

# Quantum Computing Applications: A Patent Landscape Report



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## • Headlines

- Patenting in the field of Quantum Communication, Cryptology, Algorithm and Computation has risen rapidly over the last three years – patent family publications are projected to increase by 350% between 2014 and 2017
- Over the same time period there are nearly twice as many quantum application patent families as there are involving the quantum computers themselves
- Chinese organizations are dominating the patenting of quantum applications with nearly three times as many patent families projected for 2017 as the United States, the next closest country – They are particularly interested in cryptology
- Chinese firms, Qasky, QuantumCTek, and Shenzhou Quantum are worth watching for the future considering the enormous patent portfolios they are building. These firms tend to focus on methods and protocols including Quantum Key Distribution (QKD), but when combined with Chinese Universities like The University of Science and Technology of China, and The Chinese Academy of Sciences that have significant portfolios associated with hardware aspects they could produce a powerful combination



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## • Headlines

- Japanese firms, NEC, NTT, and Toshiba have some of the largest portfolios, and have been interested in the field for decades – they tend to patent both on the methods and protocols as well as the hardware associated with quantum cryptology, and communication
- Raytheon has a substantial portfolio in Quantum Information Technology (QIT) – they have four Qubit Technology patent families, but most of their patenting is in applications, especially cryptology and communication
- Quantum computer manufacturers are patenting more generally on quantum computational methods as opposed to non-manufacturers who are focusing specifically on quantum cryptology and communication
- Approximately 76% of the academic patent families published in the field of quantum applications since 2012 have been from Chinese Universities
- Qinetiq, Raytheon, and Magiq Technologies are three non-Asian companies to watch closely in the field of quantum applications, but Magiq stopped publishing patents in the area in 2012



## • Headlines

- Yamaha and British Telecom have highly influential patent portfolios in the categories of quantum algorithms, and cryptology respectively, but both companies have allowed their patents to go abandoned
- The Yamaha and British Telecom documents are now in the public domain and could be essential technologies to build from, or use in products by existing, and new entrants to the field



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## • Executive Summary

- Patenting in the field of Quantum Communication, Cryptology, Algorithm and Computation has risen rapidly over the last three years
  - Patent family publications are projected to increase by 350% between 2014 and 2017
- The majority of the recent growth is coming from the Quantum communications, and cryptology areas, which are highly correlated, but not identical
- Since 2011, the number of publications in this area listing China as the priority country have grown by a factor of 23
  - Chinese firms Qasky, and Shenzhou Quantum have relatively young portfolios, but have published an enormous number of families in the last few years
  - QuantumCTek has a smaller portfolio, but has been patenting since 2009
- Half of the top eight companies in terms of portfolio size, including the top three, are Japanese: NEC, NTT, and Toshiba
- D-Wave, Microsoft, Raytheon, IBM and Nokia are North American and European with substantial portfolios that are projected to increase their patenting activity in quantum applications in 2017
  - Raytheon was a smaller player in the previous report on quantum computing with four patent families on Qubit Technologies



## • Executive Summary

- Asian organizations, especially Japanese and Chinese companies are primarily interested in quantum cryptology, and communications
  - Japanese companies generally take a broader approach to these categories patenting in both software, and hardware associated with bringing these applications to market
  - Chinese companies tend to focus more on the method and protocol related aspects including Quantum Key Distribution
  - Two top Chinese Universities, on the other hand, The University of Science and Technology of China and The Chinese Academy of Sciences have significant portfolios associated with the hardware aspects that are also being patented by Japanese companies
  - Cooperation between Chinese Universities and corporate entities would produce a powerful combination
- North American computer manufacturing companies like D-Wave, Microsoft, and IBM on other hand are interested in other, more general computational methods associated with their interest in the quantum computers themselves
- Other North American and European companies like Raytheon, HP, and Nokia, who don't necessarily look as if they will be producing quantum computers look more like Asian companies with an emphasis on quantum cryptology and communications



## • Executive Summary

- Approximately 76% of the academic patent families published in the field of quantum applications since 2012 have been from Chinese Universities
  - US Universities come in a distant second with 14% of the families
  - Three Chinese Universities – Nanjing University, Beijing University, and Zhejiang University Of Technology, have some of the largest patent portfolios in quantum algorithms, each with more than 10 patent families
- The following companies are projected to emerge with the most patent families for 2017 in the four categories covered in this report:
  - Quantum Cryptology – Shenzhou Quantum
  - Quantum Communication – Toshiba
  - Quantum Computation – Microsoft
  - Quantum Algorithms – LG/Alibaba (tied with four)
- MagiQ Technologies, Qinetiq, Raytheon, NEC, Toshiba and British Telecom have the largest number of citation links indicating they own influential patent families within the quantum cryptology field
  - Qinetiq and British Telecom are even more interesting since their portfolios are much smaller than the others





## • Executive Summary

- Similar results pertaining to the citation network for quantum communication can be seen with MagiQ Technologies, Qinetiq, Raytheon, NEC, Toshiba and British Telecom emerging as the most influential organizations in the area
  - These results clearly point to Raytheon, and Qinetiq as companies to watch in addition to the Asian leading companies in the quantum information technology (QIT) field
  - British Telecom is also highly regarded in these categories, but all of their patents have been abandoned putting these lynchpin assets in the public domain
- The citation network for general quantum computation reflects the key players seen in the original report on quantum computers mainly D-Wave, IBM, Microsoft and Northrop Grumman
  - Other influential portfolios can be found from 1QBit, Google, WARF, and Stanford
- Yamaha's emerges from the citation network in quantum algorithms
  - They account for significantly more forward citations than any other organization in this field despite only having five publications in the collection
  - Yamaha's portfolio, like British Telecom in QKD has been abandoned, and should certainly be consulted since they are now in the public domain
  - The STMicroelectronics portfolio is also influential, but it is still in-force, and in one case is co-assigned with Yamaha





# ***INTRODUCTION***

# • Definitions of Quantum Applications

- Quantum computers have fundamental differences in how they operate compared to the supercomputers of today. Classical computing is built at a base level on bytes which are used to perform calculations and each bit represents either a 1 or 0. Quantum computing is built on quantum bits, known as qubits, and these particles not only represent 1's and 0's but due to the quantum mechanical property of superposition, can actually exist as both 1 and 0 at the same time and any combination in between. This means that methods of programming a traditional computer can't be used to create applications on a quantum computer. Quantum computers are also specially suited for solving certain types of problems as opposed to classical computing
- While quantum computers will be used for a variety of applications this report focuses on the following four areas representing the largest number of patent filings over the past 20 years
  - Quantum cryptology: Most of the encryption systems employed around the world that are used to safeguard everything from personal data like banking information to highly confidential corporate and governmental data, are based on prime factorization of large numbers. For classical computers the task of factoring the encryption keys is nearly impossible, but this is not the case for quantum computers as they would be able to break every encryption method currently used. New quantum encryption methods including quantum key distribution (QKD) are being developed to address these issues
  - Quantum communication: Entangled particles remain connect so actions performed on one can impact the other even if they are separated by a large distance. A transfer of state between these particle, mainly photons can take place at a speed of more than 10,000 times the speed of light. Communication networks based on these principles would provide an essentially instantaneous method of sharing information. Quantum cryptology is often associated with this area, but there are differences between them.
  - Quantum computation: In many patents general methods of performing calculations using a quantum computer are discussed. This category captures general quantum computing methods and other applications other than cryptology and communication
  - Quantum algorithms: Algorithms that run on a realistic model of quantum computation, generally using some essential feature of such as quantum superposition, or quantum entanglement



# • Quantum Applications Patent Landscape Report

- The present patent landscape report (PLR) covers worldwide published patent applications and grants in the space of quantum applications. There is some overlap between the contents of this report and the one done previously on quantum computing. See <https://patinformatics.com/quantum-computing-report/> for a copy of the original report.
- Due to the potential disruption this technology will cause it's not surprising to see so many different organizations represented in the patent landscape. For this reason, the PLR has been broken up into three different segments: a look at quantum computing from a corporate perspective, an academic perspective and a government perspective.
- Within each of the segments, the patent families have been classified into four categories based on the definitions provided on the previous slide.
- Spatial concept maps labeled by the main concept areas have been generated with colored highlights based on the key patent assignees by organization type.

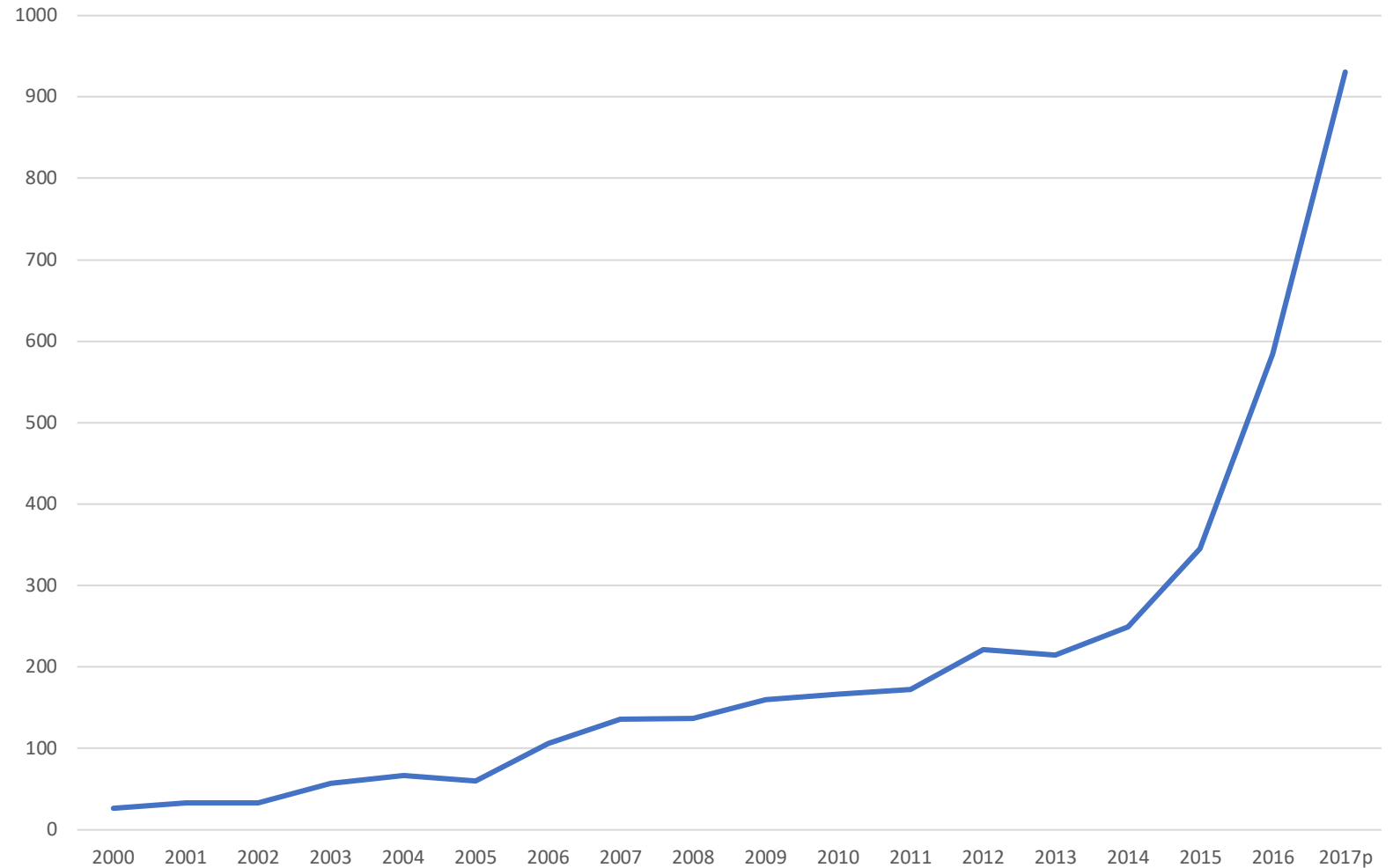


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# ***GENERAL STATISTICS***

# • Overall Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Publication Year

- The fields of quantum communication, cryptology, algorithms and computation have experienced exponential growth over the last two years, and that is projected to continue through 2017
- These areas began showing steady growth beginning in 2005 and lasting until the explosion in growth that began in 2014
- Since 2014 filings are projected to increase by over 350% for 2017

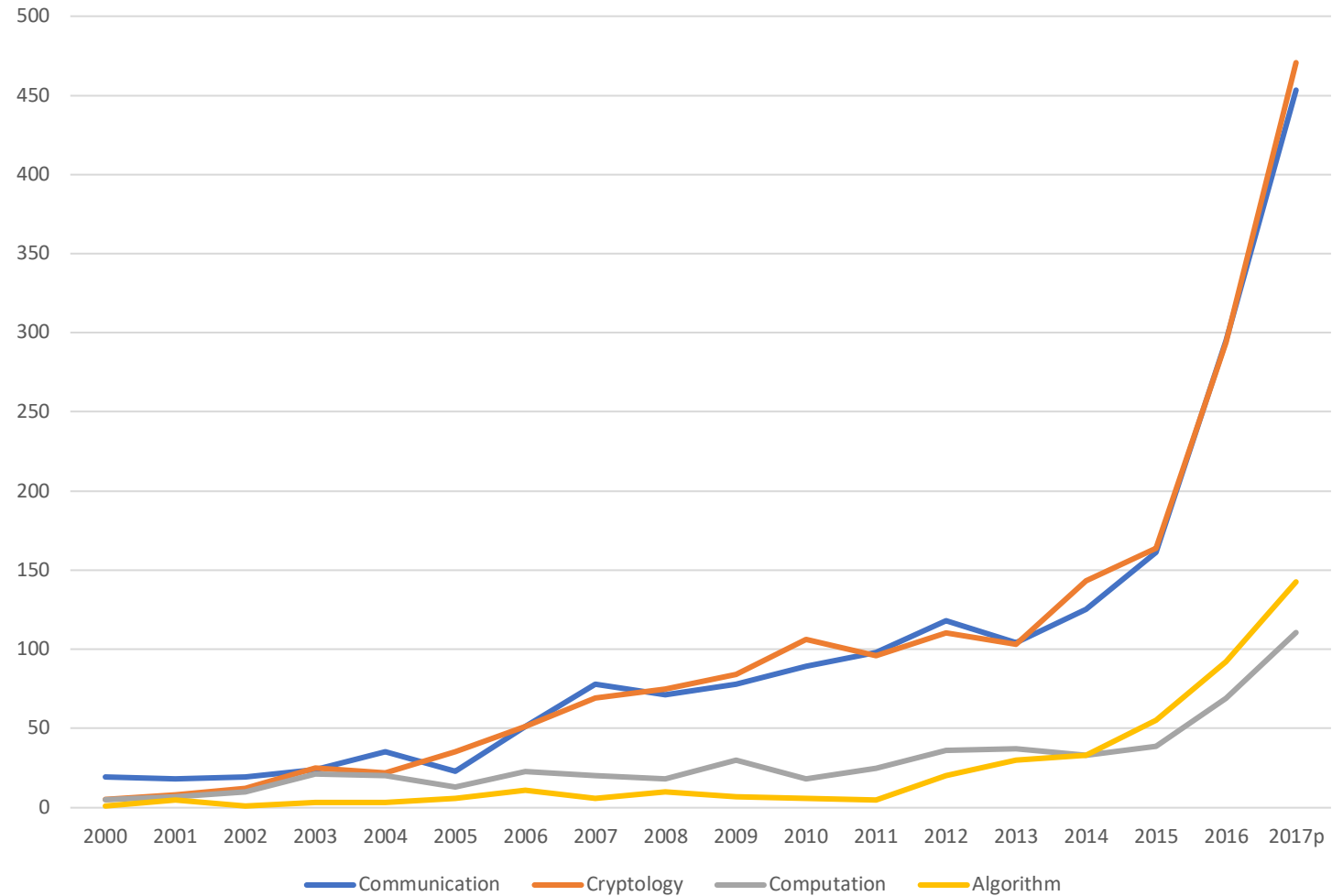


Note: Based on 3,618 Quantum Communication, Cryptology, Algorithm and Computation patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country; Currently 698 documents for 2017.

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# • Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Category and Publication Year

- There is a strong correlation between communication, and encryption, since many of the communication methods involve encryption, but these two areas are still distinct
- Quantum communication and encryption have experienced an exponential jump in growth beginning in 2014
- Quantum algorithms and computation methods began to see an increase in interest beginning in 2015

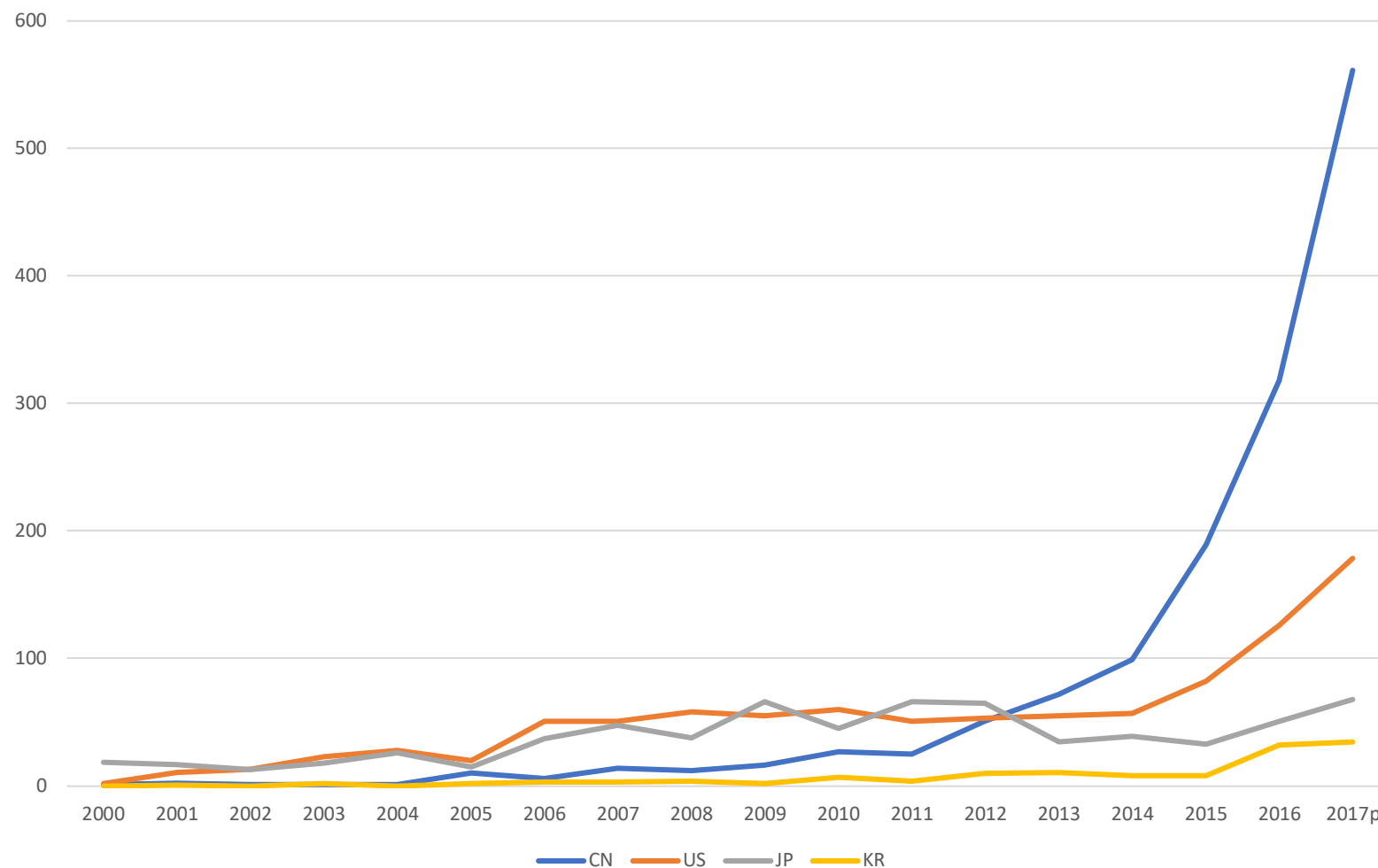


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# Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Priority Country and Publication Year

- Since 2011, the number of publications that listed China as the priority country have grown by a factor of 23, clearly illustrating high interest in these applications, especially quantum cryptography, and communications
- After nearly a decade of sustained interest, publications listing the United States as the priority country have grown by more than 300% over the last three years



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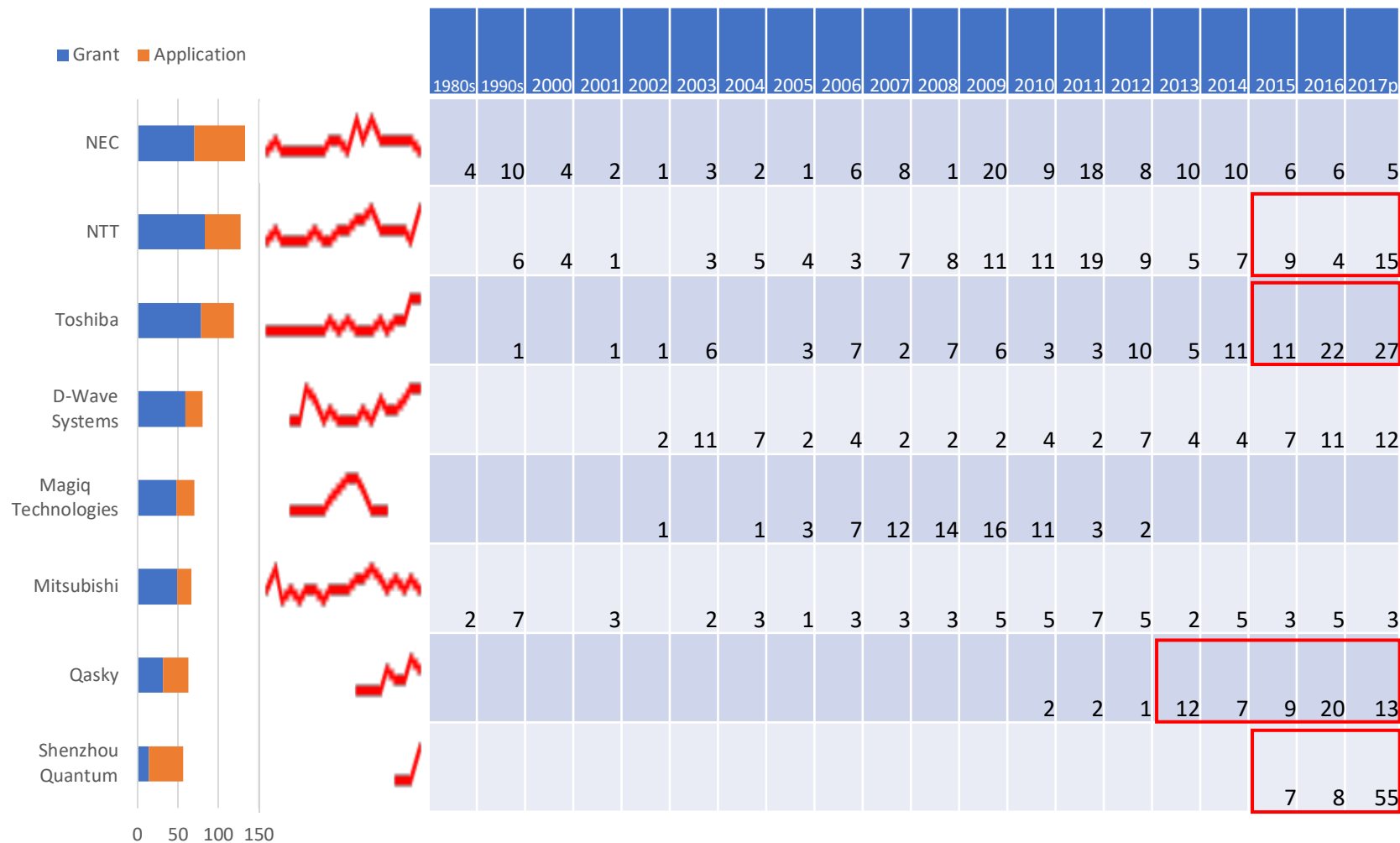
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# ***CORPORATE DISCUSSION***

# Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Top Companies

- Half of the top eight companies in terms of collection size, including the top three, are Japanese: NEC, NTT, and Toshiba; All of these organizations have been interested in quantum communication, cryptology, algorithms and computation since the 1990's.
- Chinese firms Qasky, and Shenzhou Quantum have relatively young portfolios, but have published an enormous number of families in the last few years
- D-Wave Systems has also shown an increase in activity over the last three years, unlike MagiQ who have not published any quantum related documents since 2012

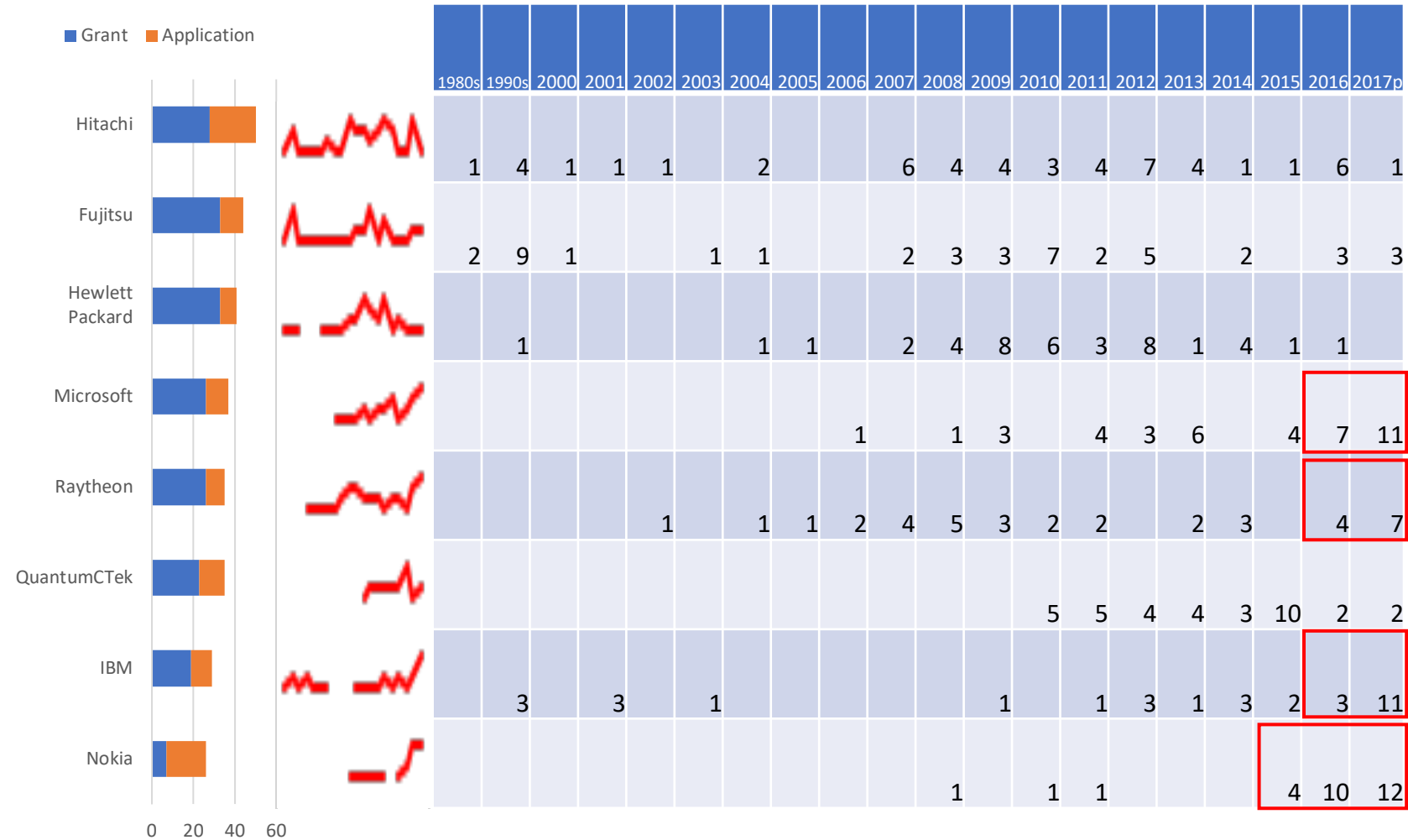


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# Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Top Companies Continued...

- D-Wave, Microsoft, Raytheon, IBM and Nokia are the only North American and European companies projected to increase their activity in quantum applications in 2017
- Similar to the other top Japanese firms, both Hitachi and Fujitsu have a long history dating back to the 1980's of interest in these fields
- Hewlett Packard has only published two families since 2014
  - QuantumCTek, has published 14 over that same time period (10 in 2015)

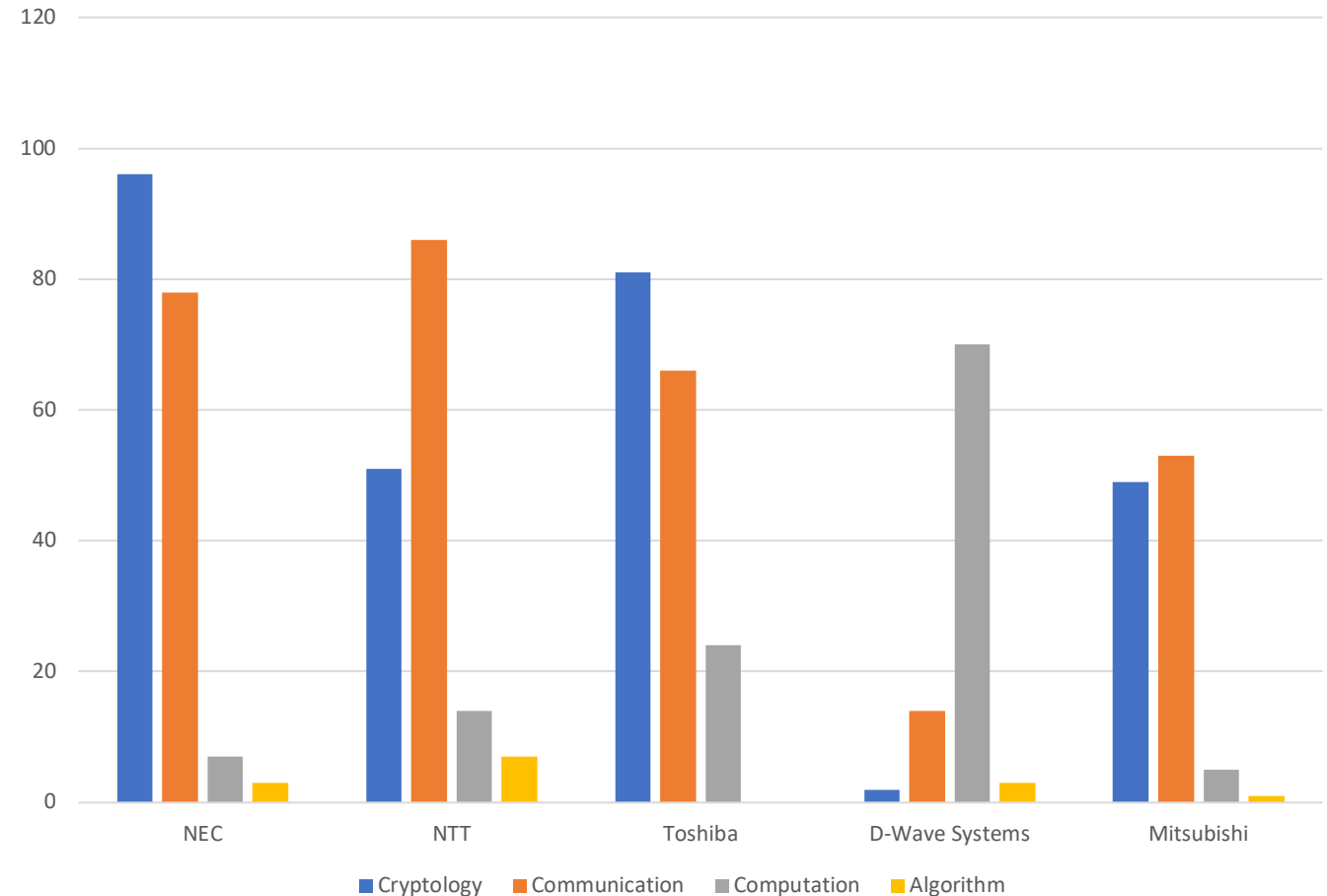


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# • Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Top Companies and Category

- The Japanese companies in quantum applications display a similar distribution by category
- Quantum cryptology and communication are the two largest categories for each Japanese organization
  - NEC and Toshiba both slightly favor cryptology, while NTT, and to a lesser degree Mitsubishi favor communication
- D-Wave, by comparison is mostly interested in other types of computational methods including graphing and image recognition

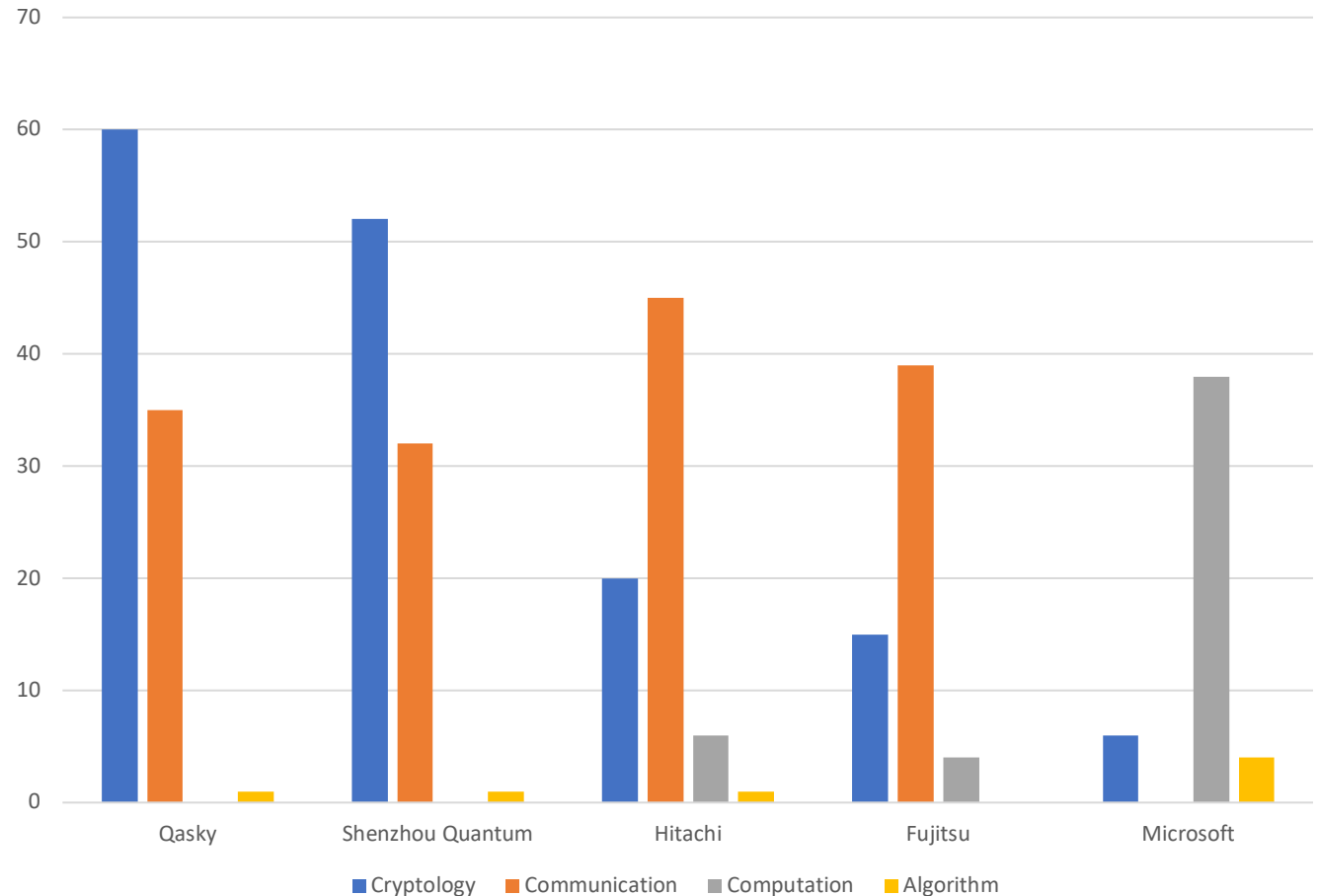


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# • Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Top Companies and Category

- Qasky, and Shenzhou have almost identical distributions within their portfolios with a heavy focus on quantum cryptology
  - Generally, they are also quite similar to the leading Japanese companies in this study
- Japanese companies Hitachi, and Fujitsu follow a similar patenting pattern as other Asian companies, but they are focused on quantum communications
- Microsoft, like D-Wave, as a computer manufacturer takes a more general approach to quantum computation

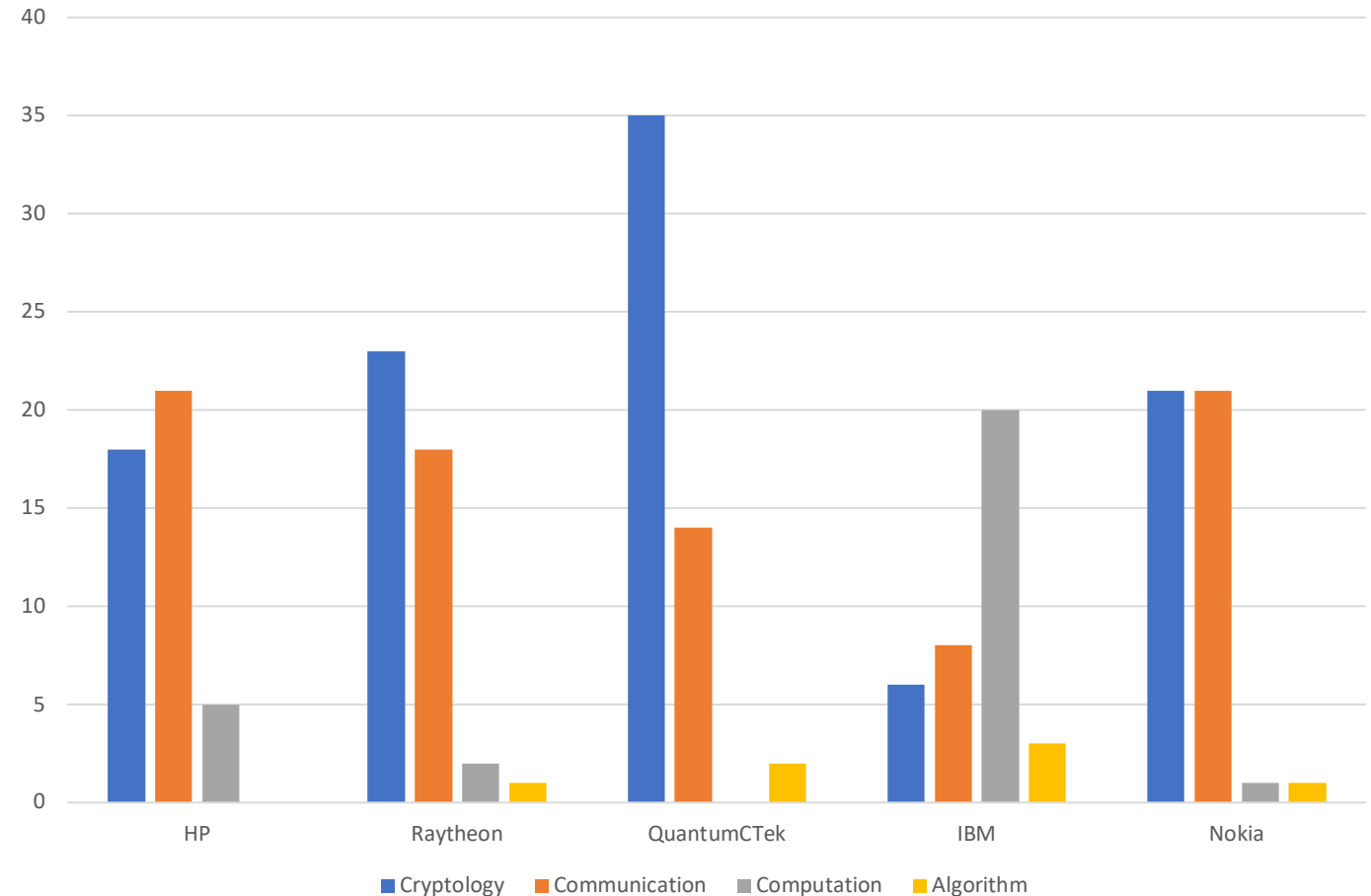


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# • Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Top Companies and Category

- QuantumCTek, another Chinese company in the field once again looks nearly identical to Qasky and Shenzhou Quantum with regards to distribution within the application categories
- IBM, another computer manufacturer looks similar to D-Wave, and Microsoft except they have a higher interest in quantum cryptology and communication
- Raytheon, HP, and Nokia, non-Asian companies that don't appear to be manufacturing quantum computers look much more similar to their Asian counterparts by portfolio distribution

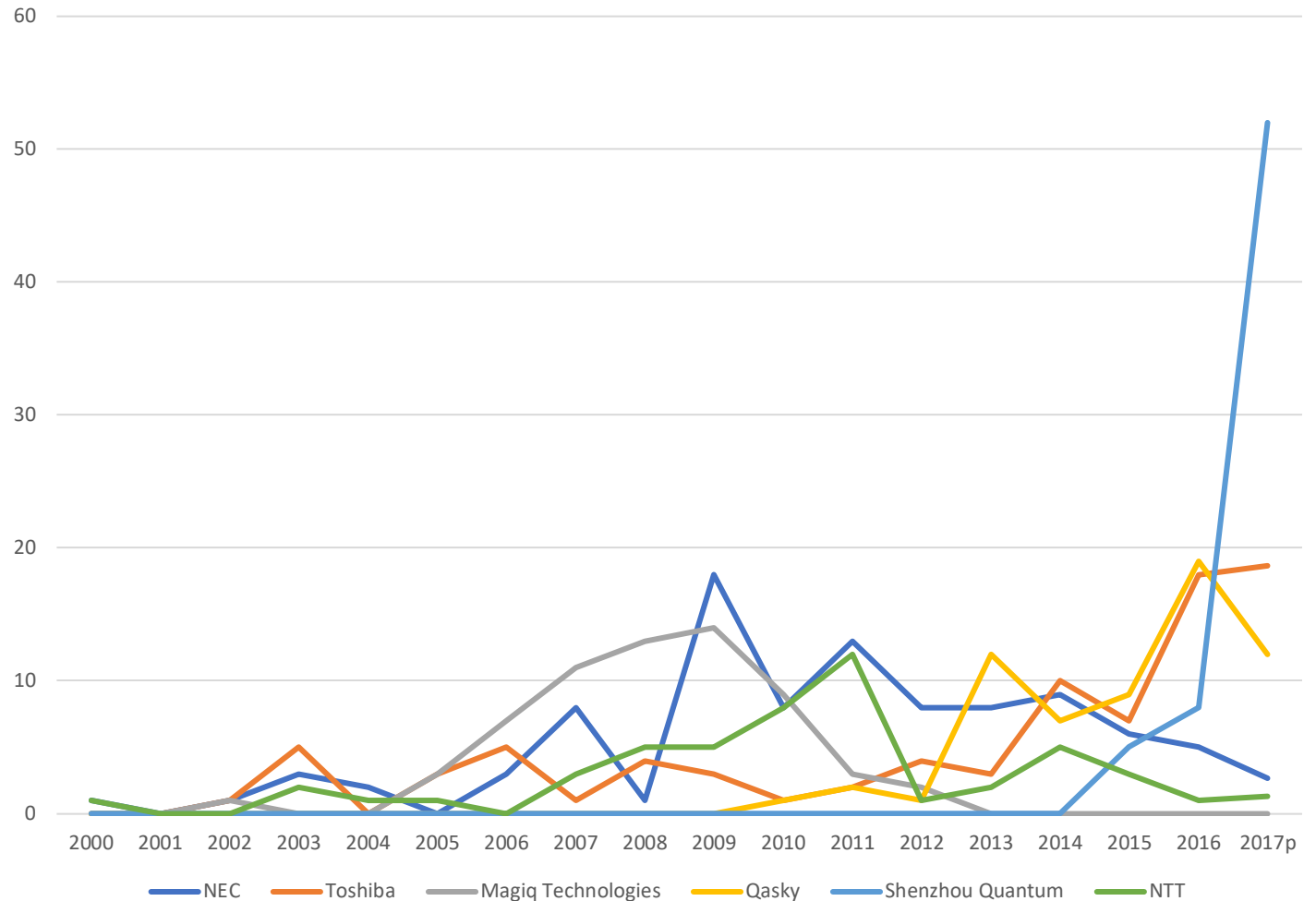


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## • **Quantum Cryptology Focus – Count of Patent Families by Top Companies and Publication Year**

- Only one of the top six companies in terms of portfolio size in quantum cryptology (Magiq Technologies) is not headquartered in either Japan or China, and they have not published in this field since 2012.
- Both Chinese companies have relatively new portfolios, dating back to 2010, however since 2013 they account for more than 50% of all publications of the top six companies
  - Shenzhou Quantum is projected to have over 50 patent families published in 2017 alone
- NEC, Toshiba and NTT all have a long history of interest in cryptology, however only Toshiba is projected to increase their number of publications for 2017



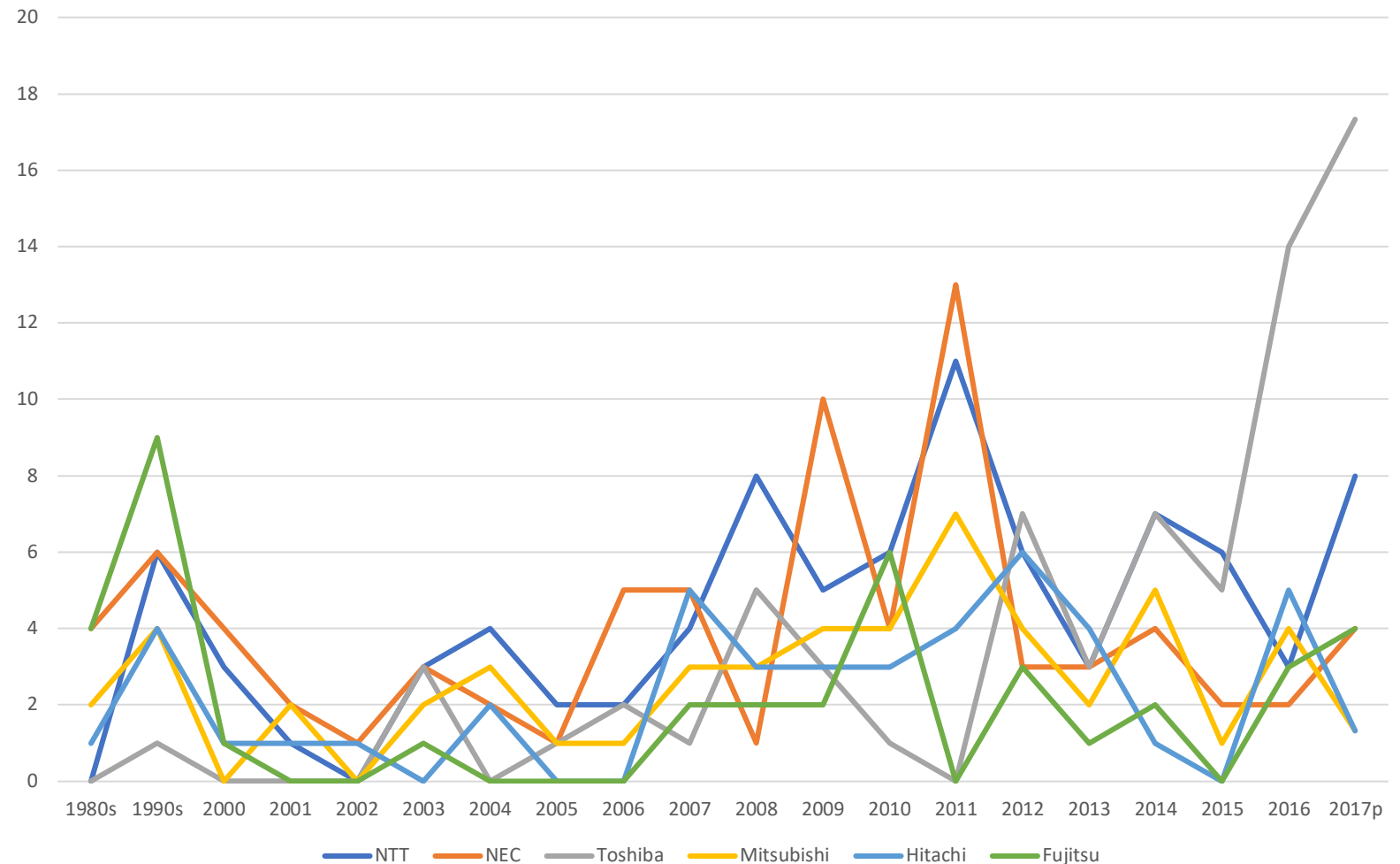
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## • **Quantum Communication Focus – Count of Patent Families by Top Companies and Publication Year**

- All of the top six companies in the quantum communication field are Japanese firms
- Toshiba, while third overall has shown the most interest in this field over the last five years with almost twice as many publications as the next closest company (NTT)
- NTT and NEC have consistently been leaders in quantum communication over time, but both experienced recent declines in publications after previous yearly high marks in 2011
- Both companies are projected to increase their number of publications in 2017

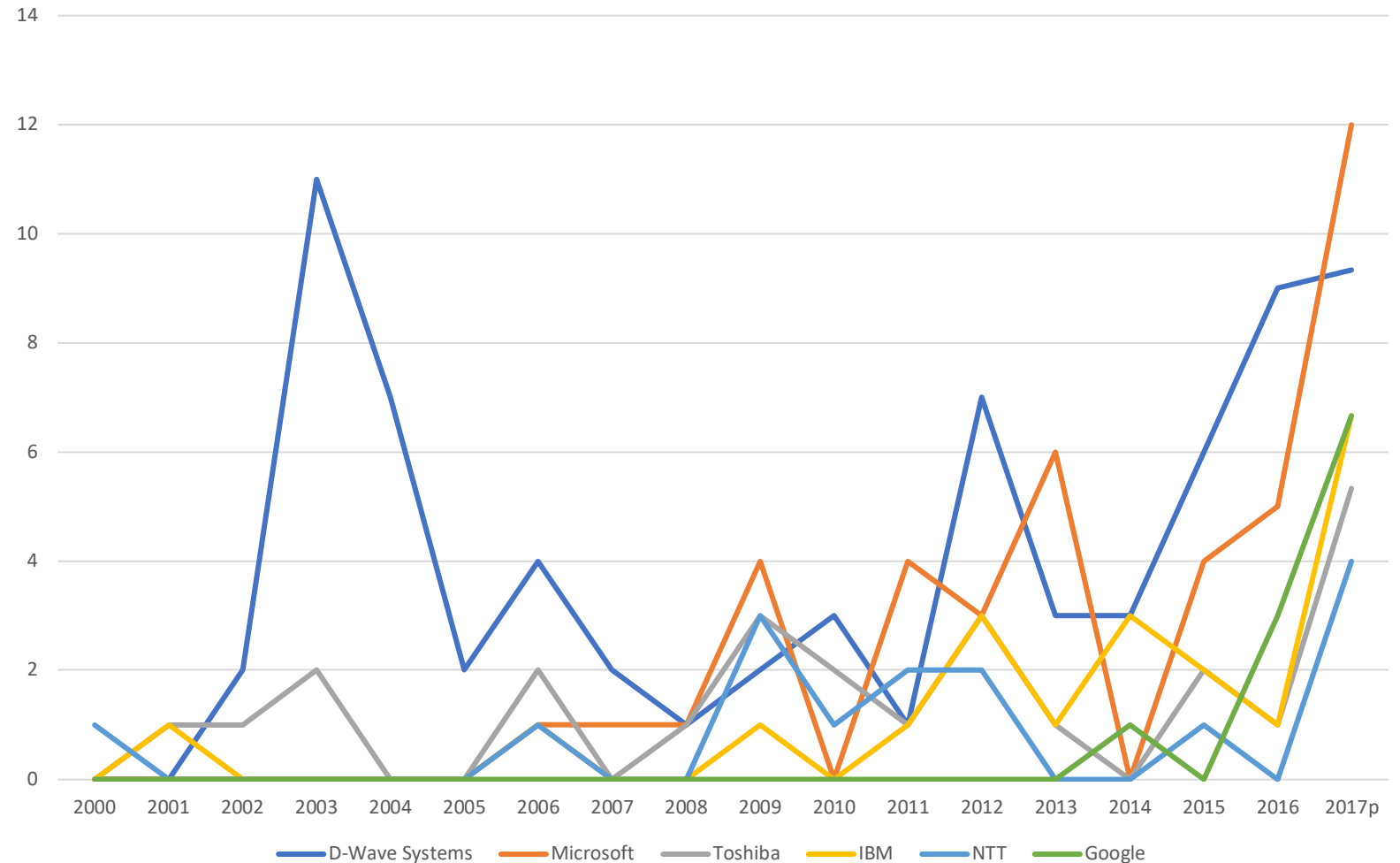


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## • **Quantum Computation Focus – Count of Patent Families by Top Companies and Publication Year**

- All of the top companies in the quantum computation field are projected to double their 2016 publication numbers in 2017 except D-Wave
- D-Wave has historically been the leading firm in the quantum computation field, owning a portfolio twice as large as Microsoft (second largest collection)
- However, Microsoft is projected to become the top assignee for 2017
- Google was a late entrant into this field yet they are projected to be one of the top three (tied with IBM) assignees by patent family count for 2017

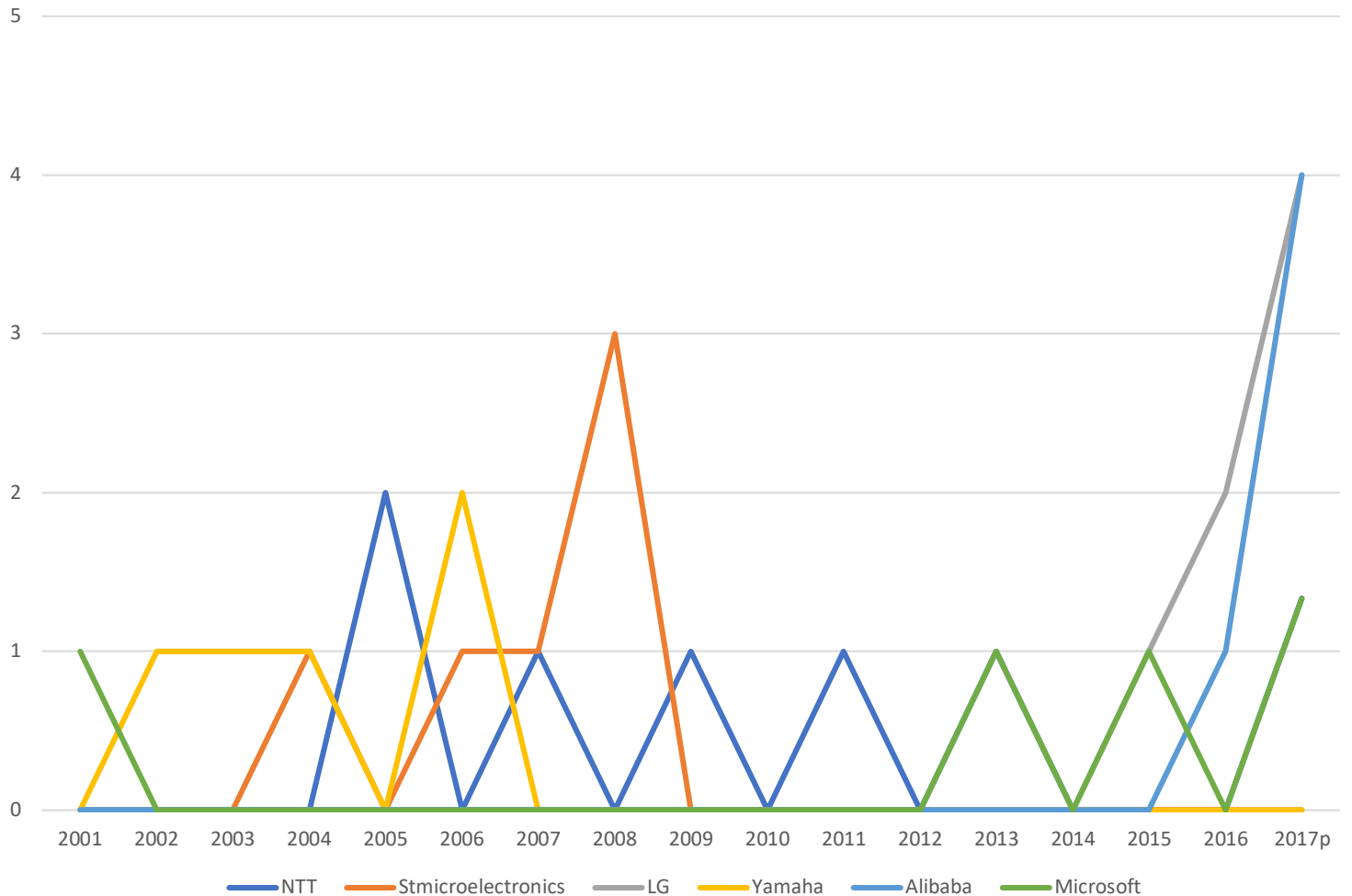


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## • **Quantum Algorithms Focus – Count of Patent Families by Top Companies and Publication Year**

- The field of quantum algorithms is on average three times smaller than quantum cryptology, communication and computation, and appears to have a random publication history among the top companies
- Alibaba and LG both project to have four patent families published in 2017, which is more in a single year than the previous high of three from STMicroelectronics.
- The leading company, NTT only has four families over the last 10 years
- Yamaha comes in fourth by count of patent families in this sub-field, but has not shown any activity in quantum algorithms since 2006

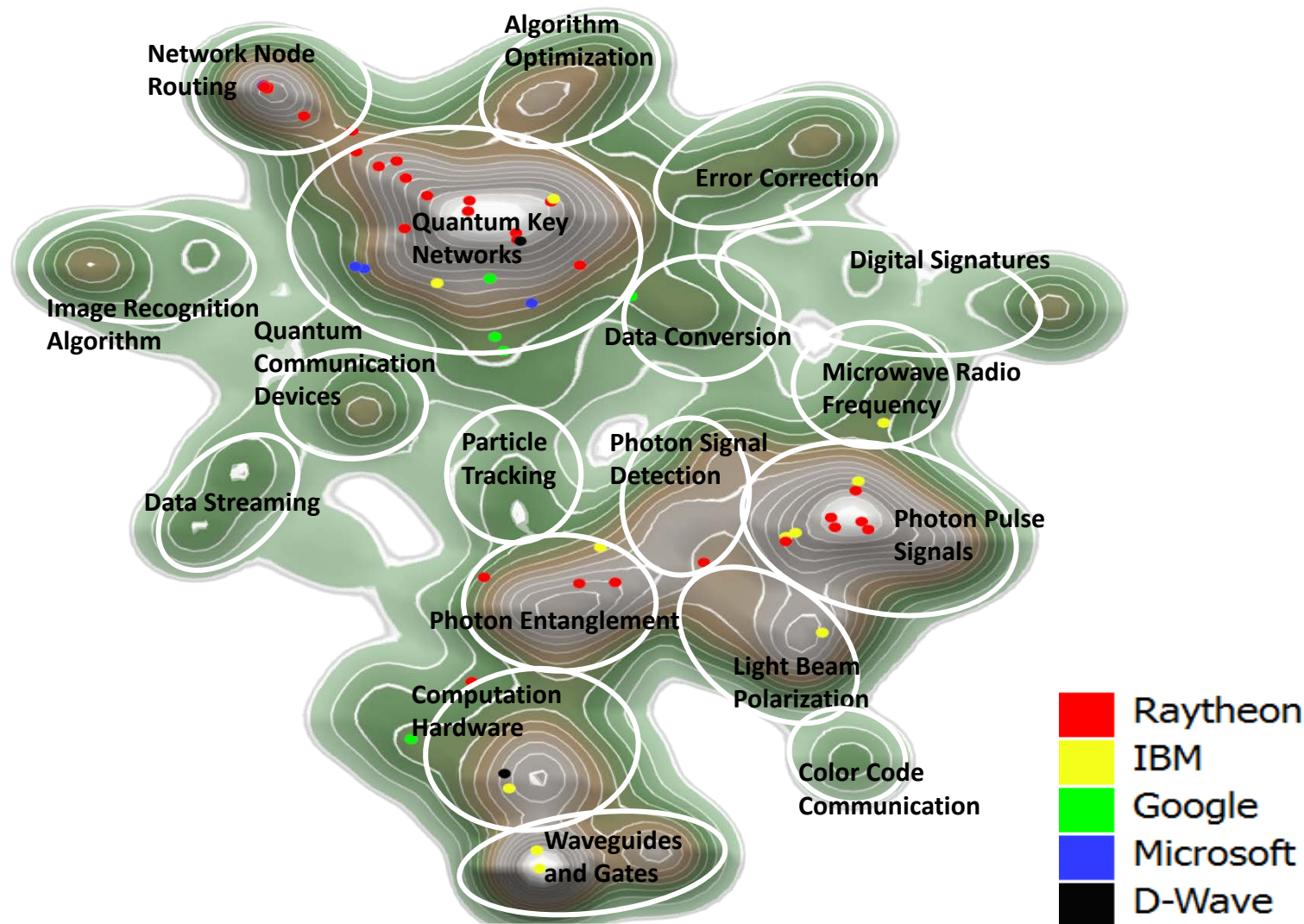


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# Quantum Communication, Cryptology, Algorithm and Computation Patent Families Spatial Concept Map by Top North American Companies

- As these companies were heavily featured in our patent landscape report on practical quantum computers and both collections contained significant overlap, only patent families not covered in the previous landscape are mapped here
- Raytheon has the least amount of overlap between both collections and is interested specifically in quantum key networks and photonic signals
- IBM has a similar portfolio to Raytheon except they are also working in waveguides and other communications hardware
- Microsoft and D-Wave have the most overlap with the previous collection, but exclusive to this collection they are mainly interested in quantum key encryption



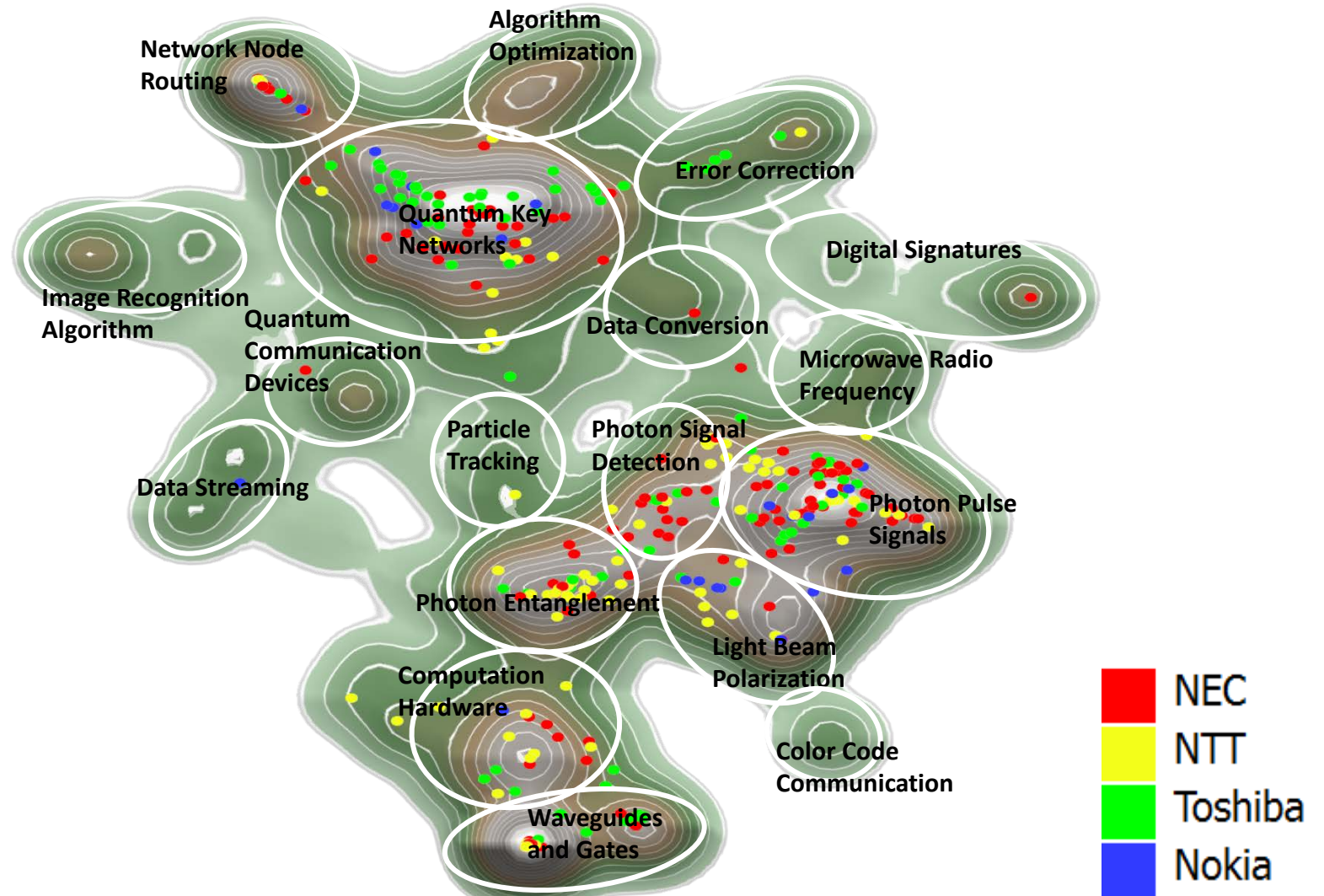
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# Quantum Communication, Cryptology, Algorithm and Computation Patent Families Spatial Concept Map by Top Japanese and European Companies

- The top Japanese companies are working in quantum communication, cryptology and computation however they don't appear to have as much interest in quantum algorithms
- NEC, NTT and Toshiba have very similar distributions with dense clustering in photonic communication, quantum key fields, and waveguides and other computation hardware; Toshiba and NTT are also working in error correction
- Nokia is interested in photonic communication, and quantum key encryption, however unlike the top Japanese firms they are not very active in some of the hardware aspects associated with quantum applications

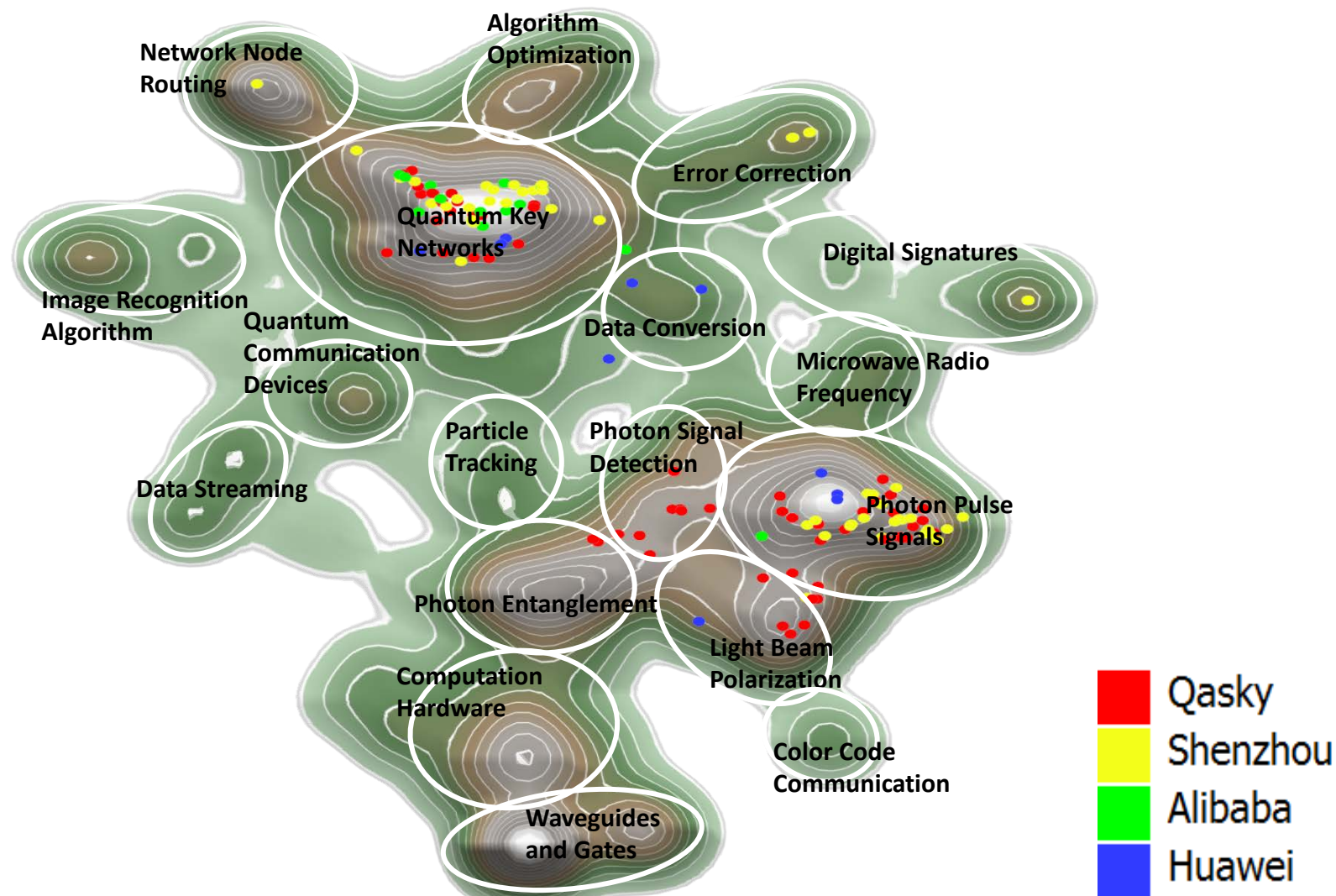


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# Quantum Communication, Cryptology, Algorithm and Computation Patent Families Spatial Concept Map by Top Chinese Companies

- The top Chinese companies are densely clustered in quantum key encryption networks, and photonic pulse communication
- Shenzhou Quantum is also interested in error correction, digital signatures, and network node routing
- Qasky is heavily leveraged in photon signal detection, and light beam polarization
- Huawei is also working in data conversion as well as quantum key encryption networks, and photonic pulse communication
- Compared to Japanese companies Chinese companies are less interested in communication hardware



Note: Based on 152 Quantum Computing patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

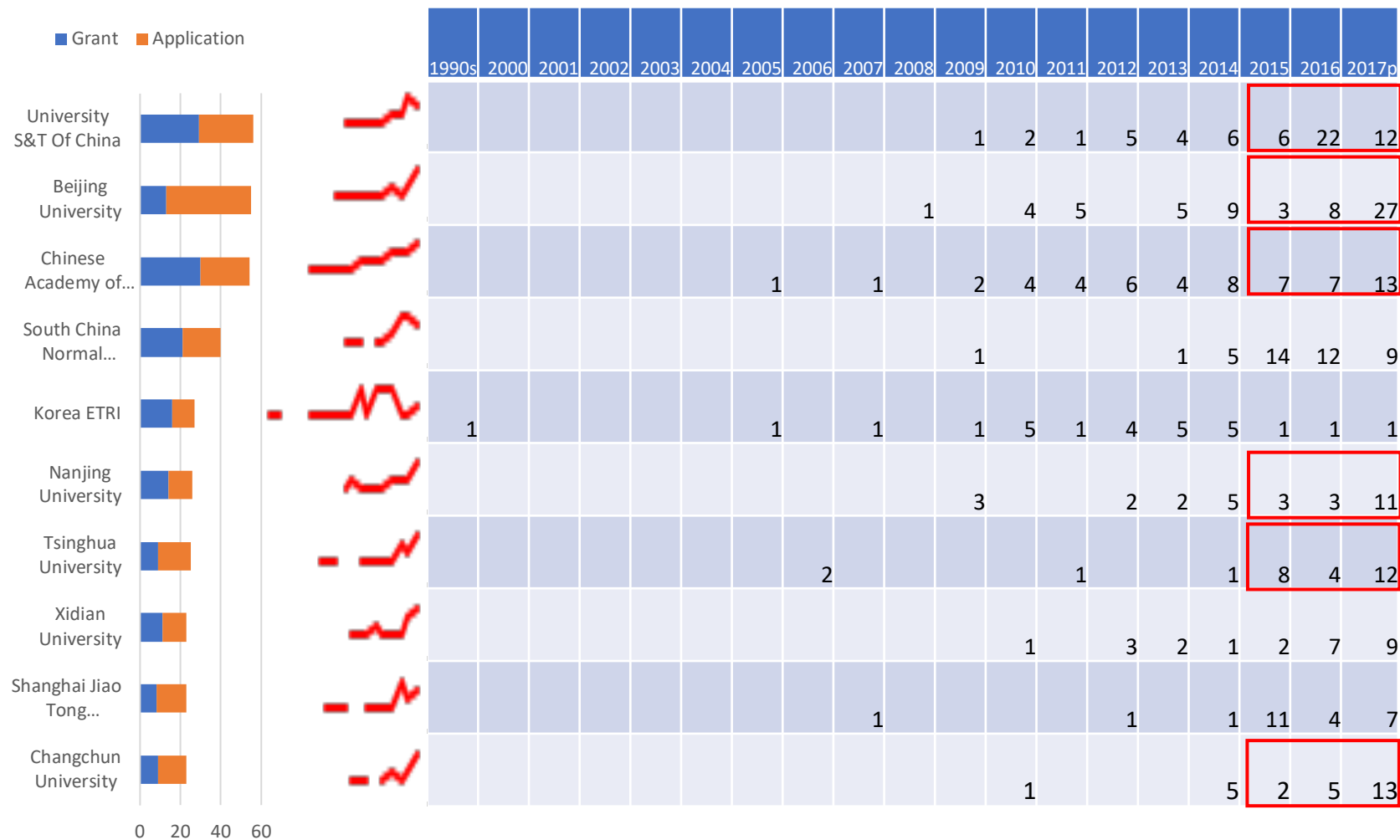
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# ***ACADEMIC DISCUSSION***



# Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Top Universities

- Nine of the top ten universities/research organizations in terms of portfolio size related to quantum communication, cryptology, algorithm and computation are Chinese with the non-Chinese institution being Korean; The first U.S. institution listed is Stanford University and they're ranked 17<sup>th</sup>
- Approximately 76% of the academic families published since 2012 have been from Chinese Universities
- US Universities come in a distant second with 14% of the families

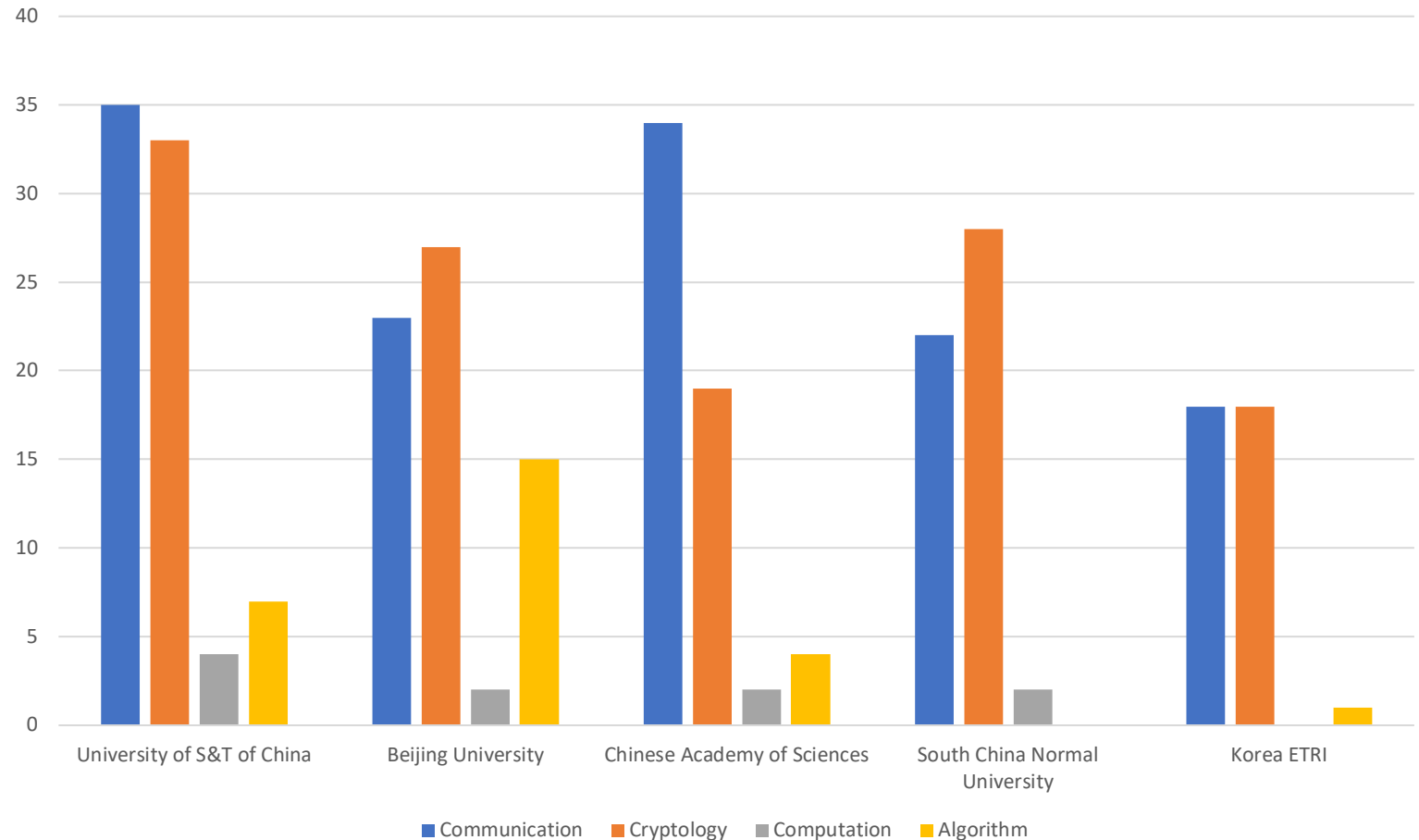


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# • Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Top Universities and Category

- All of the top Universities have significantly more interest in quantum communication and cryptology than algorithms and computation except for Beijing University where publications related to algorithms make up more than 22% of their entire portfolio
- Korea ETRI is the only University in the top five that has no interest in general quantum computation

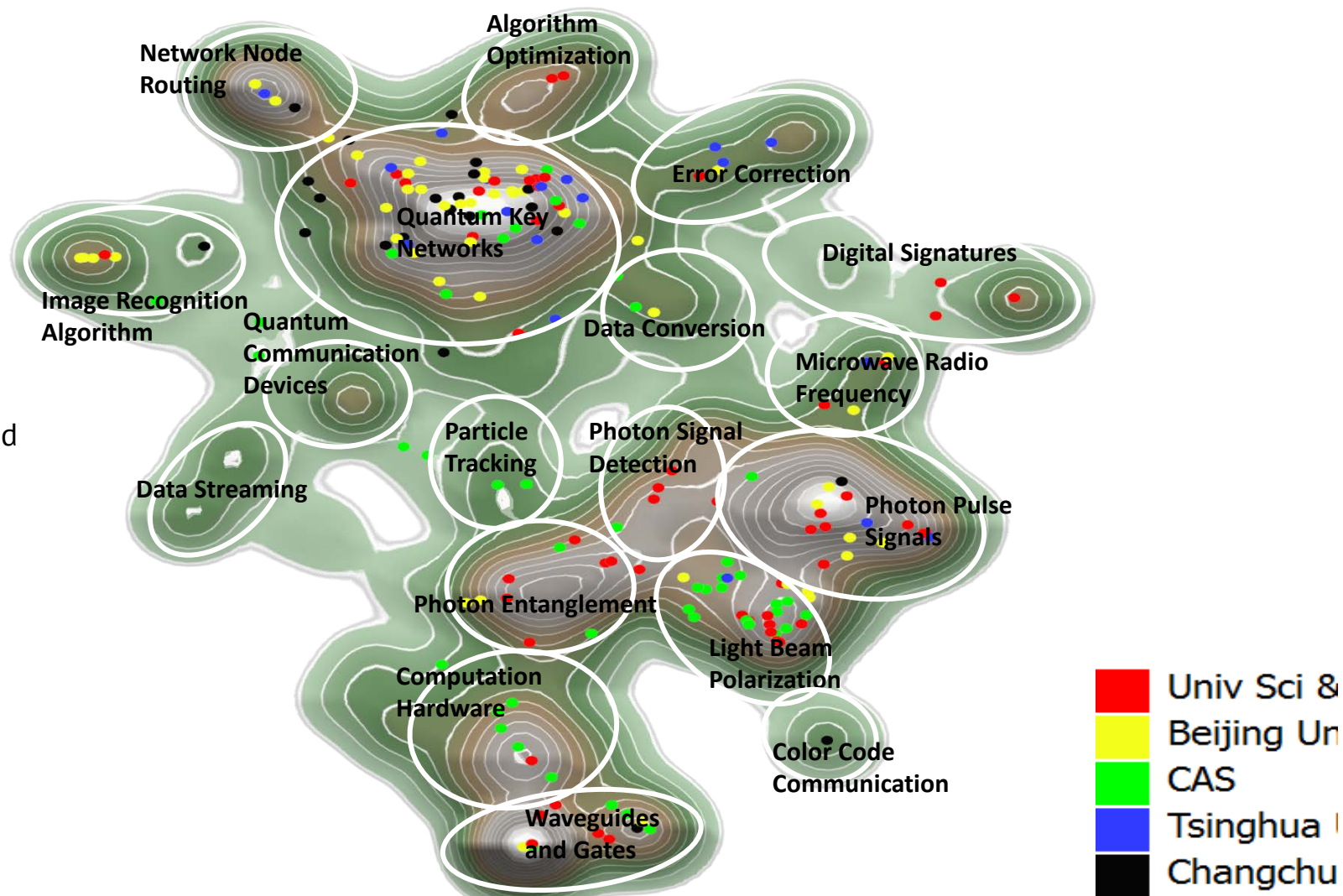


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# Quantum Communication, Cryptology, Algorithm and Computation Patent Families Spatial Concept Map by Top Chinese Universities

- The University Of Science And Technology Of China has the largest and most diversified portfolio of all of the top Chinese Universities
- Beijing University and Changchun University are both have the greatest cluster density of their portfolios in quantum key encryption
- The Chinese Academy of Sciences (CAS) and The University Of Science And Technology Of China have more interest in light beam polarization and communication hardware than any of the other top Chinese Universities
- Tsinghua University is doing most of their work in quantum key networks and error correction



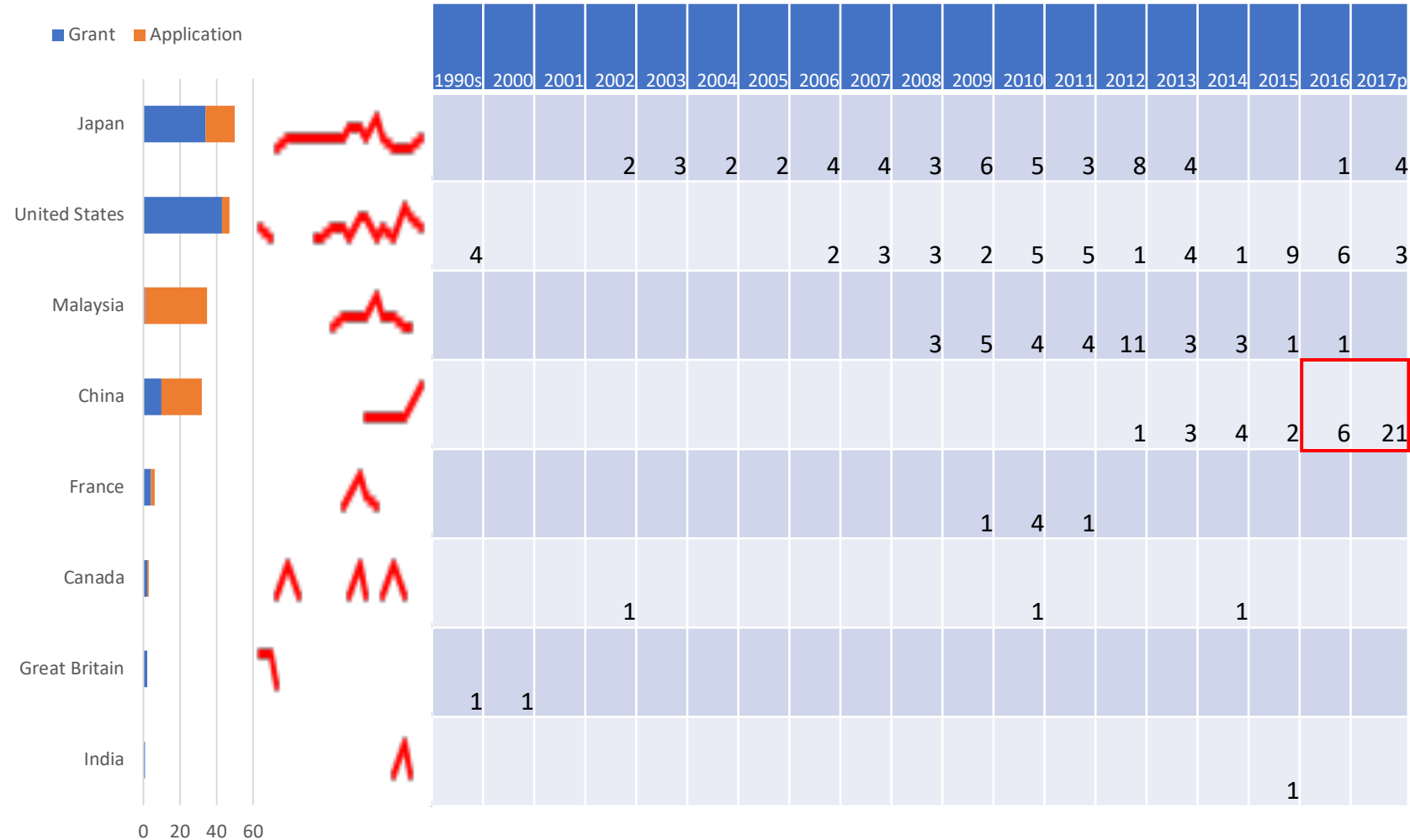
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# ***GOVERNMENT INTEREST DISCUSSION***

# Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Government Agencies

- The Chinese Govt. has only recently entered the quantum application fields, and they are projected to more than triple their publications from 2016 to 2017
- Similar to many of the Japanese companies highlighted previously, the Japanese Govt. has a relatively old portfolio, and they have been less active in recent years
- The US Govt. began showing a sustained interest in these fields in the mid-2000s; However after reaching a peak with nine publications in 2015, they appear to be on the decline.
- Malaysia through their MIMOS Berhad R&D Center became interested in these fields in the late 2000s, but have not been active in recent years

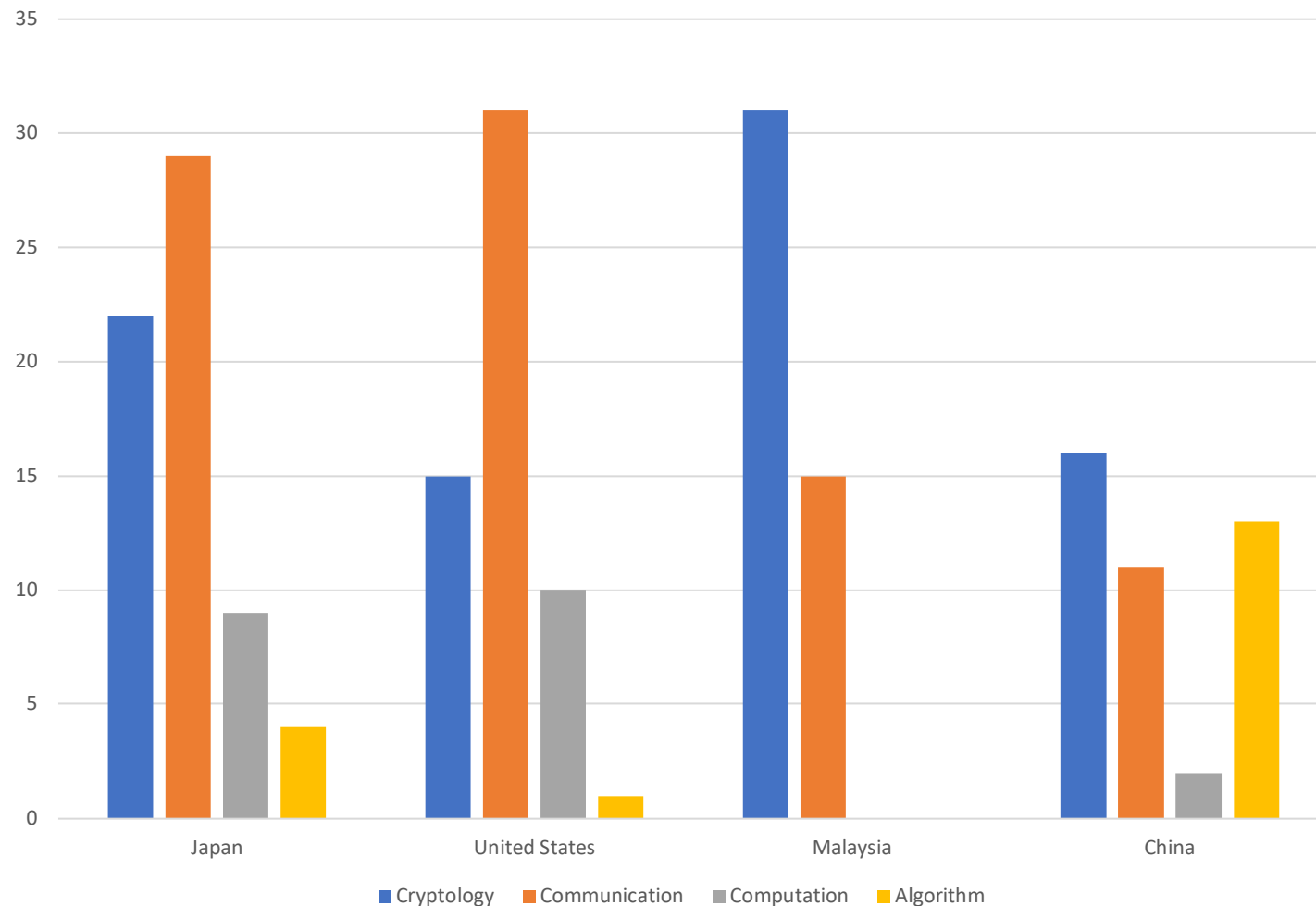


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# • Quantum Communication, Cryptology, Algorithm and Computation Patent Families by Government and Category

- Both the Japanese and the US government agencies have a similar distribution within the application categories in their portfolios
  - They are both more concerned with communication than cryptology, and have a similar level of interest in quantum computation
- China is the newest entrant, and they already have more than double the number of publications related to quantum algorithms than the other three governments combined, but cryptology is still the leading application
- Malaysia (MIMOS Berhad) is focused on quantum cryptology and communication



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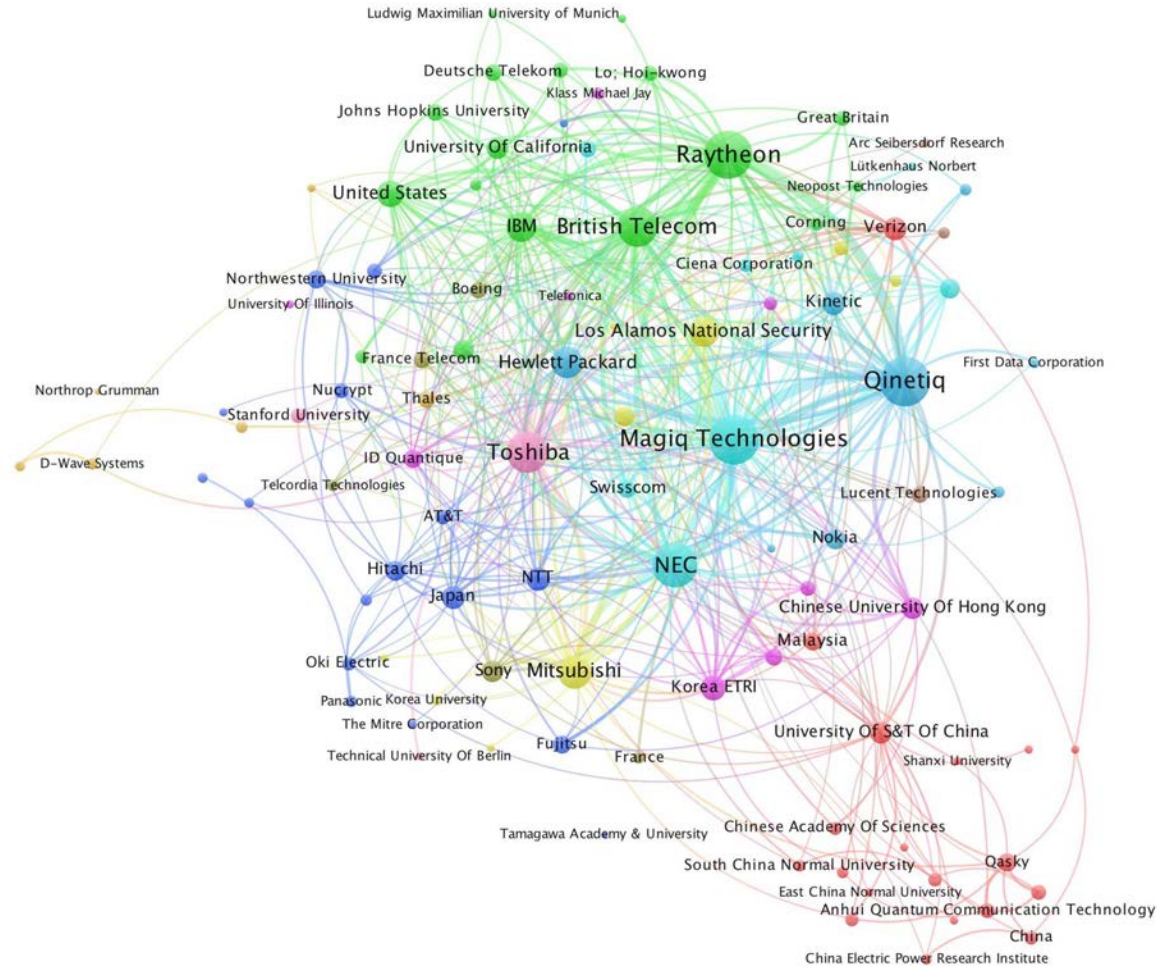
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# ***CITATION NETWORK ANALYSIS***



# • Quantum Cryptology Forward Citation Network Map

- The portfolios of MagiQ Technologies, Qinetiq, Raytheon, NEC, Toshiba and British Telecom have the largest number of citation links (based on the size of their circles) indicating they own influential patent families within the quantum cryptology field
- However when factoring the size of each companies portfolio, Qinetiq and British Telecom are even more interesting since their portfolios only contain 16 and 7 families respectively compared to others like NEC, who own 96 patent families
- The University of Science and Technology of China's portfolio is very well connected to many of the other Chinese Universities and companies as well as some of the largest organizations in the quantum field like Magiq Technologies and NEC

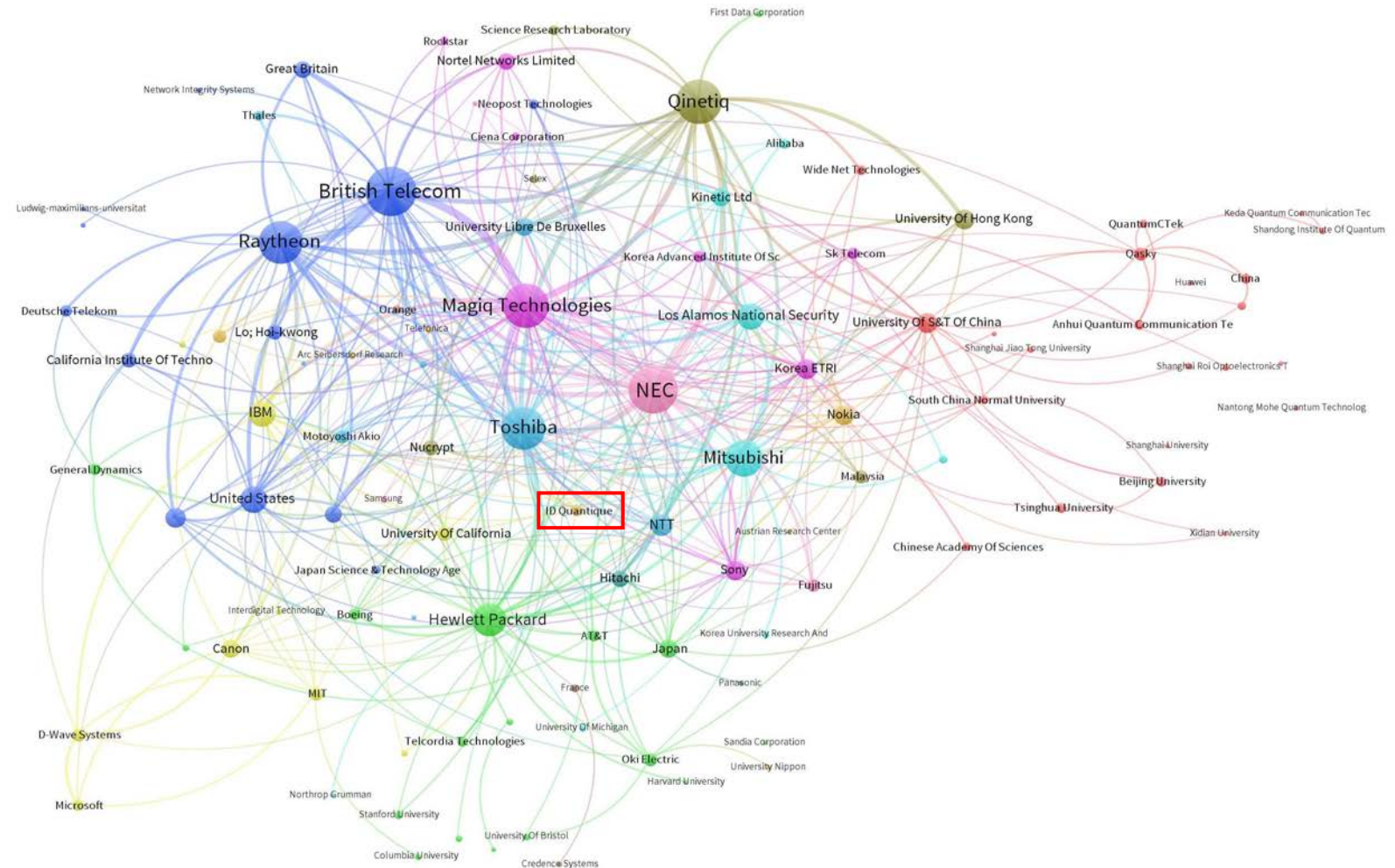


Note: Based on 1,780 Quantum Cryptology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

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# • Quantum Communication Forward Citation Network Map

- Similar to the cryptology citation network map, both Qinetiq and British Telecom own influential portfolios in quantum communication that are made up of nine, and eight patent families respectively
- ID Quantique, a quantum information technology company headquartered in Switzerland, has only two patent families in the quantum communication collection but are connected to many of the larger organizations in this field including NEC, Toshiba, IBM, Hewlett Packard, and Magiq Technologies to name a few



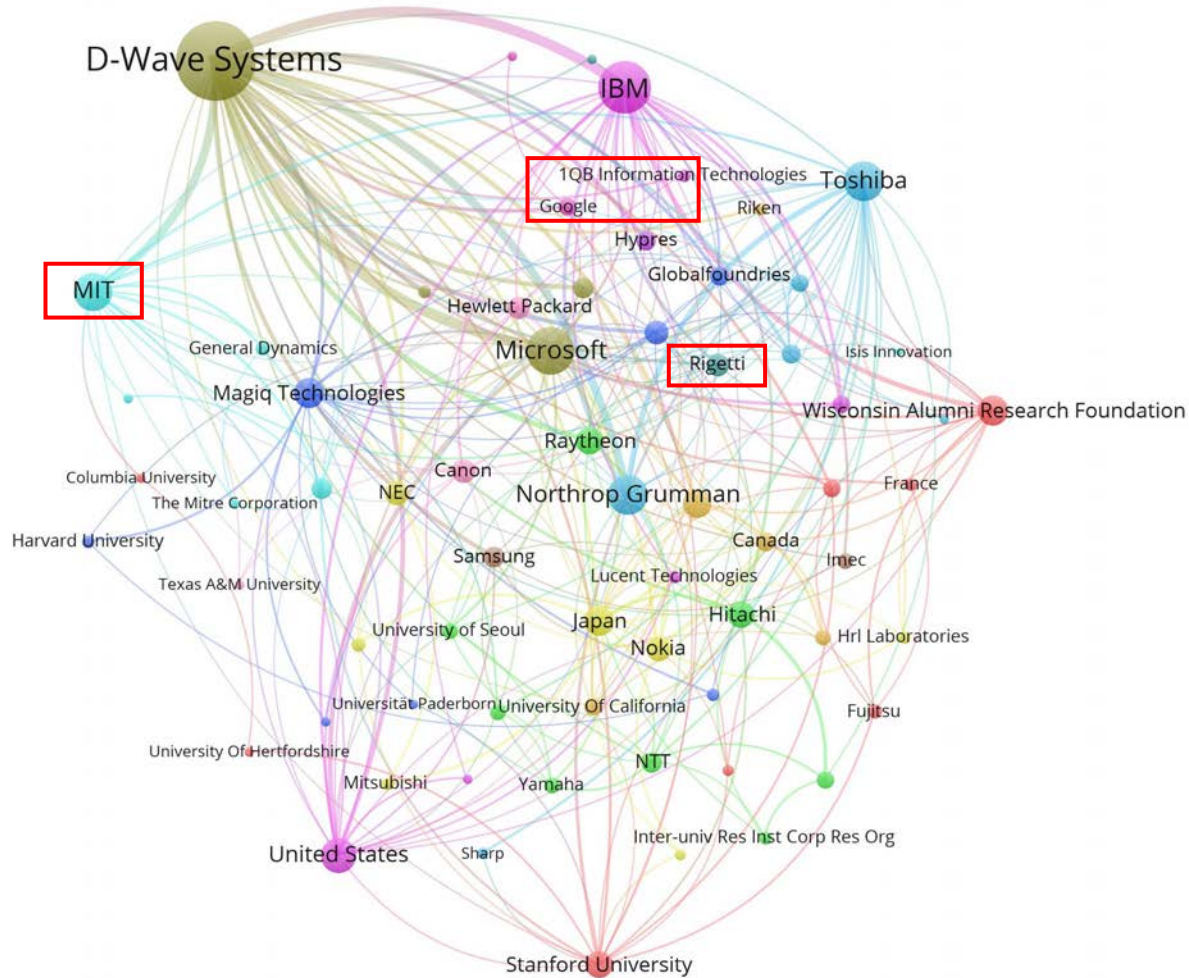
Note: Based on 1,857 Quantum Communication patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

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- Quantum Computation Forward Citation **Network Map**

- The quantum computation field is dominated by many of the organizations considered to be the major players in developing practical quantum computers including D-Wave, IBM, Microsoft, MIT and Northrop Grumman.
- Rigetti Computing, a quantum circuit developer, and MIT both hold just three patent families in the quantum computation collection yet are heavily connected to many of the larger organizations in this field including D-Wave, IBM and Microsoft
- 1QBit, Google, WARF, and Stanford also stand out in this analysis

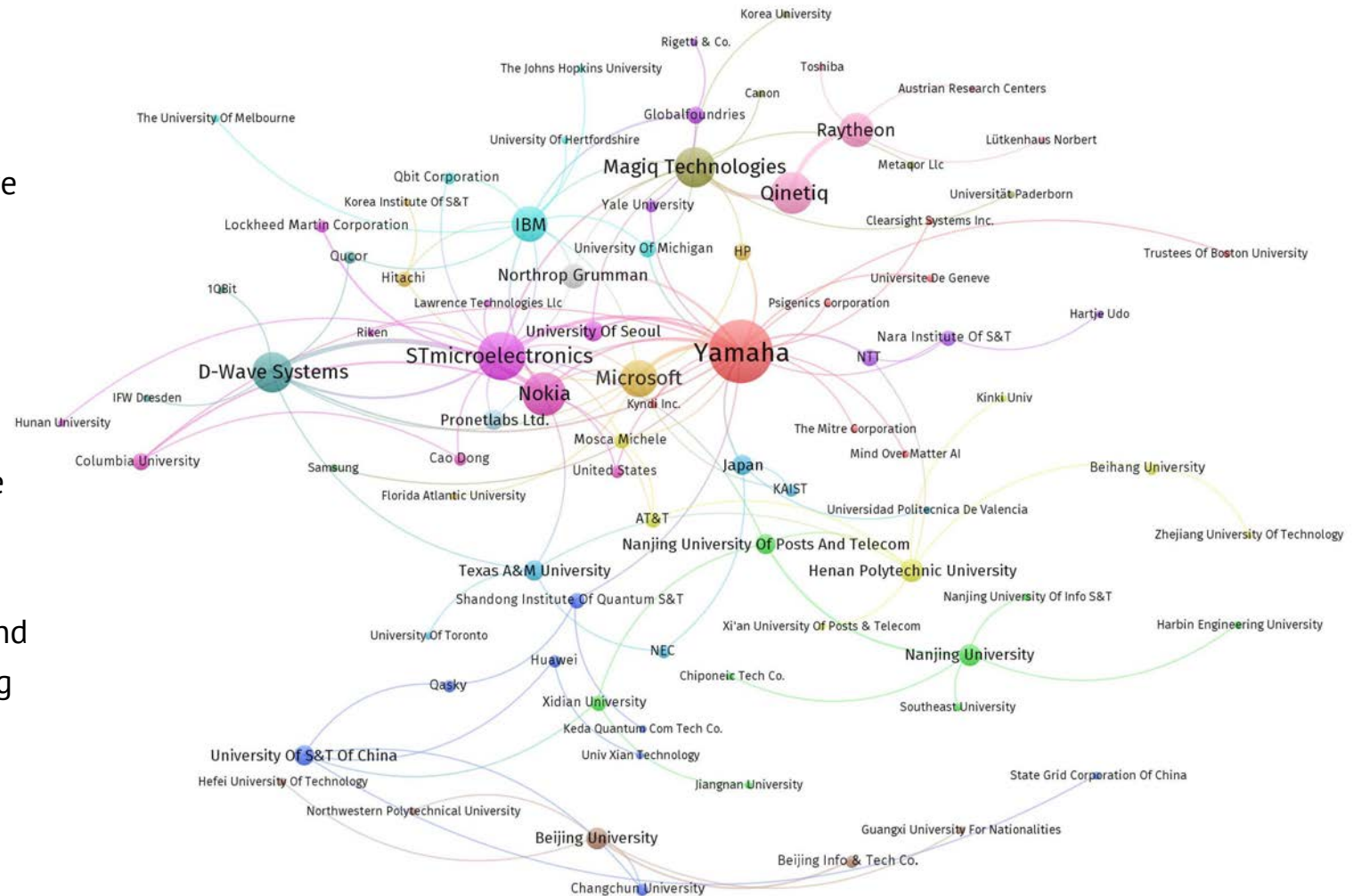


Note: Based on 536 Quantum Computation patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

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# Quantum Algorithm Forward Citation Network Map

- Yamaha's work in quantum algorithms is clearly well respected, as they account for significantly more forward citations than any other organization in this field despite only having five publications in the collection
- Also of note, Yamaha's portfolio has all been abandoned, and should certainly be consulted since they are now in the public domain
- The STMicroelectronics portfolio is also influential, but it is still in-force, and in one case is co-assigned with Yamaha
- Perennial quantum standouts including Qinetiq, Magiq Technologies, D-Wave, Microsoft, Nokia and IBM are all influential in this sub-field indicating the importance of quantum algorithms in all quantum information technology fields



Note: Based on 407 Quantum Algorithm patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

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# • Collection methodology

- Searching was conducted in worldwide patent documents in Derwent Innovation for the following concepts:
  - IPC / CPC classes specific to quantum communications, or encryption
  - For the concepts of quantum communication(s) or encryption(s), or algorithm(s), or computation(s) in the Titles, Abstracts, or Claims
- Collection was limited to one document per family using DWPI families
  - The US was retained as the primary country
- Categorization based on classification codes, and hedge searching was conducted for these families
- Assignee names were standardized based on known mergers, acquisitions, and change of ownership



# • Acknowledgements

- Patinformatics would like to thank the following organizations for the use of data, or tools for the development of this study:
  - Clarivate Analytics — Derwent Innovation was used for searching, and for reviewing patent records for categorization and relevance
  - Evaluserve — the KMX Patent Analytics package was used for the creation of the spatial concept maps
  - The majority of the charts, and graphs used in this study were generated using Microsoft Excel



# • The Analysts



Bryan Scanlon attended Ohio State University where he majored in finance. After Ohio State, Bryan accepted a consulting role at Accenture where he spent time working with AT&T on a number of projects including data analytics work. Now he works with Patinformatics in an analyst role helping clients drive business insights from intellectual property data.



Anthony (Tony) Trippe is Managing Director of Patinformatics, LLC. Patinformatics is an advisory firm specializing in patent analytics and landscaping to support decision making for technology based businesses. In addition to operating Patinformatics, Mr. Trippe is also an Adjunct Professor of IP Management and Markets at Illinois Institute of Technology teaching a course on patent analysis, and landscapes for strategic decision making.

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