Response to NTIA Notice of Inquiry on DNSSEC

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Table of contents

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1. Introduction

There is no doubt the earliest opportunity is the proper time for action in DNSSEC deployment. The present NTIA Notice of Inquiry [NTIA_NOI] is thus welcome and the opportunity to reply is very much appreciated.

DNSSEC support at the root will be a significant development in the Internet history as the first fielding of a public key digital signature mechanism with a global applicability. Both the PKI (Public Key Infrastructure) and the LDAP (Lightweight Directory Access Protocol) technologies were once envisioned with similar global applicability, but neither were implemented as originally intended.

This very DNSSEC global applicability motivates the present comment submission, which is focused on cryptographic key management issues, mainly as they relate to the organizational aspects of authoritative root zone management. Basically, our claim is that given a reasonable organizational arrangement (requirements), we are able to contribute to cryptographic key management guidelines (solution elements) that would allow better use of cryptographic techniques in the specific context of the NOI document.

Overall, the information provided by NTIA in the NOI document plainly delineates the scope of the issues, their relevance, available options. In doing so, it suggests a willingness to proceed diligently with the DNSSEC implementation a the authoritative root zone management level.

The present author has been involved in various aspects of cryptographic key management since 1994, and since 2005 in support of DNSSEC. Foremostly, this involvement includes a general dedication to the proper adaptation of cryptographic key management schemes to operational and organizational arrangements. On many occasions, the present author reminded an audience that cryptographic mechanisms *do not control information*; they merely *shift information controls into fewer hands*. This principle applies to the subject matter of the present NOI: the RKO (Root Key Operators) are essentially these few hands holding the DNS integrity controls.

1.1 Expectations from Stakeholders

The US government oversight of the Domain Name System is a much debated issue. The NTIA is indeed part of the executive branch of the US government. In this subsection, we make some simplifying observations about the expectations of DNS root key management strategies by NTIA. In our attempt to simplify, there are only two classes of stakeholders:

- the vast majority of Internet users, including most e-commerce operators, who simply whish to benefit from higher trustworthiness of data retrieved from the DNS, and have no logical ground to fear US government interference in the DNSSEC hierarchy of digital signatures, and

- an extremely small group of stakeholders, perhaps limited to foreign governments, who might need assurance that RKOs can't be subverted for highly strategic "attacks" on DNS integrity, in the limited sense that we will explain below.

The above is a simplification only because stakeholder expectations are not always logical. Some may see some special status affixed to the role of RKOs. Mistrust directed at government controls may be extended to the technical control of the DNSSEC integrity scheme under unspecified justification or mere paranoia. Confusion may arise with other internet governance issues that are more sensitive to differentiated stakeholder expectations, e.g the enforceability of trademark rights in the Internet domain namespace. Superfluous expectations may come from a wrong understanding of the the DNSSEC technique as a *confidentiality* mechanism, while DNSSEC is actually limited to an *integrity* function. We ignore these grounds for making DNSSEC more policy-intensive than we see fit.

Thus, for the vast majority of stakeholders, the DNSSEC deployment strategies at the root need not challenge the *US Principles on the Internet's Domain Name and Addressing System* (reference 19 in the NOI document). Although the NOI may not be the proper place to make observations that are not aligned with these principles, we take such liberty when our discipline of adapting key management to organizational issues suggests so. As hinted above, this will occur in relationship with the perspective of strategically-concerned stakeholders.

Generally, there is an assumed expectation of RKO dedication to state-of-the-art IT security technologies and compliance to adequate procedures. The present comment submission does not review this generic security requirement. The proposals by ICANN and Verisign, respectively (references 25 and 26 in the NOI document) seems fairly comprehensive in this respect. The generic security requirement and the criticalness of DNSSEC root keys introduce the issue of RKO *accountability*. To the extent the accountability aspect creates concerns with the assignment of DNSSEC root operational responsibilities, it may be noted that the NTIA as a US government entity happens to have the right accountability relationship with US federal government agencies as DNSSEC relying parties, a self-service arrangement not nominally available to other national governments.

We now try to describe what strategically-concerned stakeholders could logically fear if the RKOs are subverted. The good news for everyone is that it's a vulnerability totally devoid of attractiveness for would-be fraudsters even if it could be implemented in a DNSSEC island of trust other than the root. We describe it merely to indicate how a strategically-concerned stakeholder may remain unsatisfied even if the RKO arrangement is fully satisfactory with respect to the generic security requirements in the preceding paragraph. Basically, we are referring to a targeted integrity attack on the assumed integrity provided by DNSSEC. Any non-targeted attack would be noticed as the root nameservers are very public. The victim is a relying party that relies on DNS data in a DNS zone like cfo.headquarters.example.org such that spoofed data could have a severe impact also desirable to an adversary who subverted the RKOs. The adversary obtains a signed version of the root zone file that is authoritative for cfo.headquarters.example.org and proactively spoofs DNS replies to queries from the victim's systems. The attack success depends on an inordinate extent of required protocol hacking, nameserver replication, and cache defeating tricks. It is nonetheless worth a description in here as the single logical base known to us for strategically-concerned stakeholders to object to a DNS signed root "under control" of the US government. In the final analysis, the wrong behavior that could be suspected from the RKOs given the cryptographic machanisms is so remotely applicable that only the RKO accountability issue appears relevant.

2. Accommodating technology

The DNSSEC deployment at the root implies some unique tchnological requirements that are derived more from the uniqueness of the root in the distributed DNS hierarchy than from the DNSSEC protocol details.

2.1 Split or Dual Control of KSK Private Key

Among the best practice security procedures, split or dual control of important cryptographic key material is an inescapable requirement. Nowadays with the use of PKC (Public Key Cryptography) in highly automated network services, the split control of key mterial may not appear as a foremost requirement, but its ever-present justification is intact in the case of DNSSEC root keys. In practice, the requirement enters the DNSSEC root deployment as the control mechanism to either inject or enable the KSK (Key Signing Key) into an HSM (Hardware Security Module) for off-line KSK digital signatures. Whether it is implemented as a split knowledge technique for the private key value, as a token-based access control for turning the HSM unit into an operational state, or as a multi-signature scheme for RSA, the operational principle is the same.

Note that the ZSK need not be subject to split or dual control. It is the very purpose of an emergency ZSK rollover procedure, applying KSK signatures, to make ZSK compromise recovery possible without re-configuration of the whole population of DNS resolvers.

Operationally, failure to properly implement split or dual control of important key material such as the root KSK puts a person in the position of a single point of failure. With the transparency of procedures that every party is advocating for the DNSSEC root signature operation, such a failure is not an option. Note that the justification is a matter of RKO accountability, and not a matter of mitigating any excessive "power" associated with the RKO role. The two remaining questions are

- whether split or dual control custodians should be employees of a single organization, agents of a single organization, or organizations dealing at arm's length, and
- whether a threshold scheme should be applied such that a subset of key custodians is sufficient for injection or enabling the KSK private key operation.

The first question will be addressed below when looking at the institutional arrangements. In reference to the process flows detailed in the NOI document, we just observed that the differentiated characteristics of the 6th one should be applied somehow to any process flow solution, so the first 5 should be amended accordingly and compared using other decision criteria.

2.2 Technology Intensiveness of the RKO Role

Essentially, the RKO role comprises

- the initial KSK generation,
- organization of KSK rollovers,
- participation in scheduled ZSK rollovers,
- readiness for participation in emergency ZSK rollovers, and
- last but not least, the safeguard of KSK private key components (or tokens used to enable KSK signature capability).

The ZSK rollover operations is essentially a delegation of signing authority to the DNS expert personnel in charge of the authoritative root zone file change management, which is a highly visible activity watched by DNS experts throughout the world. With the exception of the DNSKEY root RRset (the set of public signature keys for authoritative root zone file), no inspection or handling of DNS data is required. Thus the technical quality assurance does not rest critically on the RKO oversight. Some institutional quality assurance or audit function should be part of the RKO role definition.

The most technology-intensive portions of the RKO role are the initial KSK generation and scheduled KSK rollovers. Ideally, the RKO "entities" should be autonomous in these activities instead of relying on the DNS experts so they are less vulnerable to "social engineering attacks," i.e. being misdirected into undesirable KSK handling operations by the very individuals responsible for the activities delegated by the RKO. To make things more puzzling, it is not even clear that suitable secure systems and devices are available commercially for the DNSSEC root

KSK handling. The HSM suppliers have product line offerings with token-based split or dual control of digital signature capabilities, but the DNS root KSK application may require more transparency and independent public audit than vendors would accept. Also, the threshold split control of digital signatures could be on some vendors' catalog but never actually deployed by customers (we never encountered a public or confidential report of threshold scheme actual usage). The root KSK digital signature technology procurement effort should also account for technology obsolescence since the lifetime of rolled-over root KSKs is expected to span beyond the typical product life-cycle in specialized electronics products.

2.3 No Need for Further KSK Rollover Provisions

Reader's note: this subsection uses more acronyms and specialized terms than the rest of the document, without systematically explaining them.

The two preceding subsections apply the IT security technology such that the DNSSEC root KSK processes are adequately protected, notably by classical separation of duties. Similar separation of duties arrangements would be needed if the DNSSEC root KSK management was to rely on [RFC5011] with the intent to formalize scheduled KSK rollovers and emergency KSK rollovers, the latter being effective in the case of security breaches occurring in a subset of the two or more entities participating in the separation of duties arrangement.

We see no justification for [RFC5011] reliance. Serious process inefficiencies would occur if [RFC5011] reliance would be *in addition to* the separation of duties for split or dual control of KSK private key. Seemingly, the other option is the [RFC5011] reliance *as a replacement for* the separation of duties for split or dual control of KSK private key. However, we are not aware of any DNS security expert recommendation for such a strategy for any island-of-trust, notably the root (a qualified recommendation would explicitly refer to the operational aspects of the separation of suties).

For the vast majority of Internet users, it will be more important to enjoy continuous smooth DNSSEC operations when there is no root KSK security breach than to get improved assurance that some type of root KSK security breach may be recovered automatically. In practice, any detectable or publicly known root KSK security breach would make the headlines in IT sector media quicker than the typical DNS resolver operator reaction time to a cryptic log message.

At this point in time, the root zone management has a discretionary decision opportunity about DNSSEC root zone KSK management. This observation comes from the lack of consensus or widespread requests from the part of early DNSSEC adopters for [RFC5011] support by DNSSEC island-of-trust zone managers. The limit to the discretionary decision is the minimal root KSK management sophistication that would still allow DNS resolvers to automatically update their root trust anchor state when a scheduled KSK occurs (for which a need is widely recognized). There is thus a back-and-forth interplay of DNS resolver community expectations and root zone management commitments. As a starting point, we suggest the following DNS resolver behavior as a model for a typical DNS resolver.

A very robust DNS resolver software behavior (assuming recovery of KSK security breaches need not be automated) is specified in three simple rules:

- it accepts a new trust anchor KSK if it appears in the DNSKEY RRset endorsed by an existing trust anchor KSK;
- it deletes a trust anchor KSK if it has not been used for a long period (e.g. 3 years) and there are at least a given number (e.g. 6) trust anchor KSKs that were last used more recently (than the one under consideration); and
- it may require manual configuration if it remains off-line for more than some period (e.g. 11 months).

This should work when the DNSSEC island-of-trust implements simple ad-hoc KSK rollover procedures and [RFC5011] as well.

We suggest a formalization of the above paragraph as representative of the initial NTIA commitment as a root zone manager participant. Unless otherwise told, NTIA may assume that the vast majority of DNSSEC resolver operators would be satisfied with this level of commitment with respect to automated KSK rollovers.

3. Accommodating Institutions

3.1 Allocation of RKO Role

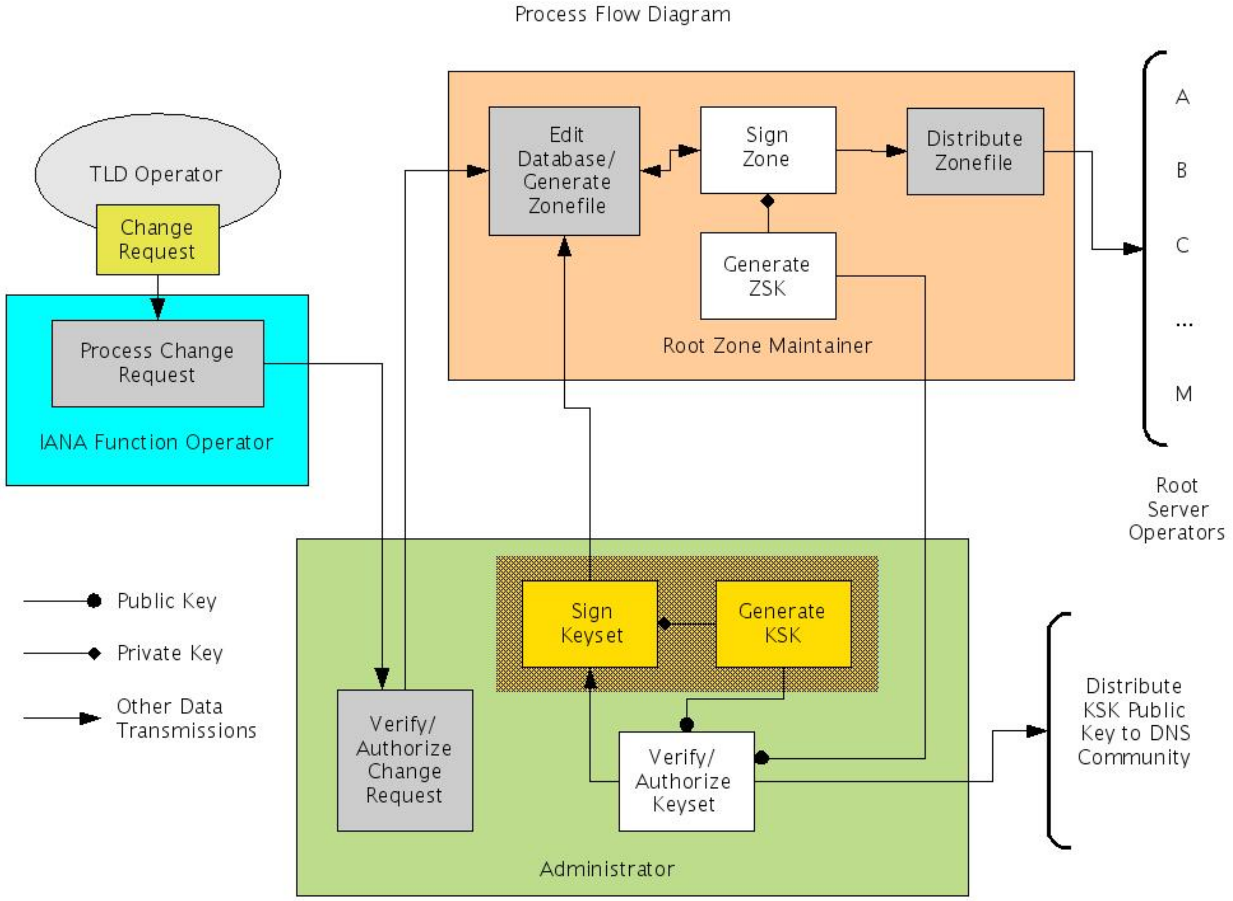
Institutional arrangements for RKO entities are easy to derive from the above section "2.1 Split or Dual Control of KSK Private Key" and the advocated correspondence between key management and organizational issues. In this perspective, the RKO entities should be employees or agents of NTIA as a direct consequence of the following citation from the NOI document: "*As with other changes to the root zone, the Administrator would be responsible for verifying/authorizing updates to the root keyset.*" Since responsibility and operational control allocations should match, and since root keyset signature is controlled by the RKOs, RKO entities should act on behalf of the Administrator, i.e. NTIA.

We are not in a position to suggest whether NTIA employees or agents are more appropriate. Maybe the selection of agents by NTIA would exhibit increased transparency and accountability. By NTIA agents, we mean organizations or individuals acting with the same mission definition as the NTIA but without direct supervision by NTIA (or DOC?) management. Professionals governed by their profession code of conduct could fit the definition. Without much clues about how likely are interagencies arrangements in the US government, we think other divisions of the US government executive branch might qualify as RKO entities, e.g. from GAO, Finance, Justice, other DOC divisions, or a division of another department having the operational responsibility of a PKI certification authority. Entities outside of the US government might not be sufficiently bound to the *US Principles on the Internet's Domain Name and Addressing System* (reference 19 in the NOI document).

3.2 Matching Time Horizons, Long Term Versus Short Term

The idea of linking KSK key custodians to the Administrator accommodates the long term perspective implicit in the NTIA oversight of the Internet naming and addressing system. In contrast, both the IANA Function Operator and the Root Zone Maintainer have an operational horizon aligned with the shorter terms of their respective contracts. The alignment of RKO role allocation to these time horizons reduces the Internet community blind faith in the continued operation of current holders of the IANA function or root maintenance roles.

4. Process Flow Summary



The figure shows the process flow corresponding to the above observations. In essence, this is the NOI document process flow number 5 except that the KSK operations are located in the Administrator facilities instead of collocated with the Root Zone Maintainer facilities. The position of the multiple key custodians is now shown on the figure, except collectively by the yellow hatching rectangular area surrounding the "Generate KSK" and "Sign Keyset" functional blocks.

5. A Different Process Flow Option

The process flow characteristics suggested above are offered to NTIA and the Internet community as a bona fide effort using the terms and perspective of the NOI document. In the process of finalizing them, a few limitations were noticed that could be addressed with the submission of TAKREM for DNSSEC as the base for a different process flow.

The limitations to the above process flow are listed here:

- the long-term reliance on the HSM technology, presumably from a single supplier with limited interoperability, creates an additional global DNSSEC dependency,
- the key custodian role remains perhaps more technology intensive than what is desirable,
- it is not administratively efficient to request key custodians (notably if they are not working at the same employer location) to meet for the recurring ZSK rollover operations, and
- it is not administratively efficient to request an Administrator operation as an integral part of the recurring ZSK rollover operations.

Thus, an annex to the present contribution document [ANNEX] has been prepared to make sure the option once promoted by the present author organization remains available for further investigation of the DNSSEC root deployment.

6. References

[ANNEX]
Thierry Moreau, "Towards a Process Flow for DNS Root Zone File Signature with KSK Rollover Provisions", CONNOTECH Experts-conseils inc., Document Number C004711, 2008/11/24 (available at http://www.connotech.com/connotech_noi_resp_annex.pdf).

[NTIA_NOI]
National Telecommunications and Information Administration, US Department of Commerce, "Enhancing the Security and Stability of the Internet's Domain Name and Addressing System", Federal Register, Vol. 73, No. 197, pp 59608-59612, October 9, 2008

[RFC5011]
M. StJohns, "Automated Updates of DNS Security (DNSSEC) Trust Anchors", RFC 5011, September 2007. (available at http://www.ietf.org/rfc/rfc5011.txt).

Towards a Process Flow

for

DNS Root Zone File Signature

with

KSK Rollover Provisions

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Document Revision History

C-Number	Date	Explanation
C004218	2007/09/15	Initial release of the predecessor document under the title *A (Pro?-)Position Paper re DNS Root Zone File Signature Using DNSSEC Protocols*
C004222	2007/10/09	Updates to the predecessor document prior to public distribution
C004711	2008/11/24	Major changes from the predecessor document [1] including a change in title. Removed coverage and discussion of RFC5011. Removed much discussion text related to institutional arrangements. See the introductory section for more background information.
C004711		Current version

Table of contents

1. Introduction

1.1 A Response to a Recent Development in the Field

A significant development occurred recently for DNSSEC support at the top of the DNS name hierarchy (“signing the root”): a “Notice of Inquiry” (NOI) was issued by NTIA [1], a division of the US Department of Commerce. This document is the result of a major but straightforward edition of its predecessor document [2], taking into account the contents of this NOI as it provides or suggests answers to many previously unanswered questions. This document is respectfully submitted as an integral annex to a public comment by the same author to the NOI process [3].

As a result, this document positions the author's proposal TAKREM for DNSSEC to the specifics of the DNS root controlled by ICANN, Verisign, and NTIA, respectively the *IANA function operator*, the *root zone maintainer*, and the *administrator* in the NOI document terminology.

DNSSEC is an IT security technology based on cryptographic techniques. TAKREM is a cryptographic key management scheme. In the context of the predecessor document, the foremost issue surrounding the “signing the root” project was the detailed institutional answer to the question “who controls the root.” Now the focus is on effective process flows coherent with the fact that ICANN and Verisign are contractually bound to NTIA. In both cases, the TAKREM concepts are identically applicable.

The relative position of this document as an annex to the main contribution to the NOI is indicative of three simple facts 1) as a bona fide voluntary expert contribution to the advance of DNS integrity, the main contribution was first drafted as a self-contained one, and remains so in its final version with the TAKREM proposition as an option, 2) the predecessor document was conveniently edited to document this option, and 3) the option may be rejected.

1.2 Intended Audience and Purpose

This document is intended for knowledgeable readers, having a prior understanding of the DNS operations at the root, and the current institutional framework including ICANN, its specialized operational division IANA, the US government Department of Commerce (DOC), the US-based Verisign corporation, and secondary DNS root operators.

The purpose of this document is to present the TAKREM scheme (Trust Anchor Key REnewal Method) with a focus on the unique DNS root in the current context where DNSSEC deployment is envisioned, and currently being planned as described in the NOI document [1]. The

relevance of this document lies in its exposition of "better" DNSSEC root key management procedures. This is indeed a bold contribution where "better" implies the recourse to the TAKREM procedure justified by arguably stricter compliance to key management principles but using unique solution elements.
described at the institutional perspective taking the TAKREM features as a yardstick – the implied challenge is to describe better yardstick and/or description or definition for acceptable DNSSEC root key procedures.

1.3 Origin and Status of the Proposed Deployment Scheme

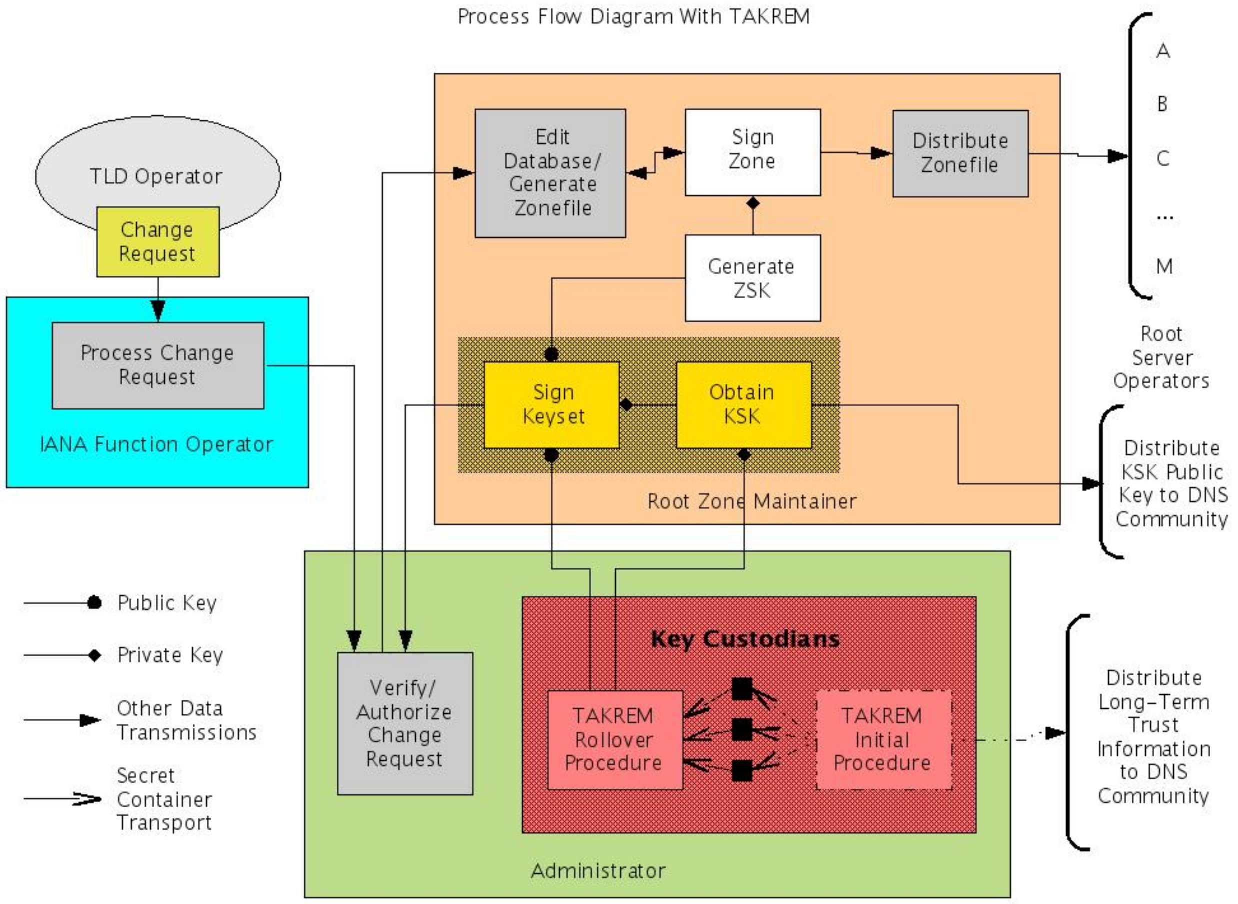
Originally, the invention of TAKREM [4] was not related to the DNS, but the applicability to DNSSEC trust anchors came quickly and turned into two Internet drafts [5] [6]. An implementation-level contribution [7] completes the picture for server-side technical details. The TAKREM proposal was not accepted by IETF DNSEXT working group as an interoperability specifications applicable generally to any trust anchor, i.e. not addressing the specific requirements of the DNS root as in the present document. Throughout this discussion, the technical validity of the proposal was never seriously challenged. If this proposal attracts attention to the TAKREM implementation details, observations made in reference [8] should not be lost.

The present document assumes the TAKREM technical validity, from security and protocol interoperability perspectives. It narrowly focuses on institutional arrangements that might apply to DNSSEC deployment support for the root. In the document [9], a different approach addresses DNSSEC deployment challenges near the top of the DNS hierarchy, including limited-scale DNS alternate root nameservice operations to palliate the *lack of a signed DNS root*. Thus, the reference [9] is orthogonal to the present one.

The effort behind this proposal is project is sunk cost project supported by private financing.

2. Institutional Perspective

This section explains the present proposal with an abstraction of the existing institutional framework for DNS root management. Another terminology is used in the NOI document, but unfortunately the present document version has not been thoroughly reviewed to adapt to it. However, the NOI document comes with neat process flow diagrams that were straightforward to adapt to the present proposal, giving the figure below.



2.1 The DNS Root Zone Management Role

In the abstracted view, a single organizational entity manages the DNS root zone file. In practice and as described in the NOI document [1], this is done partly by the IANA function operator, an operational division of ICANN, and partly by Verisign as the root zone maintainer, and with endorsement by the NTIA as the administrator.

When the DNSSEC support is added to the picture, the DNS root zone file updates require a digital signature. The NOI document assigns this role to the root zone maintainer in five out of six depicted process flows, but acknowledges a proposal by ICANN in which the signatory is the IANA function operator. The present proposal is agnostic about this question, but is documented using the root zone maintainer as the signatory.

2.2 An Authority-granting Role

NTIA, with its contractual relationship with the other two parties involved and the US government assertion of legitimacy as an Internet naming and addressing oversight authority [10], fits the abstracted view of an *authority-granting role*. At the abstracted institutional level, it is the authority granting role that enables the IANA function operator to perform the DNS root zone management role. The abstract level and the proposed cryptographic key management scheme are intended to be functionally coherent. By essence, the authority-granting role has a longer time horizon than the zone management role, and has an intuitive hands-off characteristic. Long-term key material naturally belongs to the organization fulfilling the authority-granting role.

Correspondingly, this proposal assigns new cryptographic key management duties concurrent with renewals of zone management role assignment. In practice, a root maintainer contract renewal would concur more or less with delegation formalities described in subsection 2.2.2.1 below. The overall scheme requires preparatory procedures described in subsection 2.2.1, and periodic or occasional delegations described in subsection 2.2.2.

2.2.1 Preparation Phase

Here is an account of the additional duties for the authority-granting role for DNSSEC support. These additional duties are straightforwardly derived from the TAKREM usage for DNSSEC root trust anchor. Specific implementation details are in reference [7].

2.2.1.1 A Preparation Session for DNSSEC Deployment

This operation is performed once for the expected lifetime of the DNSSEC support at the root, e.g. from 20 to 50 years. The purpose is the generation of cryptographic key material, i.e. secret information allowing the authority-granting role to be performed, and the corresponding publicly distributed configuration data (this is called *trust anchor key initial distribution message* in the reference [4]). The preparation session requires

- an ordinary computer system with specialized hardware options for random number generation,
- customized cryptographic key management software,
- a laser printer for bar code page printout,
- stationery supplies, and
- active and passive participants, respectively security experts in charge of operating the system and software and educated witnesses of varied origins for assurance of operational integrity.

The only actual output of the preparation session is

a) sealed bags or boxes of envelopes holding bar code printouts of secret key material, and
b) a few bar code pages for the publicly distributed configuration data to be publicly distributed.

All the electronics used in the session should be meticulously destroyed, so that information leakage is virtually impossible. This recourse to paper, sealed envelope, and sealed bags or boxes for the decades-long security of the global Internet is a most serious proposal. It is indeed a unique feature of the present proposal to offer an integrated DNSSEC deployment roadmap in which non-technical managers are offered simple methods for the ultimate DNS “control” implied by the DNSSEC technology: non-technical managers will seldom need computer systems or security experts after the preparation session for the fulfillment of the authority-granting role.

The computer security experts should know what to do with the item b) in the preparation session output. This is to say, the present proposal brings no noteworthy contribution to the issue of *DNSSEC priming* for the unique DNS root. The reference [9] addresses the issue of DNSSEC priming, but it remains peripheral to the present document purpose. In any event, computer security experts walk away of the preparation session with item b) in their possession.

2.2.1.2 Delivery of Sealed Bags to Key Custodians Entities

This is actually the latest portion of the above preparation session; it is described separately because it introduces the important notion of *split control* of the authority-granting role. This split control is an institutional arrangement opportunity that merely adapts an old technique in cryptographic key management, namely *split-knowledge storage of secrets* [11], or a modern number-theoretic improvement, namely *secret-sharing*. The actual solution embedded in the reference [7] is either a two-parties split-knowledge storage scheme, a three-parties split-knowledge scheme, or a two-out-of-three secret-sharing scheme (made with a trivial triplication of a two-parties scheme). The *secret components* are just the item a) in the preparation session output.

What does this mean to the simple instructions to non-technical personnel in the organization fulfilling the authority-granting role? Taking the two-out-of-three scheme for explanation purposes, the organization assigns the *key custodian* role to three organizational entities, each equipped with a safe box and internal control procedures for access to the safe box. If the organization was a corporation, the three key custodian entities might be the corporate finance department, the corporate legal department, and the external accounting auditor firm. Each key custodian entity sends two delegates to the preparation session, and receives, through these delegates, one of the sealed bag or box of envelopes created during the preparation session. The delegates then safely carry the sealed bag or box to the safe box of their organizational entity.

2.2.2 Delegation of Authority to the DNS Root Zone Management Role

After the preparation session and the delivery of sealed bags to key custodian entities, the authority-granting role consists of periodic or occasional delegation of authority to the DNS root zone management role. As an illustrative analogy with a car rental operation, this delegation is like a car location clerk handing keys and traveling documents to the client. A concern in car rental operations is a client who never returns the car; the analogous concern in the present proposal is addressed below with the period of validity for the delegated key.

The ability to perform the authority-granting role requires the cooperation of any two of the three key custodian entities. The authority-granting role is performed mainly by manual operations devoid of technological means, so the chances of subversion by computer experts are minimized. The authority-granting role is also conceptually simple: to safeguard secrets that are gradually transferred to the zone management role on a time frequency similar to the current IANA contract renewal/option mechanism.

It should be noted that the authority-granting role is institutionally independent of the DNS root zone management role. This two-tiered institutional control implies a two-tiered accountability allocation. Notably, a serious operational mishaps in the zone management role can be recovered by a TAKREM emergency rollover procedure, ensuring continuity of DNSSEC services even if a reorganization of the zone management role was needed.

The split-knowledge storage scheme originates from cryptographic technology. The mere desirability of best available security mechanisms for the DNSSEC root private keys implies the suggestion of its application in the institutional arrangement for the DNSSEC support at the root. This logic applies to any approach to DNSSEC root private key procedures since split-knowledge storage applies to any type of secret or private cryptographic key material, and is appropriate for key material having network-wide significance.

Overall, the present proposal includes a precise fit of cryptographic key material operations and institutional roles. Combined with the technology-deprived nature of manual operations, this is advantageous for transparency and auditability of the authority-granting role. The present author suggests that a DNSSEC deployment strategy devoid of such characteristics needlessly relies on blind faith in an institution's operational integrity. In the case of the DNS root, the issue is irrelevant for the vast majority of Internet operators, but perhaps the DNSSEC deployment strategy needs to care for an influential minority.

Other DNSSEC root deployment proposals might achieve a similar fit of cryptographic key material operations and institutional roles. The main contribution to the NTIA NOI by the present author [3] is an example of specifying the desired fit starting the process flows already sketched in the NOI document, but without other characteristics found in the present proposal such as the technology deprived nature of the key custodian role.

2.2.2.1 Delegation Operation by the Authority-Granting Organization

The delegation operation described here is from the authority-granting role to the DNS root zone management role, with the delegation announcement role as an intermediate step (see subsection 2.3 below). The delegation basically grants the DNS root zone management operation the keys to operate the DNS root signature for a period *with a ritual that can be authenticated by the minority of Internet operators that counts*. As far as the authority-granting organization is concerned, that should be adequate.

For the non-technical representatives of the key custodian entities, the delegation operation is fairly simple:

- by more or less formal coordination, they come to an agreement as to when, where, and with which secret envelope they intend to gather at a delegation meeting;
- each key custodian entity sends one or two representatives to the delegation meeting, carrying a secret envelope,
- at the meeting, they (ceremoniously) scan the series of bar codes present in the envelope they brought to the meeting, using a bar code scanner connected to a then-state-of-the-art digital signature device or system, and
- they also (but less ceremoniously) scan the *public portion* present in the series of bar codes form the respective envelopes, this time using a bar code scanner connected to a computer system without special capabilities.

The difference between the last two bullets lies in the private versus public portions of digital signature keys. This is a manifestation of the fit between cryptographic principles, manual operations, and allocation of institutional accountability.

That's almost it: a skill level similar to the one of a grocery checkout clerk. There are tree additional points, linked to the assurance of good behavior in the performance of the DNS root zone management role:

a) the key custodian representatives should ear a beep or witness a visual feedback from the digital signature device or system confirming that it received sufficient secret bar code information to recover a private digital signature key;

b) the authority-granting organization, or each key custodian entity if they operate et arm's length, should make sure the digital signature device is adequate, e.g. certified according to some IT security certification program;

c) the authority-granting organization, or each key custodian entity if they operate et arm's length, should ensure that the initial delegation announcement, explained below, announces the proper period of validity for the delegated key.

Admittedly, the items b) and c) are not as technology-deprived as a non-technical representative of a key custodian entity might expect. However, these two activities are time-limited, i.e. the means to accomplish items b) and c) need not be the same over successive delegation operations, notably over a switch from one zone management entity to another, e.g. if the IANA contract was transferred to another contractor.

This gathering of key custodian representatives to merge secret information from separate envelopes is straightforwardly derived from the TAKREM recourse to split storage of secrets in reference [7]. The private digital signature key recovery mentioned in item a) above is the starting point for the TAKREM rollover operation, or *delegation announcement*, explained below.

2.3 A Limited but Pivotal Role: Delegation Announcements

From the institutional perspective, the delegation announcement is the mating point between the authority-granting role and the DNS root zone management role. This is in contrast with the authority-granting role that could be devoid of any operational involvement in trust anchor key management.

With the better understanding of DNSSEC root signature process flows based on the NOI document and its recent references (notably [12]), it is now appropriate to emphasize the dual institutional justification for the delegation announcement:

- to fulfill the DNSSEC protocol interoperability requirements through the KSK rollover operation, so that the vast majority of Internet users can benefit from higher trustworthiness of DNS data,
- to address the very specific trust anchor management expectations of *the minority of Internet operators that counts.*

To address the needs of the vast majority, KSK security breaches and change of delegation of the IANA function role can be ignored either as practically impossible events, or very exceptional events requesting DNS resolver manual reconfiguration. The minority of operators that count expects both automated DNS resolver reconfiguration and assurance that DNSSEC trust anchor keys are handled appropriately even in the exceptional circumstances.

The delegation announcement role is specific to DNSSEC and is non-existent in the current plain DNS institutional framework. The TAKREM procedure components corresponding to the delegation announcement role are the rollover operation and the rollover message. As detailed below, in the TAKREM application to DNSSEC, the needs of the vast majority are met by KSK rollover procedures selected independently of TAKREM, and the minority expectations are addressed by the SDDA mechanism.

2.3.1 Delegation Announcements

Here is a technical description of delegation announcement. In its application to the DNS root, the TAKREM rollover operation consists of:

- preparation of two DNS RRsets, namely
  - the DNSKEY RRset augmented with the new trust anchor key – this requires the other entries in the DNSKEY RRset from the zone manager – and
  - an SDDA RRset specific to the TAKREM scheme [5] [6]– this requires the validity period for the rolled-in public signature key ;
- the DNSSEC signature operation of these two DNS RRsets with the rolled-in private signature key, producing two RRsig RRs;
- the return of these two DNS RRsets and two DNS RRSIG RRs to the zone managed by the zone manager for inclusion in the DNS root zone file for later publication by the DNS root nameservers.

What is critical for the authority-granting role is that the validity period for the SDDA RRset goes through the complete cycle up to the actual publication by the DNS root nameservers for a duration long enough so that it can be authenticated by most of the minority of Internet operators that counts. Presumably the required minimum publication duration would be in the range of one week to one month. This ensures that the delegation duration is understood by the minority of Internet operators that count.

Delegation announcement should be controlled by the DNS root zone management organization. The economy of administrative procedures precludes other arrangements such as an independent agent of the authority-granting organization. There is thus a form of *delegation of delegation announcements* implied by the present proposal. With respect to the operational considerations in the delegation announcement role, the DNSSEC root signature process flow proposal by ICANN [12] contains a suitable description of a KSK public key generation ceremony. Thus the reference [12] hints that delegation announcements could realistically be implemented by the DNS root zone management organization as a security critical operational assignment. In reference to the process flows sketched in the NOI document, either process flow number 5 or number 4 is a starting point for the allocation of the delegation announcement role proposed here. Respectively, the process flow number 5 does not change the current function allocations among IANA and Verisign, and process flow number 4 would follow the streamlined arrangement proposed in reference [12] (as indicated earlier, the present proposal is agnostic about this question).

It should be understood that a few events may trigger a rehearsal of the delegation announcement with the same rolled-in digital signature key. Mainly, this is either a change in the DNSKEY RRset after the initial delegation announcement, or a reduction of the validity period for the SDDA RRset. The former may be caused by a Zone Signing Key (ZSK) rollover. A reduction of the validity period may be caused by an emergency trust anchor key rollover or another unexpected termination of delegation to the zone management organization. At the institutional perspective, the authority-granting role includes a closer oversight over the delegation announcements than the rest of DNS root zone management operations. But the economy of administrative procedure precludes the involvement of key custodians for these operations, and correspondingly the DNS root zone management organization controls the KSK private keys.

3. Root Zone Management

The DNSSEC deployment at the root has significant implications in the management of the DNS root zone contents and in the operations of root nameservers. The present document section pertains to the trust anchor at the DNS root.

The DNS root zone management role encompasses the *concurrent compliance* with the present proposal and a simple ad-hoc KSK rollover procedure. Whenever the DNS root zone manager needs a new KSK for the rollover operation, it obtains it from the authority-granting organization, instead of generating it locally. Such coordinated operation obviously requires inter-organization planning of scheduled rollover events.

4. Sources of Guidance for DNSSEC Root Trust Anchor Key Management

A higher level of abstraction is used here to support the legitimacy of unilateral commitments to the selected DNSSEC root key process flow.

We assume a Single Organization (SO) fulfills every relevant roles in the DNS root zone management. When it comes to DNSSEC trust anchor key management, SO has to announce the *rituals* it intends to follow, and then abide by its commitment, and finally receive and handle critics that will most likely be expressed. This peculiar description of trust anchor key management departs from the simple view that an interoperability specifications tells SO what to do. In fact, the “trust” element in a trust anchor key forever remains *a belief*, despite being encoded as a configuration data element. This belief is acquired through indirect observations that some ritual has been performed appropriately. This very “trust” element may not simply be published in the DNS root zone file like other DNS data.

Hence the view that SO has to decide a trust anchor key management ritual. Generally, DNSSEC deployment starts by the nameserver side before the resolver side. In the case of trust anchor management, this extends to selection of proper rituals, i.e. SO should affirm how it intends to provide evidence of trustworthiness. Resolver-side software compliance and configuration issues are almost of secondary relevance, at least with respect to the timing of deployment.

If contrary to the above, the resolver-side expectations of acceptable DNS root trust anchor key management would prevail as a deployment strategy, at least two difficulties would be encountered. First, the DNS resolver operator community is an open-ended one, so the expectations may become extraordinary, or even frivolous or malicious. Second, the digital signature technology in DNSSEC requires the proper handling of private keys, and a commitment to demanding operating standards is better left as an assertion by the organization that must handle the private keys, and not as whish list from third parties.

5. Conclusion

TAKREM for DNSSEC, a specific trust anchor key management proposal, has been presented in sections 2, 2 and 3, as if it was the preferred and obvious way forward. To the present author knowledge, this proposal is unique in its superimposition of cryptographic key management and institutional/contractual arrangements for DNS root zone management.

This proposal uniqueness would originate from a) the lack of security experts attention to the need to secure the applied cryptographic schemes with explicit manual key management procedures, combined with b) the tendency of institutions to look at issues in a compartmented way. Any envisioned DNSSEC deployment at the root brings an additional layer of accountability, based on principles of cryptography.

6. Acronyms

DNS

Domain Name System

DNSEXT

DNS EXTensions, the name of an IETF working group working on standardization of DNS protocol extensions

DNSKEY

a technical acronym of the DNSSEC protocol referring to a public signature key entry in the DNS registry

DOC
Department of Commerce

HSM
Hardware Security Module

IANA
Internet Assigned Numbers Authority

ICANN
Internet Corporation for Assigned Names and Numbers

KSK
Key Signing Key, a technical acronym of the DNSSEC protocol referring to a digital signature public key having special status for authentication of other keys, including ZSK

NTIA
National Telecommunications and Information Administration

RR
Resource Record, a technical acronym of the DNSSEC protocol referring to an entry in the DNS registry

RRset
Resource Record set, a technical acronym of the DNSSEC protocol referring to sets of related entries in the DNS registry

RRSIG
a technical acronym of the DNSSEC protocol referring to digital signature entry in the DNS registry

SDDA
a TAKREM-specific technical acronym of the DNSSEC protocol referring to an entry in the DNS registry

TAKREM
Trust Anchor Key REnewal Method

ZSK
Zone Signing Key, a technical acronym of the DNSSEC protocol referring to a digital signature public key generally intended for authentication of DNS zone data

7. References

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