PROTECT

# New cryptographic technology for the quantum computer age

*Proposal of Public Key Encryption based on Lattices for International Standardization*

It has been known that a quantum computer of sufficient performance is capable of breaking RSA and discrete logarithm problems, which are currently used to secure communications over the Internet. At the same time, the commercialization of quantum computers and their availability as a free-of-charge cloud service in recent years reflect the progress made in their performance and penetration. It is therefore possible that current public key encryption will be unable to provide secure communications sometime in the future (Fig.1).

To protect the communication of information in the age of quantum computers, the Cybersecurity Research Institute of NICT developed LOTUS (Learning with errOrs based encryption with chosen ciphertexT secUrity for poSt quantum era) as a new cryptosystem that aims to satisfy the following conditions:

(1) Quantum-resistant: Must be difficult to break even by quantum computers
(2) Versatile: Must be applicable to browsers, databases, and many communication, transportation, and industrial systems.

**"A base cryptosystem is added with functionality"**

LOTUS is a lattice-based cryptosystem*1 based, in particular, on the LWE problem*2, which has been intensively studied of late. The LOTUS team at Security Fundamentals Laboratory explains the design rationale of LOTUS as follows: "It is achieved by first configuring a base cryptosystem and then adding functionality for checking the structure of ciphertext at the time of decryption."

This cryptographic technology is a first-round candidate in the PQC standardization process held by the National Institute of Standards and Technology (NIST) of the United States. All submitted candidates, including LOTUS, are being analyzed by experts in this field for a period of three years or more that started at the end of 2017 to choose a new standard for the future.

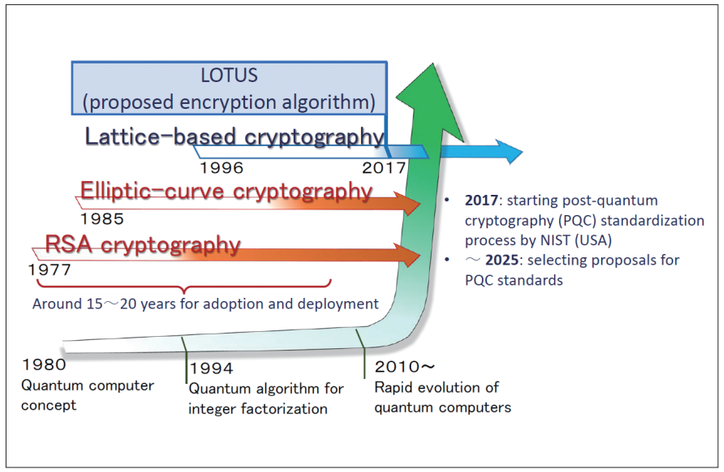


Fig.1 : Transition of public key encryption

**Footnote**

***1 Lattice-based cryptosystem**
A set of points arranged in a regular way in space is called a lattice and a cipher that ensures safety by using the mathematical properties of a lattice is called a lattice-based cryptosystem. Here, expressing the property of regular arrangement as a matrix enables encryption and decryption processing to be performed in parallel, ensuring efficient implementations.

***2 LWE problem**
Short for Learning with Errors problem. Given a set of simultaneous linear equations in which the number of equations is greater than the number of variables, this problem consists of finding an integer solution such that the difference between the left side and right side of each equation becomes small. It has been shown that this problem is as hard as the lattice shortest vector problem depending on parameters, which indicates that finding a solution would take an extremely large amount of time even for a quantum computer.





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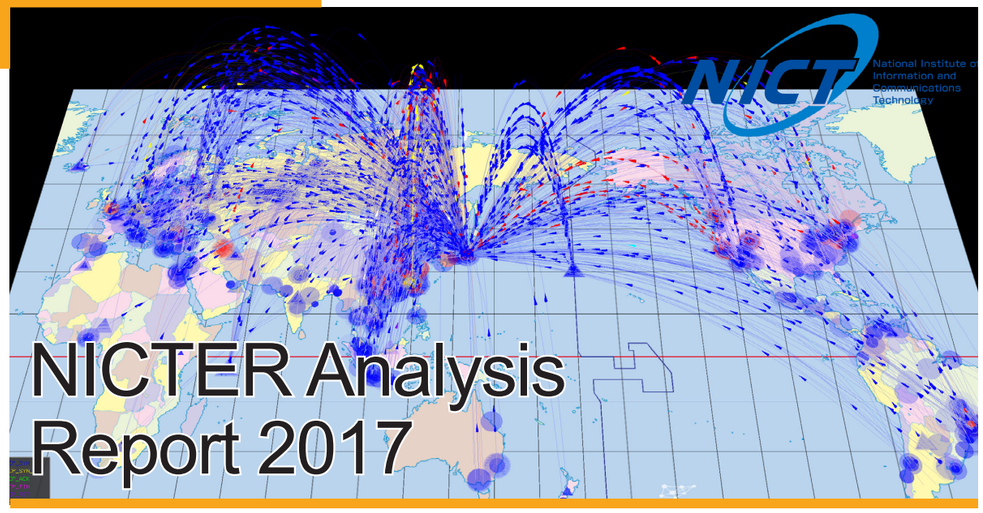


The NICT Cybersecurity Research Institute has been operating a large-scale cyberattack monitoring network (darknet monitoring) as part of the NICTER*1 project and has been monitoring cyberattack-related network packets*2 since 2005. The monitoring and analysis results of the NICTER project for 2017 (released in February 2018) are summarized below.

Cyberattack-related network packets observed in 2017 on the NICTER darknet monitoring network (about 300,000 IP addresses) rose to a total of 150.4 billion, which is about 560,000 packets per IP address per year (Fig.1).

The total number of packets per year represents only the number of packets arriving within the range of the darknet monitored by NICTER and should not be interpreted as the number of attacks mounted throughout Japan or against government institutions.

The total number of observed packets per IP address per year keeps increasing each year (Fig.2) and from 2016 to 2017, this number increased by 1,2 times.

| Year | Total packets (billion) | # of darknet IP addresses | Packets received per IP address |
|---|---|---|---|
| 2005 | 0.31 | 16,000 | 19,066 |
| 2006 | 0.81 | 100,000 | 17,231 |
| 2007 | 1.99 | 100,000 | 19,118 |
| 2008 | 2.29 | 120,000 | 22,710 |
| 2009 | 3.57 | 120,000 | 36,190 |
| 2010 | 5.65 | 120,000 | 50,128 |
| 2011 | 4.54 | 120,000 | 40,654 |
| 2012 | 7.78 | 190,000 | 53,085 |
| 2013 | 12.88 | 210,000 | 63,655 |
| 2014 | 25.66 | 240,000 | 115,323 |
| 2015 | 54.51 | 280,000 | 213,523 |
| 2016 | 128.1 | 300,000 | 469,104 |
| 2017 | 150.4 | 300,000 | 559,125 |

Fig.1 : NICTER darknet monitoring statistics

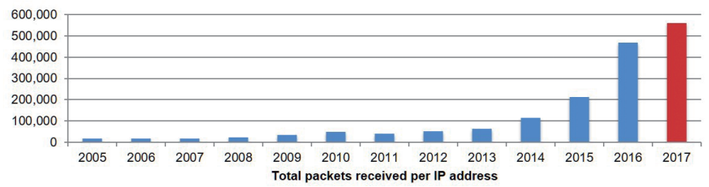


Fig.2 : Total number of observed packets per IP address per year

**"We raise our awareness of the need for applying security measures to IoT devices too."**

Figure 3 shows the top 10 attack targets (destination port numbers) observed by NICTER in 2017. The blue portions of this pie chart, which constitute more than half of the total, corre-

spond to attacks targeting vulnerabilities inherent to specific type of IoT devices such as mobile routers and home routers. These results reflect the increasing sophistication of attacks toward IoT devices.

Director Daisuke Inoue and Executive Technical Researcher Masaki Kubo of the Cybersecurity Laboratory have stated, "It is important that we raise our awareness of the need for applying security measures to IoT devices too, such as by accurately determining what IoT devices are used in the home or workplace and appropriately configuring and updating them as needed."

NICT is committed to enhancing the use of NICTER monitoring and analysis results and researching and developing security measures for IoT devices to improve security in Japan.

NICTER Analysis Report 2017 (detailed versions):
Web version: http://www.nict.go.jp/cyber/report.html
PDF version: https://www.nict.go.jp/cyber/report/NICTER_report_2017.pdf

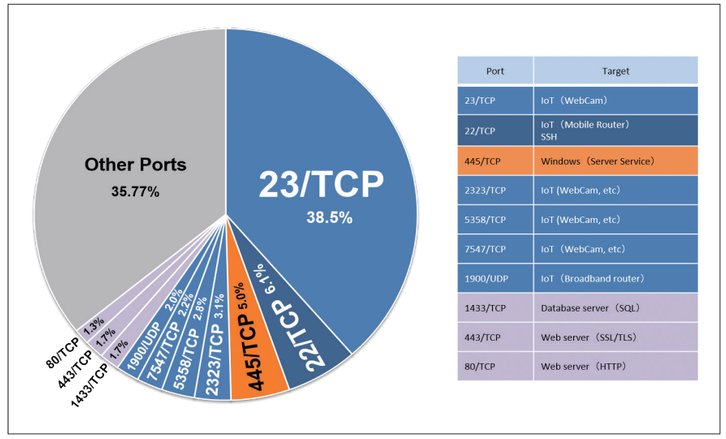


Fig.1 : Percentage breakdown of packets by destination port number
Port number 22/TCP, which ranks second in number of packets, includes scan packets to ordinary authentication servers (Secure Shell (SSH) protocol) that are not mobile routers. "Other Ports" in the pie chart also include many packets targeting IoT devices.

**Footnote**

***1 NICTER (Network Incident analysis Center for Tactical Emergency Response)**
NICTER is an integrated system for rapidly grasping various types of threats to information security over a wide area and deriving effective countermeasures. It has functions for performing correlation analysis of information obtained by observing cyberattacks and collecting malware and for investigating the root causes of security threats.

***2 Cyberattack-related network packets**
This is the generic term for packets arriving at the darknet. These include scan packets from malware-infected devices searching for the next target to infect on the Internet and backscatter packets from servers under denial-of-service (DoS) attacks.

WATCH

# Hybrid approach for more accurate "one-second"

*Synergy between optical and microwave clocks, achieving a months-long time scale with high precision*

National standard times are maintained to be synchronized with Coordinated Universal Time (UTC). Since the radiation frequency associated with the cesium hyperfine transition defines the length of "one-second," maintaining accurate Cs clocks is straightforward to keep time. Optical clocks, on the other hand, have been making rapid progress recently and now have much less systematic uncertainty than microwave standards. Nevertheless, nobody has so far generated the real-time signal of a time scale using optical clocks because it is still difficult to operate an optical clock continuously for one month or longer.

Researchers at the NICT Space-Time Standards Laboratory including atomic physicists and time-composing experts have demonstrated a novel time scale called the "optical-microwave hybrid time scale" that combines an optical lattice clock with a hydrogen maser (HM). The $^{87}$Sr lattice clock, as a standard for pace adjustment, is sparsely operated for three hours once a week. This operation calibrates the frequency of the HM, and the measurements over the latest 25 days allow them to predict how the HM ticking rate will change. Then, they can adjust the HM frequency for the following week in advance to compensate for the predicted frequency drift.

**"The method demonstrated here brings the benefit of optical frequency standards to time keeping."**

The signal generated in this optical-microwave hybrid system continued for half a year without interruption. The resultant "one-second" was more accurate than that of UTC on that date, and the time deviated by 0.8 ns in half a year relative to TT(BIPM), which is the most accurate time scale post-processed by the International Bureau of Weights and Measures (BIPM). This demonstration shows it is possible to keep time with respect to the future optical definition of the second, which may come into play in the next decade.

Tetsuya Ido, director of NICT Space-Time Standards Laboratory, states "We serve the society by providing time endlessly without interruptions. The optical-microwave hybrid method demonstrated here brings the benefit of optical frequency standards to time keeping."

NICT, which generates Japan Standard Time (JST), aims to apply this hybrid method to the JST generation system step by step. The next step would be establishing a redundancy of optical frequency references. Another optical lattice clock or single-ion clock will work. They may utilize those in other laboratories by forming connections via optical fiber network or satellite-based frequency transfer.

Dr. Ido has also said "Highly precise optical clocks are expected to be geodetic sensors to detect the variation of gravitational environment. Such applications demand a reference that remains unchanged. Highly accurate and stable national time scale may play this role that is available in 24h/7d as an infrastructure."

**Reference**

Hidekazu Hachisu, Fumimaru Nakagawa, Yuko Hanado, and Tetsuya Ido, "Months-long real-time generation of a time scale based on an optical clock," Scientific Reports 8:4243 (2018). DOI: 10.1038/s41598-018-22423-5
URL: http://www.nature.com/articles/s41598-018-22423-5

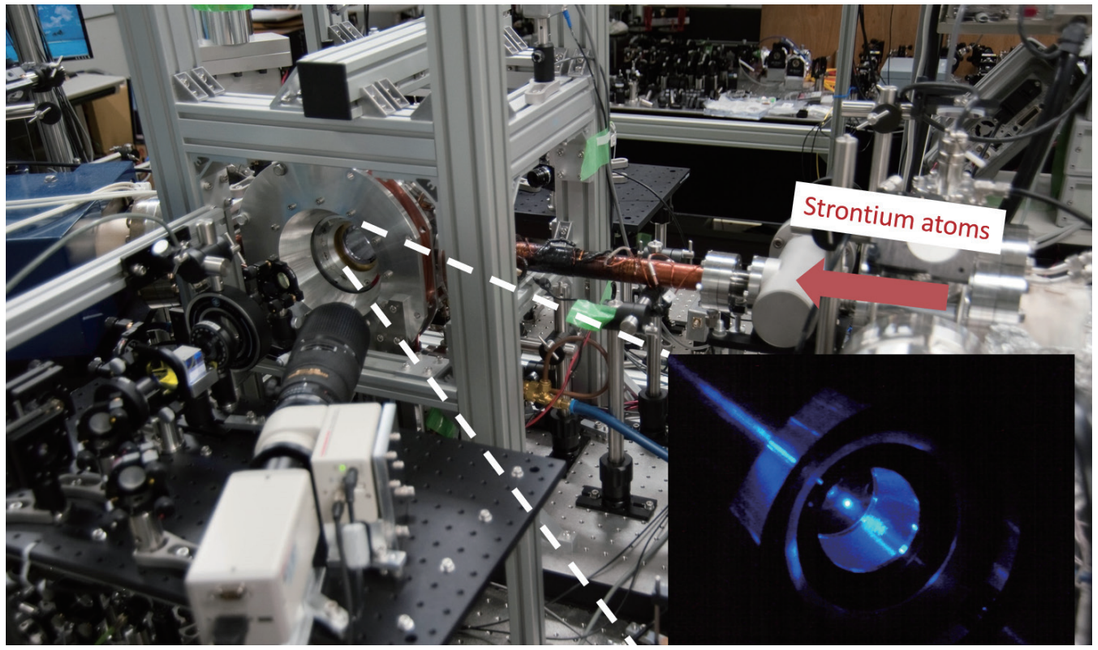


Fig.1 : $^{87}$Sr optical lattice clock