Rethinking OpenPGP PKI and OpenPGP Public Keyserver

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Abstract

OpenPGP, an IETF Proposed Standard based on PGP® application, has its own Public Key Infrastructure (PKI) architecture which is different from the one based on X.509, another standard from ITU. This paper describes the OpenPGP PKI; the historical perspective as well as its current use. We also compare three PKI technologies standardized by IETF: OpenPGP, PKIX(X.509), and SPKI/SDSI.

Since the OpenPGP PKI works without a registration authority nor certification authority, it fits well with the Internet communication with voluntary community. For example, the digital signature for email including the security patch program of free software is usually signed by not an authorized organization but the cross-PGP-signed individuals who belong to different organizations or nations.

The current OpenPGP PKI issues include the capability of a PGP keyserver and its performance. PGP keyservers have been developed and operated by volunteers since the 1990s. The keyservers distribute, merge, and expire the OpenPGP public keys. Major keyserver managers from several countries have built the globally distributed network of PGP keyservers. However, the current PGP Public Keyserver (pksd) has some limitations. It does not support fully the OpenPGP format so that it is neither expandable nor flexible, without any cluster technology.

Finally we introduce the project on the next generation OpenPGP public keyserver called the OpenPKSD, lead by Hironobu Suzuki, one of the authors, and funded by Japanese Information-technology Promotion Agency(IPA).

1 Introduction

Authentication is an essential factor of information security in network society. The difficulty of building a Public-Key Infrastructure (PKI) is a major impediment to strong authentication. Without PKI, we cannot trust neither digital signature nor certification based on the public key cryptosystem via wide-area network.

In following section 2 and 3 we overview the PKI architecture comparing several models. In section 4 we examine a PKI without authorities which is presented by
the OpenPGP technology and compare it with the other models. Then we point out the role of the PGP keyserv
in section [6] and introduce the next generation OpenPGP public keyserv project in section [7]. Finally we give
some conclusions.

2 PKI architectures

PKI has three core functions as follows to manage the users' certification and trust relations [25 s.v. "public-key infrastructure"]:

1. to register users and issue their public-key certificates
2. to revoke certificates when required
3. to archive data needed to validate certificates at a much later time

To operate these three functions with many users on a large-scale network, many PKI have a hierarchical structure for CAs and are built using a centralized architecture. However there are alternatives.

PKI is categorized by the architecture types as follows: 1) hierarchical PKI, 2) mesh PKI, and 3) trust-file PKI [25 s.v. “trusted certificate”]. The difference is the way they rely on CA (Certification Authority). A hierarchical PKI has the most significant CA in terms of trust at the root of the hierarchy tree. A mesh PKI has CAs issue cross-certificates to each other. A trust-file PKI has a local file of public-key certificates that the user trusts as starting points for certification chain.

For example, popular browsers are distributed with an initial file of trusted certificates, the starting points for certification paths. The initial file is different between among the each PKI architecture. In a hierarchical PKI, the initial file is the root certificate in a hierarchical PKI. It is usually “baked into” the browsers with no decisions by the users to trust them. In a mesh PKI, it is the certificate of the CA that issued the user’s own certificate. And in a trust-file PKI, any certificates including self-signed certificates accepted by the user can be the first public key in a certification path.

3 PKI standards

To build PKIs, different standards are developed. They are based on their own framework and architecture and they are never the same. This section compares different PKI architectures: 1) X.509 standard from ITU, 2) OpenPGP, an IETF Proposed standard based on PGP® application, and 3) SPKI, another standards based on the theoretical research.

X.509 is the earliest framework to provide and support authentication including formats for X.509 public-key certificates, X.509 attribute certificates, and X.509 CRLs. X.509 is the hierarchical PKI that a CA, central digital certificates issuer, is responsible for managing the certificates.

Historically, X.509 was standardized by ITU-T (International Telecommunication Union Telecommunication sector, formerly CCITT) and turned to be ISO standard. X.509 follows the X.500 directory service and provides an example of reliable authentication and certification. In practice, developers relax the strict X.500 service scheme. For example, X.509v3 (Version 3) certificate has “extensions” field for flexible operation.

IETF had discussed about the design based on X.509 framework from each applications to general PKI. Internet standards for X.509 PKI framework is developed at IETF Public-Key Infrastructure (X.509) Working Group. PKIX not only profiles X.509 standards, but also develops new standards apropos to the use of X.509-based PKIs in the Internet.

One of the most popular implementations of X.509-based PKI is OpenSSL (http://www.openssl.org/ formerly SSLeay). OpenSSL is a set of Open Source cryptography libraries including X.509 CA operation scripts and distributed freely, such as a part of PKI package for either commercial or non-commercial purpose.

OpenPGP is the standard based on Pretty Good Privacy® (PGP®) application which is developed by Philip Zimmermann [12]. PGP® is provided as commercial version and ‘freeware’ version for non-commercial/non-governmental purposes only.

The specification of PGP is standardized as OpenPGP by IETF OpenPGP Working Group. Today “OpenPGP Message Format” is defined in RFC2440 [3] and to be updated [4]. The most popular OpenPGP implemen-
tion is GnuPG (GNU Privacy Guard), developed by Free Software Foundation and maintained by Werner Koch of GUUG (German Unix Users Group). Either PGP or GnuPG has been known as email cryptography software firstly, however they have become the general purpose data encryption tool, including key exchange over Internet, trust computation, etc. In the following sections, we examine the only PKI part of OpenPGP.

It is worth to point out another possible architecture, as we sometimes take an closed binary question such as “X.509 or OpenPGP, which is better?”, not as “Which PKI will be the appropriate solution for different usage-scenarios?”. There exists another PKI standardized by IETF — SPKI (Simple Public Key Infrastructure). IETF SPKI Working Group finished its initial standardization process and bring into the inter-operation stage [16, 10]. It is also called SPKI/SDSI as it is a joint force with SDSI (Simple Distributed Security Infrastructure) research. SPKI is designed with distributed and scalable architecture in many aspects, i.e., no single root CA, no globally distinguished name, and flexible validity periods [1, 13].

Table 2 shows the technical comparison of X.509, OpenPGP, and SPKI/SDSI based on the analysis by Clarke [7].

4 Certification without Authority

4.1 From Face-to-Face to Web of Trust

Without a certification authority, the problem of trusting keys arise to assess applicants before giving out certificates. In OpenPGP, there are no official mechanism for creating certificates, no official channel for acquiring and distributing. It makes the process of certification into the face-to-face, ad hoc situation. Each end user is responsible to decide which certificate (public key of an user) is trusted and accepted to be added into their local trust-file (denoted “keyring” in PGP).

This certification process does not require a trusted, monitored registration authority or certification authority, however, it lacks scalability. So since PGP® 2.0 [15 pp. 201–203], “web of trust” model that PGP signer acts as an introducer between people had been supported.

Figure 1 illustrates the model of hierarchical PKI and web of trust.

4.2 Internet Usage Scenarios

OpenPGP has its own market which is different with X.509, and OpenPGP community has grown in a global Internet.

The most famous and critical use might be security alerts. FIRST (Forum of Incident Response and Security Teams) and its members including CERT(Computer Emergency ResponseTeam)/CC(Coordination Center) have their official PGP/GnuPG public keys publicly available [11], and have signed their alerts with their own PGP/GnuPG key.

Usenet, operated by volunteer NetNews managers, is another example of the distributed network with OpenPGP PKI. The digital signature for Usenet control commands should be signed with PGP keys of represented voluntary managers since 1990s [14].

4.3 What is the Web of Trust?

OpenPGP provides key management and certificate services using local trust-file PKI. The more signature is accepted, the more trust-file generated. Figure 2 is an example of a trust-file visualized the relationship of OpenPGP signature. This graph illustrates who introduce the other or who meets with face-to-face, in other words, whose key signed the others’ public key. There are no central authorities but multiplexed individual relationships in a community.
Figure 2: Visualized Web of Certificate [8]

However, this graph is not a “web of trust” but just a “web of certificates”. OpenPGP separate the trustworthy from validity of certificate. For example, the amount of trust of the introducer and unknown newcomer is different for an OpenPGP user. Even if their certification is valid, the issuer of the key is not an authority but the users own. So OpenPGP users should be responsible on “Whose keys should be taken as valid but untrusted?” [26, p. 81].

In OpenPGP, users issue their signature to the other’s public key with their degree of trust. This is denoted “trust signature” and represented as (trust level, trust amount) with OpenPGP key management and certificate service. An ordinary valid signed key is trust level 0, and The signed key is asserted to be a valid trusted introducer is level 1. Level 2 means “meta introducer” or “introducer-of-introducer” that its signed key is asserted to be trusted to issue level 1 trust signatures. (Generally, as the introducer is more trustworthy, a level $n$ trust signature asserts that a key is trusted to issue level $n-1$ trust signatures.) The trust amount is in a range from 0–255, and appointed 60 for partial trust and 120 for complete trust [3, s.v. “Trust Signature”]. As OpenPGP distinguished the trust from validity, “web of trust” is also distinguished from “web of certificates”.

4.4 PGP Revocation Problem

The weakest link of OpenPGP PKI is the revocation of public key [22, pp. 585–586] [3, p. 309]. As there is no official channel for acquiring and distributing OpenPGP public keys, there are no guarantee about how to tell everyone that your key is no longer valid.

The typical answer to this revocation problem of PGP is to use PGP public keyservers for distributing certification. “Typically, to communicate that a certificate has been revoked, a signed note, called a key revocation certificate, is posted on PGP certificate servers, and widely distributed to people who have the key on their public keyrings. People wishing to communicate with the affected user, or use the affected key to authenticate other keys, are warned about the hazards of using that public key” [7, pp. 56–57]. However, there are few research on the PGP keyservers and usually the keyservers is not considered as the part of OpenPGP PKI. In the following, this paper examines PGP keyservers as the part of OpenPGP PKI.

5 Related Works

There are several research fields related to OpenPGP public keyservers. The first is the study on the traditional PGP public keyservers, the second is the integrated channel for OpenPGP key distribution, and the third is the combined “web of trust” with other PKI.

A “web of trust” used in PGP is referred in several researches including the peer-to-peer authentication [9], trust computation [17, 5], and privacy enhanced technology [12]. However, there are few description on PGP keyservers. It might be because PGP keyservers mechanism is too simple. It is not a CA but just a pool of public keys. From users’ viewpoint, PGP keyservers has a large amount of OpenPGP public keys that provide the interesting material for social analysis of network community. For example, OpenPGP keyservers developer Jonathan McDowell also developed “Experimental PGP key path finder” [18] that searches and displays the chain of certification between the users.

As OpenPGP’s initial trust file is blank, the users have to start with a face-to-face certificate to exchange public keys. Though another initial file is provided via high integrity channel. Global Internet Trust Register [2] is
a printed book that contains “fingerprints” (hash values of certificate) of the most important public keys (mainly cryptography experts who are likely to have signed many other keys in their respective communities) [26, pp. 80–81].

OpenPGP PKI itself can be described as the superset of PKI [32], however, combining OpenPGP PKI with other authentication system is challenging work in both theoretical and operational field. Formal study of trust relationship of PKI started in the late 1990s [17, 5] and GnuPG development version in December 2002 started to support its trust calculation with GnuPG’s trust signature.

The implementation of trust calculation is ongoing and using large-scale “web of trust” (not “web of certificates”) is not so popular outside of computer experts. On the other hands, using different types of PKI has become more popular.

In the early work at MIT, PGP-signing service had been combined with Kerberos CA system that does not have public key cryptography [21]. Today, the hybrid system of OpenPGP and X.509 is both developed into some OpenPGP implementations. In 2001, German authorities BSI (Bundesamt für Sicherheit in der Informationstechnik, Germany’s agency for information technology security) accept the Ägypten project for Open Source implementation of governmental mail user agents Sphinx which supports X.509v3, PKCS, LDAP, and OpenPGP [19]. The results of the open development are begun to import to other commercial products in 2002–2003 [23]. In a same way, PGP Corporation also released PGP® version 8.0 as X.509-enabled application that can interoperate X.509 certificates and CAs [20].

6 OpenPGP Public Keyserver

Before describing our research, this section describes OpenPGP keyserver generally. Keyserver is not a CA. It only pool anyone’s public keys. Keyserver never issue any certificate for someone’s public key but only provide it.

6.1 Current Status

The first keyserver is developed at MIT in 1994 by Brian A. LaMacchia. It exchange public keys with email and keys are managedement with PGP command. For users, keyserver acts as an easy email agent who receives any valid but untrusted keys, then searches and provides the key to everyone. In 1997, PGP Public KeyServer (pksd, http://www.mit.edu/people/marc/pks/) started by MIT student Marc Horowitz. Pksd uses a database management system and has been working fine. The database system is operated via email, CGI-interface from http server, and HKP — pksd’s own communication protocol over Hypertext Transfer Protocol (HTTP). In 2003, David Shaw of GnuPG team proposed the OpenPGP HTTP Keyserver Protocol [24] based on traditional HKP as the draft for Internet Standard.

Today pksd has been working fine even if in global distributed network. There are 10 or more synchronized public keyservers in the world and the most of them are running with patched pksd. These public keyservers are operated by voluntary managers belong to organizations including MIT and Georgia Tech in United States, SURFnet in Netherlands, DFN-CERT in Germany, RedIRIS (IRIS-CERT) in Spain, JPNIC in Japan. Today they have more than 1,400,000 public keys entries and 3,000/day or more transactions between each sync sites. In 2000, SURFnet held the first PGP keyserver manager symposium [27] and the managers keep in touch with each other.

6.2 Revocation process and Keyserver

As public keyservers provides semi-official key distribution channel, keyserver adds powerful feature to OpenPGP PKI. Public keyservers can handle the PGP revocation problem that we described in section 4.4. Using keyserver provides an answer to the question “How do you tell everyone that your key is no longer valid?”. User may issue a suicide note (denoted as “revocation signature” in OpenPGP ) and post it to keyservers. Receiving a valid revocation signature, keyserver updates the key to be revoked. The update key with revocation signature is redistributed to the synchronized keyservers in the world, and finally PGP user updates their keyrings with the nearest keyserver. The updated key with valid revoked signature makes users’s older key not to be used.
6.3 Current Keyserver Problem

Today’s situation around PGP keyserver is beyond the original developers’ idea, and current pksd also has some limitations.

Firstly, the implementations of pksd are not OpenPGP-compliant. OpenPGP [3] published in 1998 defines two versions of signature formats. (Version 3 provides basic OpenPGP signature information, while version 4 provides an expandable format with subpackets.) These changes made traditional PGP applications not-OpenPGP-compliant — not only PGP® [3, s.v. “Implementation Nits”] but also pksd. Today pksd does not fully support OpenPGP format.

Secondly, the pksd does not scalability for global use. Though pksd has simple but strong database management system, it is neither sophisticated nor scalable compared with today’s Internet server. For the matter, pksd cannot handle 1 billion keys and cannot accept such many transactions as Yahoo! or eBay site. New design of OpenPGP public keyserver is required.

7 OpenPKSD: Next Generation
OpenPGP Public Keyserver

We introduce our next generation OpenPGP Public Keyserver project with a new architecture. We call it OpenPKSD (OpenPGP Public KeyServer Daemon). It is developed by one of the authors and funded by Japanese Information-technology Promotion Agency (IPA) in 2001–2002.

7.1 Server Design and Implementation

OpenPKSD supports OpenPGP subpacket format and works as high-performance server with SQL backend. The design of OpenPKSD oriented to not only high-performance, but also flexible extension capability and easy operation. We implemented OpenPKSD with Ruby and PostgreSQL backend [28].

7.2 User Interface and Security

As “Web of trust” depends on users’ decision, user interface is also important factor on security. For example, Whitten and Tygar [31] had ever pointed out some dangerous errors occurred with past PGP clients’ interface.

Users can connect to OpenPKSD with two kind of interfaces, OpenPGP client or CGI on WWW. Providing WWW interface, OpenPKSD must help users’ recognition, judgement, and handling on OpenPGP public keys.

OpenPKSD displays only 64bit KeyID to identify someone’s public keys. Though some other servers calculate and display “fingerprint” of public keys before download it, it does not help users aware of risk using keyserver. As keyserver is just a pool and not CA, users should check the public key with their own. Moreover, it is easy to make some faked keyserver by Man-in-the-Middle Attack, TCP hijacking, etc. It means that the fingerprint must be calculated under user’s (safe) machine and that is the reason why OpenPKSD does not display fingerprint.

OpenPKSD WWW interface provides additional feature to visualize subpackages of PGP keys. As OpenPKSD has an expandable format with subpackages, it is very hard to understand the data structure inside this. Using pgpdump program, key packet visualizer that displays the packet format of OpenPGP and PGP® version 2.

Many PGP users are familiar with this verification on added keys, as in 2000, PGP® version 5.5.x to 6.5.3 had a serious security hole that cannot detected with fingerprint verification. Then CERT/CC had alerted “Check certificates for ADKs [Additional Decryption Keys] before adding them to a keyring.” [6]. Pgpdump exactly visualizes these additional keys. With pgpdump, OpenPKSD helps users to recognize the information of public key and any other added keys before downloading.

7.3 Performance and Future work

OpenPKSD is implemented with Ruby language and PostgreSQL DBMS. Ruby is so-called “scripting language” and seemed not suitable for a quick response or large program development. However, OpenPKSD succeeds not only the more compact code size but also quick response compared with pksd, by loading bit calculation modules such as CRC24 checksum written by C language [29]. Table 1 shows the performance of OpenPKSD version 0.2.8, non-cluster version, installed on PC. OpenPKSD version 0.2.8 is also working well at handling usual transaction between other PGP public keyserver described in section since 2002.
Forthcoming developers’ version of OpenPKSD will support some clustering based on the research on the performance of cluster technology [10]. It will be published in 2003 and support the experimental HKP(keyserver protocol over http) balancer, keyserver cluster, and clustered database.

8 Summary

In this paper, we overlooked some PKI architectures. Using “Web of Trust,” OpenPGP PKI can help users to manage certification without CAs. However, there are the problem on public key management, i.e., how to get the receivers’ public key, or, how to tell everyone that the public key is no longer valid. PGP keyserver is the solution to the problem.

Though some PGP public keyservers have built a global PKI, traditional PGP keyserver sometimes have some limitations. We introduced OpenPKSD, newly-designed and OpenPGP-supported public keyserver project. OpenPKSD took its first step, works well in practice, and examining the cluster technology.

Availability

OpenPKSD source code and documents are available under GNU General Public License (GPL) at

http://www.openpksd.org/

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Table 1: OpenPKSD Performance

| CPU          | Intel Pentium4 1.6GHz |
|--------------|-----------------------|
| HDD          | IDE ATA100 7200rpm 60GB |
| Memory       | PC2100 768MB          |
| One key query: | 120ms average, 72ms best, 230ms worst. |
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| CA Type | CA Characteristics | Trust Model | Signatures | Certificate Revocation | Name Space | Types of Certificates | Name-to-Key binding |
|---------|------------------|-------------|------------|------------------------|------------|-----------------------|---------------------|
| X.509   | Global Hierarchy. There are commercial X.509 CAs. X.509 communities are built from the top-down. Hierarchical Trust Model. Trust originates from a ‘trusted’ CA, over which the guardian may or may not have control. A requestor provides a chain of authentication from the ‘trusted’ CA to the requestor’s key. Each certificate has one signature, belonging to the issuer of the certificate. Uses CRL(Certificate Revocation List)s | Global | Single-valued function: each global name is bound to exactly one key (assuming each user has a single public-private key pair). | | Global | Name Certificates | |
| OpenPGP | Egalitarian design. Each key can issue certificates. PGP communities are built from the bottom-up in a distributed manner. | Web of Trust, file-based PKI. | Each certificate can have multiple signatures; the first signature belongs to the issuer of the certificate. A ‘key revocation certificate,’ suicide note is posted on PGP keyservers, and widely distributed to people who have the compromised key on their public keyrings. | | Global | Name Certificates | Single-valued function: each global name is bound to exactly one key (assuming each user has a single public-private key pair). |
| SPKI/SDSI | Egalitarian design. The principals are the public keys. Each key can issue certificates. SPKI/SDSI communities are built from the bottom-up in a distributed manner. | Trust originates from the guardian. A requestor provides a chain of authorization from the guardian to the requestor’s key. The infrastructure has a clean, scalable model for defining groups and delegating authority. Each certificate has one signature, belonging to the issuer of the certificate. Advocates using short validity periods and Certificates of Health. | | Local | Name Certificates, Authorization Certificates | Multi-valued function: each local name is bound to zero, one or more keys (assuming each user has a single public-private key pair). |

Table 2: Comparison of X.509, OpenPGP, and SPKI/SDSI