The Quantum Leap into Computing and Communication: A Chinese Perspective

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Introduction

Former Director of the National Security Agency, Vice Admiral Noel Gayler once wrote, “Important as it is in peacetime, communications security becomes even more important in wartime.”[1] For a few decades nations have been relying on encryption systems to protect a wide variety of computerized transmissions ranging from commerce to government to military communications. While today's encryption systems are considered to be reasonably secure, the possibility of quantum cryptography and quantum computing offer a whole new dimension and threat to computerized secrecy.

China is among the growing number of countries seeking to unlock the science of quantum cryptography and computing, which many experts believe will one day revolutionize computerized security. With the country's ongoing push to modernize its military and become a global innovative force, success in this area could materialize into an enormous economic and military advantage.

This paper will examine the significance of these technologies, China's progress in quantum communication and quantum computing, and the consequences for the United States and other nations should the Middle Kingdom acquire a real capability in the science. It is an area that U.S. analysts will need to closely follow in the coming months and years.

China Leaps into Quantum Computing and Quantum Cryptography

The world is currently in the midst of a second quantum revolution.[2] The first quantum revolution began in 1900 when the new rules governing physical science were discovered. In the second one, these rules are being used to develop new revolutionary technologies. Two such possible technologies are quantum computing and quantum cryptography, which falls within the area of quantum communication. While they each rely on the properties of quantum physics, their end goals differ. For one thing, a quantum computer theoretically would be able to break present day encryption systems while quantum cryptography is said to be unbreakable, even by a quantum computer.

The Quantum Computer – Code Breaker or Problem Solver?

The idea of creating a quantum computer has been around since the 1970s. These computers would be vastly more powerful since they can harness quantum properties. Unlike an ordinary computer, which uses binary numbers (1 or 0) to represent data, a quantum computer would use quantum bits (or qubits). A qubit can simultaneously have the value of 0, 1, or any "superposition" of the two.[3] The quantum phenomenon becomes even more bizarre when considering the concept of "entanglement." Entanglement links the properties of two or more qubits together. These qubits, even when separated, will remain strongly correlated or interconnected in a manner much stronger than any classical relationship. This is what famed physicist Albert Einstein called "spooky action at a distance." A quantum computer using entangled qubits would therefore be vastly faster than the average computer, which is based on simple binary numbers. Once a quantum computer comes online, theoretically it will be able to break current day encryption systems, such as RSA (Rivest, Shamir, and Adleman), a commonly used computer encryption and authentication system that uses a complex algorithm developed in 1977 by Ron Rivest, Adi Shamir, and Leonard Adleman. These encryption systems are needed to protect information such as financial transactions as well as military and government communications.

In 2001, Guo Guangcan, an academician of the Chinese Academy of Sciences, established the Key Laboratory of Quantum Information at the University of Science and Technology China (USTC) in Hefei. The laboratory became “the most important research center of quantum information in the country.”[4] In January 2006, while the field of quantum technology was still considered to be in its infancy in China, Guo predicted that the first quantum computer would likely be developed in the next 15 to 20 years.[5] In 2007, Dr. Pan Jianwei, Director of the Division of Quantum Physics and Quantum Information at Hefei’s National Laboratory for Physical Sciences at Microscale, USTC, optimistically predicted that the country might be the first to develop a quantum computer.[6] More recently, however, Pan seems to have shifted his focus. A 2010 article quoted him as saying that quantum communication (quantum cryptography falls within the science of quantum communication) is “more important for China because it is already closer to application” than developing a quantum computer, although the latter is still “very attractive to me,” he said.[7] If Pan really did shift his focus, it could be that the reality of the challenges involved with building a quantum computer had indeed set in.

Dr. Ivan Deutsch, Professor and Regents’ Lecturer at the University of New Mexico, explained the difficulty in achieving a quantum computer. In quantum cryptography, which is explained more in depth below, the goal is to distribute two shared secret keys. Basically, the secret keys are created using the properties of quantum randomness. It works on a particle-by-particle basis. In other words, for quantum encryption one photon can be sent at a time. It is simple to control a single particle. Quantum computing, on the other hand, is much more complex because it deals with computation as opposed to the transmission of single photons. Computations require logic and logic requires the use of many ones and zeros, which cannot be sent individually since they are all interdependent. Further, each qubit needs to be in an entangled state simultaneously. Due to this added degree of complexity, quantum computing is much further away from being realized than quantum cryptography.[8]

Despite this seeming shift in interest from quantum computing to quantum cryptography, in February 2013, a Chinese report emerged touting a breakthrough in trying to achieve the quantum computer. A “solid-state quantum research crew from USTC”, is reported to have successfully performed “quantum logic gate operation on one single electron at 10 picoseconds, renewing the previous world records by nearly 100 times.”[9] Prior to China’s achievement, U.S. and Japanese research institutes had achieved the “electrically controlled semiconductor logic gate at 1,000 picoseconds.”[10] China’s achievement, however, increased the operational speed by nearly 100 times to 10 picoseconds. According to Guo Guoping, director of the research project, China launched the quantum chip project to gain a foothold in the global competition in the next-generation computer chips. The quantum chip “will make the quantum computer characterized by exponentially increased operational speed and greatly improved data processing capabilities.”[11]

Along with the ability to break current encryption systems, making modern day information vulnerable, an inherent risk to national security should a quantum computer come online would be in the ability to tap into archived information previously protected by systems, such as today's RSA encryption. Dr. Jonathan Dowling, a professor and Hearne Chair of Theoretical Physics at Louisiana State University, explained that information encrypted using RSA can be intercepted and archived today in its encrypted format. Once a quantum computer comes online, it could be used to go back and break older archived encrypted data, which might not yet have been declassified.[12]

Carl Williams, Division Chief of Quantum Measurement Division at the National Institute of Standards and Technology (NIST), agrees that there are certain risks to quantum computers, but adds that there are benefits as well, pointing out that they could one day be used to solve problems of profound scientific and technical benefit. "If you ask me 100 years from now what the benefit of this technology is, I would probably say it is a societal benefit," said Williams.[13]

Quantum Communication – The Pursuit of the Perfect Encryption System

"A nation's success in military operations often rises and falls on the basis of how well it communicates. When a nation does not secure its communications effectively, its enemies intercept and read its communications and win thereby military and diplomatic advantages."[14]

Encryption methods have evolved over time, becoming increasingly complex and difficult for an adversary to break. The trend in cryptography has gone from traditional, manual enciphered and deciphered codes, to mechanical encryptions, to computerized cryptography, all of which have previously been or have the potential to eventually be broken with the right technology. Today’s top cryptography systems, such as RSA and PGP (Pretty Good Privacy) are considered highly secure. Breaking messages has become nearly impossible with the growing sophistication of today’s cryptography. However, experts believe that it is only a matter of time before today’s encryption systems can be broken.

Currently there are projects in place to try to counter the threat of a future quantum computer. “Post quantum cryptography” is a relatively new field in which research is being conducted on public key encryption systems that are not breakable using quantum computers.

Quantum cryptography offers another way to try to counter the risks of a quantum computer coming online. This newest form of cryptography, which is based on quantum theory, is proving to be unbreakable.

Quantum key distribution (QKD), a process within the context of quantum cryptography, generates a random encryption key shared by the sender and recipient. The biggest advantage is that if a third party attempts to intercept it, they will be detected and therefore the secret message will not be sent. QKD deals with photon states and works like this: Alice, Bob, and Eve are three fictional characters. In quantum cryptography, Alice wants to send a secret message to Bob. She has to first send him the key, through the process known as QKD. This basically means she is sending him a series of photons in random quantum states. If Eve tries to intercept the message, it changes the quantum states of the photons.

QKD is already a reality, although limited in capability. A small number of commercial companies have offered quantum encryption systems. For example, MagiQ, a U.S. based technology company, sold a system called the Q-Box, which was released in 2003. The Q-Box is a single-photon based system developed for further research related to QKD. These systems, however, are far from perfect, and have had a limited distribution.

QKD can be sent either via fiber optic or through free space. Going through fiber optic, it generally cannot travel further than 50 kilometers without a quantum repeater, which has not yet been developed.

China has touted a number of successful experiments in the area of quantum communication. For example, in 2004 the Key Laboratory of Quantum Information reportedly completed a 125 kilometer fiber point-to-point QKD experiment. This experiment, according to Chinese reports, "solved the problem of stability in quantum cryptography systems."[15] These results are questionable, however, but not impossible. According to Carl Williams of NIST, "If I wait long enough and my fiber is perfectly dark and still, I can probably get a photon through at a longer distance than 50 kilometers."

In a November 2005 article, China claimed to lead the United States, France, and Austria in quantum entanglement research when it provided an "experimental demonstration of five-photon entanglement and open-destination teleportation."[16] The more photons that can be successfully entangled, the higher the accuracy of the transmission.[17]

In 2006, China reported having fulfilled quantum teleportation of a two-particle system. 565 academics at the Chinese Academy of Sciences voted this to be the ninth most significant development for that year in all the country's science-technology sector.[18]

In 2007, a report stated that China had created a quantum router, which they claimed was the first quantum router in the world. The router was said to have succeeded in encrypting data flowing between four computers on a commercial communications system. The router is different from point to point transmissions conducted in other parts of the world because it makes a "quantum network" possible.[19] Then, in May 2009, a report emerged in the Chinese press claiming that the country had built the world's first quantum encrypted government network. The article stated that the network was put into trial operation in Wuhu City, in the eastern Chinese province of Anhui, and served eight government departments in Wuhu.[20]

In 2012, scientists in China reportedly teleported multiple photons 97 kilometers across a lake in the country.[21] The significance of this experiment is that it put China one step closer to achieving global transmission of quantum communications. Scientists have their sites on one day using satellites to achieve global transmission of quantum communications. The distance that a quantum key can be sent through free space depends on which direction it is traveling. Traveling straight up toward space, it can go further due to the integrated air mass. The air becomes less dense. China recognizes that "by using satellites, ultra-long-distance quantum communication and tests of quantum foundations could be achieved on a global scale."[22]

By 2016, China plans to launch the first "Chinese Quantum Science Satellite," a satellite dedicated to quantum experiments, which, according to the China Daily, will put the country ahead of both the United States and Europe. According to Pan, "The satellite will provide scientific answers to the feasibility of intercontinental quantum teleportation – to make it simple, whether I can talk to my friend in Vienna from Beijing on a quantum phone."[23]

According to Matthew Luce, a researcher at the Defense Group Inc.'s Center for Intelligence Research and Analysis, because of the applications for satellite, as well as the security level, "quantum communication technology figures centrally in the objectives of the Chinese military to upgrade their growing command and control capabilities. A functional satellite-based quantum communication system would give the Chinese military the ability to operate further afield without fear of message interception."[24] Furthermore, as Luce points out, China's research in quantum applications could help the country to be able to expose weaknesses in a network should the United States or another nation win the race in achieving the same technology.[25]

The Power of Quantum through a Military Perspective[26]

While the possibility of cracking quantum technology is often viewed by scientists in academia as a personal challenge, presenting a potential opportunity to receive a Nobel Prize or a patent, it is also viewed by militaries and governments as having great security potential and implications. For example, In November 2012, the U.S. Army News Service reported that scientists at the U.S. Army Research Lab were conducting research and development on data teleportation in hopes of one day achieving secure, tamper resistant security. According to Ronald E. Meyers, who is leading an Army project in collaboration with the Joint Quantum Institute at the University of Maryland at

College Park, “The greatest potential that a quantum communications network holds for the Army is secure communications.” Meyers also contends that “Quantum computers will be able to easily decrypt communications that are currently secure… That’s one reason why it’s vital for us to explore quantum encryption.” Meyers envisions a future in which there will be “very powerful quantum computers with a lot of intelligence. They’ll be able to work over long distances without being intercepted. It’s going to change the world.”[27]

China has also recognized the potential power of quantum communications and there is evidence indicating that the country is researching the possibilities at a higher level. Reports indicate that the University of National Defense Science and Technology has been conducting quantum information technology research since the 1990s.[28] The PLA has clearly taken an interest in quantum communications, since other institutions are also studying the topic. For example, the PLA’s University of Science and Technology (PLAUST) reportedly opened eleven new research directions in 2011, to include quantum communication technology.[29] Some researchers believe that quantum communications, along with cloud computing, intelligence optic networks, and high-speed satellite communications, provide asymmetric operational superiority for military forces and generate new types of combat power.

PLAUST has worked with both military and non-military research institutes, achieving major successes in key technologies. The university conducts strategic cooperative research with civilian institutes to establish joint laboratories, which have reportedly resulted in over 90 percent of their achievements being applied to the armed forces’ needs. Quantum communications research is just one area, with information grid networking and electromagnetic camouflage and protection also being researched.[30] China's Academy of Space Technology (CAST) has done preparatory work to establish China's first quantum remote-sensing laboratory. The aerospace community believes that remote sensing is an important area for the application of quantum information technology. It is hoped the laboratory will allow Institute 508 to apply for funding from the national 863 and 973 programs. Such a funding request appears appropriate, since, in 2012, quantum information technology was designated as one of the four key areas of scientific research in the next fifteen years.[31]

More recently, quantum communication received recognition as a key technology by the Chinese Academy of Sciences after CAS president Bai Chunli announced China's plans to establish five innovation centers that would unite the country's leading scientists and experts in advanced science and technology. The fields of study were quantum information and technology, Tibet plateau and Earth system science, particle physics, brain science, and thorium molten salt reactors.[32] As a result, China established the CAS Center for Excellence Quantum Information and Quantum Physics in Hefei, Anhui Province on January 15, 2014. This new center is recognized as a model for the other four centers.[33]

Research, Academics, China's Education Dilemma and the Economic Impact

China considers itself the number two nation in the world in terms of research and development spending, and it has conducted original research in quantum communications that have had an international impact.[34] Research has been ongoing in the Chinese Academy of Sciences (CAS) since 1998, when innovative projects along with quantum communications held interest.[35] Quantum topics have had high-level interest for some time. Former President Hu Jintao, in a speech stated that quantum communications had exerted great influence on China's economic and social development.[36] Premier Wen Jiabao noted that "quantum theory and the theory of relativity stimulated the development of semiconductors and microelectronic integrated circuit technology, information technology, laser technology, nuclear energy, and related technologies."[37] State Councilor and Communist Party of China (CPC) Central Committee Political Bureau member Liu Yandong noted in 2011 that quantum communications have made "fresh contributions to scientific development."[38] In 2012 she stated that quantum communication technology has important strategic significance in ensuring the safety of state information. More importantly, she made these remarks while attending a ceremony to launch the financial information quantum communication verification network.[39]

With such high level cover it is not surprising that China's rapid S&T development has been tied to quantum information.[40] As an example of the use of quantum information, in 2011 CAS reported on cooperation between the Institute of Modern Physics and the International Atomic Energy Agency. The physics research team "reportedly made significant progress in the research on the quantum state of ion-atom collisions, contributing to the better understanding of plasma evolution and plasma state diagnosis."[41] Such discoveries are ongoing and expanding.[42]

China has been on a path to expand its overall technological capabilities. One approach has been to overhaul the country's education system. During China's ninth Five-Year Plan (1996-2000), the government began to initiate actions to strengthen a number of higher learning and key disciplinary areas. The goal was to upgrade 100 institutions to greatly improve their quality of education, scientific research, management, and institutional efficiency. The select 100 institutions were expected to, through their own merit, easily "exert significant impact on the country's social and economic development, scientific and technological advancement, and the national defense."[43]

Funding available in China for basic research has also been increasing steadily. In 1986 the investment in basic research was only 80 million yuan (approximately $9 to $10 million).[44] By 2012, according to Chen Yiyu, director of China's National Science Foundation, the Chinese government allocated more than 15 billion yuan ($2.38 billion) from the central budget to the National Science Foundation. While only a portion of the money goes toward researching quantum information, the National Science Foundation is a key source of funding for China's research and development on quantum properties and applications.

China's growing economy and increasing wealth make it easier than most other countries to sink money into research and development programs. During the U.S. Naval Research Laboratory's second annual Karles Invitational Conference, Zachary J. Lemnios, Assistant Secretary of Defense for Research and Engineering, pointed out that, "nations with strong GDP growth – think China, Russia, South Korea – are using their increasing wealth to bolster investments in basic science, applied research, and advanced technology development, and these investments are increasingly focused. For example, the Chinese National Medium-to Long-Term Plan for the Development of Science and technology (2005-2020), aims to make China an 'indigenous innovator' by

2020, and to do this they are investing in 16 goal-oriented basic research ‘megaprojects,’ one of which is quantum research.”[45]

While the United States spends more money overall in basic research than any other country, Chinese investments are rising at a faster rate. According to Dowling, “One of the things that concerns me in the United States right now is that we are falling behind in our investments, particularly in basic science research… We are getting to the point where we are no longer even in the top ten in terms of per capita investment in basic research anymore.”[46] Basic research is essential for innovation.

Despite its economic wealth, however, China still has a number of hurdles to overcome before it can become a global innovative force. Pan attributes some of China’s lack of creativity to the high amount of pressure placed on students. Students devote years to intensive studying. However, according to Pan, they “are often incapable of developing independent solutions,” due to a lack of creativity. There has been talk of changing the education system. However, it has not yet happened. As Pan pointed out, there are simply too many students.[47]

China’s academic and scientific efforts point to the country’s desire to achieve global technical superiority. Williams, who recognizes that quantum technologies will likely one day offer tremendous benefits to society, also sees the importance of maintaining a competitive edge in research and development to maintain both innovative and economic superiority. According to Williams, “While quantum technologies clearly create a direct risk to national security, the bigger risk is the threat to economic security since a strong economy is required to drive a strong military and innovation and quantum technologies are likely to be an innovation driver for the 21st century."[48]

Physicist Paul Davies once wrote, "The nineteenth century was known as the machine age, the twentieth century will go down in history as the information age. I believe the twenty-first century will be the quantum age."[49] Quantum technology is still in its infancy. The organization or government that achieves quantum communication or quantum computing first, will control it, giving that country an advantage in every respect.

Conclusions

According to a 2010 article published by Time Magazine, "China is now at the cutting-edge of military communications, transforming the field of cryptography and spotlighting a growing communications arms race."[50] China, intent on becoming a global technology innovative force, has been making huge strides in research and development in many areas including quantum communication. There is a major push in the country to become the frontrunner in breakthroughs that will one day lead to the first quantum computer and the perfect quantum communication network.

Should China eventually win the race in achieving certain quantum based technologies, it could have a significant impact on national security and China's role as an emerging superpower.

Quantum technologies have the potential to revolutionize secure communications for military and intelligence organizations. A quantum computer might one day be able to break information that had been archived, but not yet declassified. Quantum technologies could also lead to revolutionary applications that will help to propel a nation to economic superiority.

While China still lags behind developed nations in many ways, as its academic programs and research methodology continue to evolve, the country could eventually gain a lead in the research and development of quantum information. It is impossible to predict who will win the race for this revolutionary technology. One thing is certain, however, that the force behind China's research and development programs is only growing.

NOTES

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