	15.94	741
22	1997	324	241.15	329	121.52	151	61.16	61	41.41	19	30.52	12	25.76	917
23	1998	358	223.14	375	116.00	205	69.53	75	42.63	31	41.70	25	44.94	1095
24	1999	320	189.26	411	120.63	237	76.27	108	58.25	43	54.89	26	44.35	1154
25	2000	426	176.86	563	115.99	332	75.00	184	69.66	60	53.76	54	64.66	1644
26	2001	523	161.81	702	107.78	548	92.26	247	69.69	80	53.42	64	57.11	2206
27	2002	539	147.27	773	104.81	622	92.48	308	76.75	108	63.69	111	87.47	2498
28	2003	830	143.81	1279	109.98	932	87.88	464	73.32	209	78.16	145	72.46	3939
29	2004	953	129.31	1555	104.71	1331	98.28	660	81.67	231	67.65	202	79.05	5030
30	2005	1048	114.50	1898	102.91	1798	106.89	834	83.10	313	73.80	252	79.40	6247
31	2006	948	100.94	1912	101.03	1843	106.78	961	93.32	386	88.70	267	81.99	6410
32	2007	947	88.81	2192	102.01	2039	104.05	1196	102.29	437	88.45	381	103.05	7278
33	2008	979	82.72	2373	99.50	2340	107.58	1401	107.95	550	100.29	388	94.55	8078
34	2009	1071	82.46	2603	99.46	2545	106.63	1542	108.28	632	105.03	410	91.05	8864
35	2010	1085	78.50	2794	100.31	2708	106.61	1618	106.75	703	109.77	482	100.57	9434
36	2011	1199	80.31	2894	96.19	2820	102.78	1850	113.00	808	116.80	579	111.85	10190
37	2012	1090	76.52	2732	95.18	2754	105.21	1775	113.64	767	116.21	549	111.16	9722
38	2013	1071	71.57	2790	92.52	2857	103.88	1934	117.86	880	126.91	636	122.57	10214
39	2014	1073	66.50	3137	96.48	2983	100.60	2064	116.65	948	126.80	752	134.41	11013
40	2015	893	68.08	2515	95.16	2363	98.04	1636	113.75	825	135.75	673	147.98	8952
Total		17417	100	35096	100	32007	100	19098	100	8070	100	6039	100	118873

The CAI for single authored publications during the study period is high from 1993 onwards which starts from 109 in year 1993 and 893 in 2015. During this period there is fluctuation of results for single author publications. Similarly, for two author articles from 1988 onwards it is an interesting trend upto 2010 which is 100.31. However, since 2011 it is in decreasing trend which is less than 100. On the other hand, the CAI for three and more than three authors has shown fluctuation trend.

Table 9 Co-Authorship Index (CAI) in Coded Form

S. No.	Year of Publication	CAI	CAI	CAI	CAI	CAI	CAI
		Single Author	Two Authors	Three Authors	Four Authors	Five Authors	More than Five Authors
1	1976	++	--	--	--	++	--
2	1977	++	--	--	--	--	--
3	1978	++	--	--	--	--	--
4	1979	++	++	--	--	--	--
5	1980	++	--	--	--	--	--
6	1981	++	--	--	--	--	--
7	1982	++	--	--	--	--	--
8	1983	++	--	--	--	--	--
9	1984	++	--	--	--	--	--
10	1985	++	--	--	--	--	--
11	1986	++	--	--	--	--	--
12	1987	++	--	--	--	--	--
13	1988	++	++	--	--	--	--
14	1989	++	++	--	--	--	--
15	1990	++	++	--	--	--	--
16	1991	++	++	--	--	--	--
17	1992	++	++	--	--	--	--
18	1993	++	++	--	--	--	--
19	1994	++	++	--	--	--	--
20	1995	++	++	--	--	--	--
21	1996	++	++	--	--	--	--
22	1997	++	++	--	--	--	--
23	1998	++	++	--	--	--	--
24	1999	++	++	--	--	--	--
25	2000	++	++	--	--	--	--
26	2001	++	++	--	--	--	--
27	2002	++	++	--	--	--	--
28	2003	++	++	--	--	--	--
29	2004	++	++	--	--	--	--
30	2005	++	++	++	--	--	--
31	2006	++	++	++	--	--	--
32	2007	--	++	++	++	--	++
33	2008	--	--	++	++	++	--
34	2009	--	--	++	++	++	--
35	2010	--	++	++	++	++	++
36	2011	--	--	++	++	++	++
37	2012	--	--	++	++	++	++
38	2013	--	--	++	++	++	++
39	2014	--	--	++	++	++	++
40	2015	--	--	--	++	++	++

In order to identify the priority status of research productivity index, the values are replaced with symbol (Benchmark) as suggested by Barre (1987), CAI has been further simplified as symbolic representation as CAI =100 for the normal average of co-authorship index then the value of more than 100 value is called above average as ‘++’, less than 100 values called as below average of CAI as ‘--’ and the same is shown in Table 9.

It is seen from the table 9 that the solo research was in decreasing trend, where as there is an increasing trend when compared to the other authorship pattern. This indicates that the collaborative research were in increasing trend specifically after 2006.

The single author trend has been seen “++” during the period 1976-2006. Similarly the two authors trend gaining momentum during the period 1988-2007 where as other authorship pattern such as three authors, four authors and above can be seen from 2006 onwards. The collaborative researches were gaining momentum since 2006 onwards.

7. MAJOR FINDINGS

The findings of the study were

- A total of 1,21,697 records were identified in the field of “Cryptography”, out of which 1,18,873 research literatures (97.68%) are directly related to Cryptography. (Table 1)
- On an average 2972 articles were published during the study period of 40 year i.e. 1976-2015 (Table 1).
- The solo research paper can be seen only 14.7%, and collaborated research works out to 84.3% . Only 1.0% of papers from anonymous (Table 1).
- The 1,18,873 papers were contributed by 3, 44,703 authors (Table 2).
- The average number of authors works out to 2.90 which enable us to infer that there were three authors in an average per paper (Table 3).
- On an average, 435 papers by single author publications. It is followed by 877 two authors paper; 800 three authors paper; 477 four authors papers; 202 five authors paper and 151 six and above authors papers were appearing on average per year (Table 3).
- Solo research was evident during the first two block years i.e. between 1976 and 1985; between 1986 and 1995. From the block year 1996-2005 and 2006 -2015 collaborative research were evident (Table 4).
- The degree of collaboration ranges between 0.21 and 0.90 and the average is 0.85. This indicates that there is existence of collaborative research in the field of Cryptography (Table 5).
- 50.2% of articles were conference papers. Nearly 45.2% of publications were Journal articles (Table 6).
- The average of CI is 2.83 and the Collaborative coefficient is 0.55. The MCC value ranges between 0.14 and 0.61 and the average MCC is 0.57 (Table 6 and Table 7).
- The CAI for three and more than three authors has shown fluctuation trend (Table 8).
- Collaborative research gaining momentum since 2006 onwards in the field of cryptography (Table 9).

8. CONCLUSIONS

This study carried out with the objective to enumerate the patterns of authorship, intensity of research-collaboration and to measure the collaboration-index in this particular domain. To analyse the collaborative trend of cryptography research output, 40 years publications (1976-2015) of 1,18,873 research articles during the period 1976 to 2015 collected from Scopus database. In this study, the Collaboration trend on Cryptographic research output has been analysed using the indicators such as Authorship pattern i.e. Single, Multiple authors Frequency, Collaboration Index (CI), Degree of collaboration (DC), Collaborative Coefficient (CC), Modified Collaborative Coefficient (MCC) and Pattern of Co-authorship Index (CAI). The collaborated research works out to 84.3% which shows that collaborative research can be seen in the field of cryptographic research. The same has been experienced by Hazarika et al (1995)¹³; Shokeen and Kaushik (2004)¹⁴ and Zainab et al (2009)¹⁵. Conference papers were more than journal articles in cryptography research output. Out of 53,741 (45.2%) journal articles, nearly 29,730 articles were two authors and three authors’ publications. Similarly, out of 59,646 (50.2%) conference papers 35470 articles were two authors and three authors’ publications. The overall research output on cryptography shows multi authored works that

outnumbered the solo research. The authorship indicators used in this paper shows exponential growth during the study period.

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