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A Root Key Trust Anchor Sentinel for DNSSEC

Abstract

The DNS Security Extensions (DNSSEC) were developed to provide origin authentication and integrity protection for DNS data by using digital signatures. These digital signatures can be verified by building a chain of trust starting from a trust anchor and proceeding down to a particular node in the DNS. This document specifies a mechanism that will allow an end user and third parties to determine the trusted key state for the root key of the resolvers that handle that user's DNS queries. Note that this method is only applicable for determining which keys are in the trust store for the root key.

Status of This Memo

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1. Introduction

The DNS Security Extensions (DNSSEC) [RFC4033], [RFC4034], and [RFC4035] were developed to provide origin authentication and integrity protection for DNS data by using digital signatures. DNSSEC uses Key Tags to efficiently match signatures to the keys from which they are generated. The Key Tag is a 16-bit value computed from the RDATA of a DNSKEY Resource Record (RR) as described in Appendix B of [RFC4034]. RRSIG RRs contain a Key Tag field whose value is equal to the Key Tag of the DNSKEY RR that was used to generate the corresponding signature.

This document specifies how security-aware DNS resolvers that perform validation of their responses can respond to certain queries in a manner that allows an agent performing the queries to deduce whether a particular key for the root has been loaded into that resolver's trusted-key store. This document also describes a procedure where a collection of resolvers can be tested to determine whether at least one of these resolvers has loaded a given key into its trusted-key store. These tests can be used to determine whether a certain root zone Key Signing Key (KSK) is ready to be used as a trusted key, within the context of a planned root zone KSK roll.

There are two primary use cases for this mechanism:

- o Users may wish to ascertain whether their DNS resolution environment's resolver is ready for an upcoming root KSK rollover.
- o Researchers want to perform Internet-wide studies about the proportion of users who will be negatively impacted by an upcoming root KSK rollover.

The mechanism described in this document satisfies the requirements of both these use cases. This mechanism is OPTIONAL to implement and use. If implemented, this mechanism SHOULD be enabled by default to facilitate Internet-wide measurement. Configuration options MAY be provided to disable the mechanism for reasons of local policy.

The KSK sentinel tests described in this document use a test comprising a set of DNS queries to domain names that have special values for the leftmost label. The test relies on recursive resolvers supporting a mechanism that recognizes this special name pattern in queries; under certain defined circumstances, it will return a DNS SERVFAIL response code (RCODE 2), mimicking the response code that is returned by security-aware resolvers when DNSSEC validation fails.

If a browser or operating system is configured with multiple resolvers, and those resolvers have different properties (for example, one performs DNSSEC validation and one does not), the sentinel test described in this document can still be used. The sentinel test makes a number of assumptions about DNS resolution behavior that may not necessarily hold in all environments; if these assumptions do not hold, then this test may produce indeterminate or inconsistent results. This might occur, for example, if the stub resolver is required to query the next recursive resolver in the locally configured set upon receipt of a SERVFAIL response code. In some cases where these assumptions do not hold, repeating the same test query set may generate different results.

Note that the measurements facilitated by the mechanism described in this document are different from those of [RFC8145]. RFC 8145 relies on resolvers reporting towards the root servers a list of locally cached trust anchors for the root zone. Those reports can be used to infer how many resolvers may be impacted by a KSK roll but not what the user impact of the KSK roll will be.

1.1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

This document contains a number of terms related to the DNS. The current definitions of these terms can be found in [RFC7719].

2. Sentinel Mechanism in Resolvers

DNSSEC-validating resolvers that implement this mechanism MUST perform validation of responses in accordance with the DNSSEC response validation specification [RFC4035].

This sentinel mechanism makes use of two special labels:

- o root-key-sentinel-is-ta-<key-tag>
- o root-key-sentinel-not-ta-<key-tag>

These labels trigger special processing in the validating DNS resolver when responses from authoritative servers are received. Labels containing "root-key-sentinel-is-ta-<key-tag>" are used to answer the question, "Is this the Key Tag of a key that the validating DNS resolver is currently trusting as a trust anchor?"

Labels containing "root-key-sentinel-not-ta-<key-tag>" are used to answer the question, "Is this the Key Tag of a key that the validating DNS resolver is **not** currently trusting as a trust anchor?"

The special labels defined here were chosen after extensive IETF evaluation of alternative patterns and approaches in light of the desired behavior (Sections 2.1 and 2.2) within the resolver and the applied testing methodology (Section 4.3). As one example, underscore-prefixed names were rejected because some browsers and operating systems would not fetch them because they are domain names but not valid hostnames (see [RFC7719] for these definitions). Consideration was given to local collisions and the reservation of leftmost labels of a domain name, as well as the impact upon zone operators who might desire to use a similarly constructed hostname for a purpose other than those documented here. Therefore, it is important to note that the reservation of the labels in this manner is definitely not considered "best practice".

2.1. Preconditions

All of the following conditions must be met to trigger special processing inside resolver code:

- o The DNS response is DNSSEC validated.
- o The result of validation is "Secure".
- o The Extension Mechanisms for DNS (EDNS(0)) Checking Disabled (CD) bit in the query is not set.
- o The QTYPE is either A or AAAA (Query Type value 1 or 28).
- o The OPCODE is QUERY.
- o The leftmost label of the original QNAME (the name sent in the Question Section in the original query) is either "root-key-sentinel-is-ta-<key-tag>" or "root-key-sentinel-not-ta-<key-tag>".

If any one of the preconditions is not met, the resolver **MUST NOT** alter the DNS response based on the mechanism in this document.

Note that the <key-tag> is specified in the DNS label as an unsigned decimal integer (as described in [RFC4034], Section 5.3) but is zero-padded to five digits (for example, a Key Tag value of 42 would be represented in the label as 00042). The precise specification of the special labels above should be followed exactly. For example, a label that does not include a Key Tag zero-padded to five digits does

not match this specification and should not be processed as if it did -- in other words, such queries should be handled as any other label and not according to Section 2.2.

2.2. Special Processing

Responses that fulfill all of the preconditions in Section 2.1 require special processing, depending on the leftmost label in the QNAME.

First, the resolver determines if the numerical value of <key-tag> is equal to any of the Key Tag values of an active root zone KSK that is currently trusted by the local resolver and stored in its store of trusted keys. An active root zone KSK is one that could currently be used for validation (that is, a key that is not in either the AddPend or Revoked state, as described in [RFC5011]).

Second, the resolver alters the response being sent to the original query based on both the leftmost label and the presence of a key with given Key Tag in the trust-anchor store. Two labels and two possible states of the corresponding key generate four possible combinations, summarized in the table:

Label	Key is trusted	Key is not trusted
is-ta	return original answer	return SERVFAIL
not-ta	return SERVFAIL	return original answer

The instruction "return SERVFAIL" means that the resolver MUST set RCODE=SERVFAIL (value 2) and the Answer Section of the DNS response MUST be empty, ignoring all other documents that specify the content of the Answer Section.

The instruction "return original answer" means that the resolver MUST process the query without any further special processing, that is, exactly as if the mechanism described in this document was not implemented or was disabled. The answer for the A or AAAA query is sent on to the client.

3. Sentinel Tests for a Single DNS Resolver

This section describes the use of the sentinel detection mechanism against a single DNS recursive resolver in order to determine whether this resolver is using a particular trust anchor to validate DNSSEC-signed responses.

Note that the test in this section applies to a single DNS resolver. The test described in Section 4 applies instead to a collection of DNS resolvers, as might be found in the DNS configuration of an end-user environment.

The critical aspect of the DNS names used in this mechanism is that they contain the specified label for either the positive or negative test as the leftmost label in the query name.

The sentinel detection procedure can test a DNS resolver using three queries:

- o A query name containing the leftmost label "root-key-sentinel-is-ta-<key-tag>". This corresponds to a validly signed name in the parent zone, so that responses associated with this query name can be authenticated by a DNSSEC-validating resolver. Any validly signed DNS zone can be used as the parent zone for this test.
- o A query name containing the leftmost label "root-key-sentinel-not-ta-<key-tag>". This also corresponds to a validly signed name. Any validly signed DNS zone can be used as the parent zone for this test.
- o A query name that is signed with a DNSSEC signature that cannot be validated (described as a "bogus" RRset in Section 5 of [RFC4033] when, for example, an RRset is associated with a zone that is not signed with a valid RRSIG record).

The responses received from queries to resolve each of these query names can be evaluated to infer a trust key state of the DNS resolver.

An essential assumption here is that this technique relies on security-aware (DNSSEC-validating) resolvers responding with a SERVFAIL response code to queries where DNSSEC checking is requested and the response cannot be validated. Note that other issues can also cause a resolver to return SERVFAIL responses, and so the sentinel processing may sometimes result in incorrect or indeterminate conclusions.

To describe this process of classification, DNS resolvers are classified by five distinct behavior types using the labels: "Vnew", "Vold", "Vind", "nonV", and "other". These labels correspond to resolver-system behavior types as follows:

Vnew: A DNS resolver that is configured to implement this mechanism and has loaded the nominated key into its local trusted-key stores will respond with an A or AAAA RRset response for the associated "root-key-sentinel-is-ta" queries, SERVFAIL for "root-key-sentinel-not-ta" queries, and SERVFAIL for the signed name queries that return "bogus" validation status.

Vold: A DNS resolver that is configured to implement this mechanism and has not loaded the nominated key into its local trusted-key stores will respond with a SERVFAIL for the associated "root-key-sentinel-is-ta" queries, an A or AAAA RRset response for "root-key-sentinel-not-ta" queries, and SERVFAIL for the signed name queries that return "bogus" validation status.

Vind: A DNS resolver that is not configured to implement this mechanism will respond with an A or AAAA RRset response for "root-key-sentinel-is-ta", an A or AAAA RRset response for "root-key-sentinel-not-ta", and SERVFAIL for the name that returns "bogus" validation status. This set of responses does not give any information about the trust anchors used by this resolver.

nonV: A non-security-aware DNS resolver will respond with an A or AAAA RRset response for "root-key-sentinel-is-ta", an A or AAAA RRset response for "root-key-sentinel-not-ta" and an A or AAAA RRset response for the name that returns "bogus" validation status.

other: There is the potential to admit other combinations of responses to these three queries. While this may appear self-contradictory, there are cases where such an outcome is possible. For example, in DNS resolver farms, what appears to be a single DNS resolver that responds to queries passed to a single IP address is in fact constructed as a collection of slave resolvers, and the query is passed to one of these internal resolver engines. If these individual slave resolvers in the farm do not behave identically, then other sets of results can be expected from these three queries. In such a case, no determination about the capabilities of this DNS resolver farm can be made.

Note that SERVFAIL might be cached according to Section 7 of [RFC2308] for up to 5 minutes and a positive answer for up to its TTL.

If a client directs these three queries to a single resolver, the responses should allow the client to determine the capability of the resolver and, if it supports this sentinel mechanism, whether or not it has a particular key in its trust-anchor store, as in the following table:

		Query		
		is-ta	not-ta	bogus
Type	Vnew	Y	SERVFAIL	SERVFAIL
	Vold	SERVFAIL	Y	SERVFAIL
	Vind	Y	Y	SERVFAIL
	nonV	Y	Y	Y
	other	*	*	*

In this table, the "Y" response denotes an A or AAAA RRset response (depending on the query type of A or AAAA records), "SERVFAIL" denotes a DNS SERVFAIL response code (RCODE 2), and "*" denotes either response.

Vnew: The nominated key is trusted by the resolver.

Vold: The nominated key is not yet trusted by the resolver.

Vind: There is no information about the trust anchors of the resolver.

nonV: The resolver does not perform DNSSEC validation.

other: The properties of the resolver cannot be analyzed by this protocol.

3.1. Forwarders

Some resolvers are configured not to answer queries using the recursive algorithm first described in [RFC1034], Section 4.3.2 but instead relay queries to one or more other resolvers. Resolvers configured in this manner are referred to in this document as "forwarders".

If the resolver is non-validating and has a single forwarder, then it will presumably mirror the capabilities of the forwarder's target resolver.

If the validating resolver has a forwarding configuration, and it sets the EDNS(0) Checking Disabled (CD) bit as described in Section 3.2.2 of [RFC4035] on all forwarded queries, then this resolver is acting in a manner that is identical to a standalone resolver.

A more complex case is where all of the following conditions hold:

- o Both the validating resolver and the forwarder target resolver support this trusted key sentinel mechanism.
- o The local resolver's queries do not have the EDNS(0) CD bit set.
- o The trusted key state differs between the forwarding resolver and the forwarder's target resolver.

In such a case, either the outcome is indeterminate validating ("Vind") or there are mixed signals such as SERVFAIL in all three responses ("other"), which is similarly an indeterminate response with respect to the trusted key state.

4. Sentinel Tests for Multiple Resolvers

Section 3 describes a trust-anchor test that can be used in the simple situation where the test queries are being passed to a single recursive resolver that directly queries authoritative name servers.

However, the common end-user scenario is where a user's local DNS resolution environment is configured to use more than one recursive resolver. The single-resolver test technique will not function reliably in such cases, as a SERVFAIL response from one resolver may cause the local stub resolver to repeat the query against one of the other configured resolvers, and the results may be inconclusive.

In describing a test procedure that can be used for a set of DNS resolvers, there are some necessary changes to the nature of the question that this test can answer, the assumptions about the behavior of the DNS resolution environment, and some further observations about potential variability in the test outcomes.

4.1. Test Scenario and Objective

This test is not intended to expose which trust anchors are used by any single DNS resolver.

The test scenario is explicitly restricted to that of the KSK environment where a current, active KSK (called "KSK-current") is to be replaced with a new KSK (called "KSK-new"). The test is designed to be run between when KSK-new is introduced into the root zone and when the root zone is signed with KSK-new.

The objective of the test is to determine if the user will be negatively impacted by the KSK roll. A "negative impact" for the user is defined such that all the configured resolvers are security-aware resolvers that perform validation of DNSSEC-signed responses, and none of these resolvers have loaded KSK-new into their local trust-anchor set. In this situation, it is anticipated that once the KSK is rolled, the entire set of the user's resolvers will not be able to validate the contents of the root zone, and the user is likely to lose DNS service as a result of this inability to perform successful DNSSEC validation.

4.2. Test Assumptions

There are a number of assumptions about the DNS environment used in this test. Where these assumptions do not hold, the results of the test will be indeterminate.

- o When a recursive resolver returns SERVFAIL to the user's stub resolver, the stub resolver will send the same query to the next resolver in the locally configured resolver set. It will continue to do this until it either gets a non-SERVFAIL response or runs out of resolvers to try.
- o When the user's stub resolver passes a query to a resolver in the configured resolver set, it will get a consistent answer over the time frame of the queries. This assumption implies that if the same query is asked by the same stub resolver multiple times in succession to the same recursive resolver, the recursive resolver's response will be the same for each of these queries.
- o All DNSSEC-validating resolvers have KSK-current in their local trust-anchor cache.

There is no current published measurement data that indicates to what extent the first two assumptions listed here are valid or how many end users may be impacted by these assumptions. In particular, the first assumption, that a consistent SERVFAIL response will cause the

local stub DNS resolution environment to query all of its configured recursive resolvers before concluding that the name cannot be resolved, is a critical assumption for this test.

Note that additional precision/determinism may be achievable by bypassing the normal OS behavior and explicitly testing using each configured recursive resolver (e.g., using "dig").

4.3. Test Procedure

The sentinel detection process tests a DNS resolution environment with three query names. Note that these are the same general categories of query as in Section 3, but the Key Tag used is different for some queries:

- o A query name that is signed with a DNSSEC signature that cannot be validated (described as a "bogus" RRset in Section 5 of [RFC4033] when, for example, an RRset is not signed with a valid RRSIG record).
- o A query name containing the leftmost label "root-key-sentinel-not-ta-<key-tag-of-KSK-current>". This name MUST be a validly signed name. Any validly signed DNS zone can be used for this test.
- o A query name containing the leftmost label "root-key-sentinel-is-ta-<key-tag-of-KSK-new>". This name MUST be a validly signed name. Any validly signed DNS zone can be used for this test.

The responses received from queries to resolve each of these names can be evaluated to infer a trust key state of the user's DNS resolution environment.

The responses to these queries are described using a simplified notation. Each query will result in either a SERVFAIL response (denoted "S"), indicating that all of the resolvers in the recursive resolver set returned the SERVFAIL response code, or a response with the desired RRset value (denoted "A"). The queries are ordered by the "invalid" name, the "root-key-sentinel-not-ta" label, then the "root-key-sentinel-is-ta" label, and a triplet notation denotes a particular response. For example, the triplet "(S S A)" denotes a SERVFAIL response to the invalid query, a SERVFAIL response to the "root-key-sentinel-not-ta" query, and an RRset response to the "root-key-sentinel-is-ta" query.

The set of all possible responses to these three queries are:

- (A * *): If any resolver returns an "A" response for the query for the invalid name, then the resolver set contains at least one non-validating DNS resolver, and the user will not be impacted by the KSK roll.
- (S A *): If any of the resolvers returns an "A" response for the "root-key-sentinel-not-ta" query, then at least one of the resolvers does not recognize the sentinel mechanism, and the behavior of the collection of resolvers during the KSK roll cannot be reliably determined.
- (S S A): This case implies that all of the resolvers in the set perform DNSSEC validation, all of the resolvers are aware of the sentinel mechanism, and at least one resolver has loaded KSK-new as a local trust anchor. The user will not be impacted by the KSK roll.
- (S S S): This case implies that all of the resolvers in the set perform DNSSEC validation, all of the resolvers are aware of the sentinel mechanism, and none of the resolvers has loaded KSK-new as a local trust anchor. The user will be negatively impacted by the KSK roll.

5. Security Considerations

This document describes a mechanism for allowing users to determine the trust-anchor state of root zone key signing keys in the DNS resolution system that they use. If the user executes third-party code, then this information may also be available to the third party.

The mechanism does not require resolvers to set otherwise-unauthenticated responses to be marked as authenticated and does not alter the security properties of DNSSEC with respect to the interpretation of the authenticity of responses that are so marked.

The mechanism does not require any further significant processing of DNS responses, and queries of the form described in this document do not impose any additional load that could be exploited in an attack over the normal DNSSEC-validation processing load.

6. Privacy Considerations

The mechanism in this document enables third parties (with either good or bad intentions) to learn something about the security configuration of recursive DNS resolvers. That is, someone who can cause an Internet user to make specific DNS queries (e.g., via web-based advertisements or JavaScript in web pages) can, under certain specific circumstances that include additional knowledge of the resolvers that are invoked by the user, determine which trust anchors are configured in these resolvers. Without this additional knowledge, the third party can infer the aggregate capabilities of the user's DNS resolution environment but cannot necessarily infer the trust configuration of any recursive name server.

7. IANA Considerations

This document has no IANA actions.

8. References

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Appendix A. Protocol Walk-Through Example

This appendix provides a non-normative example of how the sentinel mechanism could be used and what each participant does. It is provided in a conversational tone to be easier to follow. The examples here all assume that each person has just one resolver or a system of resolvers that have the same properties.

Alice is in charge of the DNS root KSK (Key Signing Key) and would like to roll/replace the key with a new one. She publishes the new KSK but would like to be able to predict/measure what the impact will be before removing/revoking the old key. The current KSK has a Key Tag of 11112; the new KSK has a Key Tag of 02323. Users want to verify that their resolver will not break after Alice rolls the root KSK (that is, starts signing with just the KSK whose Key Tag is 02323).

Bob, Charlie, Dave, and Ed are all users. They use the DNS recursive resolvers supplied by their ISPs. They would like to confirm that their ISPs have picked up the new KSK. Bob's ISP does not perform validation. Charlie's ISP does validate, but the resolvers have not yet been upgraded to support this mechanism. Dave and Ed's resolvers have been upgraded to support this mechanism; Dave's resolver has the new KSK, but Ed's resolver hasn't managed to install the 02323 KSK in its trust store yet.

Geoff is a researcher. He would like to both provide a means for Bob, Charlie, Dave, and Ed to perform tests and himself be able to perform Internet-wide measurements of what the impact will be (and report this back to Alice).

Geoff sets an authoritative DNS server for example.com and also a web server (www.example.com). He adds three address records to example.com:

```
bogus.example.com. IN AAAA 2001:db8::1
root-key-sentinel-is-ta-02323.example.com. IN AAAA 2001:db8::1
root-key-sentinel-not-ta-11112.example.com. IN AAAA 2001:db8::1
```

Note that the use of "example.com" names and the addresses here are examples, and "bogus" intentionally has invalid DNSSEC signatures. In a real deployment, the domain names need to be under the control of the researcher, and the addresses must be real, reachable addresses.

Geoff then DNSSEC signs the example.com zone and intentionally makes the bogus.example.com record have bogus validation status (for example, by editing the signed zone and entering garbage for the signature). Geoff also configures his web server to listen on 2001:db8::1 and serve a resource (for example, a 1x1 GIF, 1x1.gif) for all of these names. The web server also serves a web page (www.example.com) that contains links to these three resources (http://bogus.example.com/1x1.gif, http://root-key-sentinel-is-ta-02323.example.com/1x1.gif, and http://root-key-sentinel-not-ta-11112.example.com/1x1.gif).

Geoff then asks Bob, Charlie, Dave, and Ed to browse to www.example.com. Using the methods described in this document, the users can figure out what their fate will be when the 11112 KSK is removed.

Bob is not using a validating resolver. This means that he will be able to resolve bogus.example.com (and fetch the 1x1 GIF); this tells him that the KSK roll does not affect him, and so he will be OK.

Charlie's resolvers are validating, but they have not been upgraded to support the KSK sentinel mechanism. Charlie will not be able to fetch the http://bogus.example.com/1x1.gif resource (the bogus.example.com record is bogus, and none of his resolvers will resolve it). He is able to fetch both of the other resources; from this, he knows (see the logic in the body of this document) that he is using validating resolvers but that at least one of these resolvers is not configured to perform sentinel processing. The KSK sentinel method cannot provide him with a definitive answer to the question of whether he will be impacted by the KSK roll.

Dave's resolvers implement the sentinel method and have picked up the new KSK. For the same reason as Charlie, he cannot fetch the "bogus" resource. His resolver resolves the root-key-sentinel-is-ta-02323.example.com name normally (it contacts the example.com authoritative servers, etc.); as it supports the sentinel mechanism, just before Dave's recursive resolver sends the reply to Dave's stub, it performs the KSK sentinel check. The QNAME starts with "root-key-sentinel-is-ta-", and the recursive resolver does indeed have a key with the Key Tag of 02323 in its root trust store. This means that this part of the KSK sentinel check passes (it is true that Key Tag 02323 is in the trust-anchor store), and the recursive resolver replies normally (with the answer provided by the authoritative server). Dave's recursive resolver then resolves the root-key-sentinel-not-ta-11112.example.com name. Once again, it performs the normal resolution process, but because it implements KSK sentinel (and the QNAME starts with "root-key-sentinel-not-ta-"), just before sending the reply, it performs the KSK sentinel check. As it has the

key with key-tag 11112 in its trust-anchor store, the answer to "is this *not* a trust anchor" is false, and so the recursive resolver does not reply with the answer from the authoritative server. Instead, it replies with a SERVFAIL (note that replying with SERVFAIL instead of the original answer is the only mechanism that KSK Sentinel uses). This means that Dave cannot fetch "bogus", he can fetch "root-key-sentinel-is-ta-02323", but he cannot fetch "root-key-sentinel-not-ta-11112". From this, Dave knows that he is behind a collection of resolvers that all validate, all have the key with Key Tag 11112 loaded, and at least one of these resolvers has loaded the key with Key Tag 02323 into its local trust-anchor cache. Dave will not be impacted by the KSK roll.

Just like Charlie and Dave, Ed cannot fetch the "bogus" record. This tells him that his resolvers are validating. When his (sentinel-aware) resolvers perform the KSK sentinel check for "root-key-sentinel-is-ta-02323", none of them have loaded the new key with Key Tag 02323 in their local trust-anchor store. This means the check fails, and Ed's recursive resolver converts the (valid) answer into a SERVFAIL error response. It performs the same check for root-key-sentinel-not-ta-11112.example.com, and as all of Ed's resolvers both perform DNSSEC validation and recognize the sentinel label, Ed will be unable to fetch the "root-key-sentinel-not-ta-11112" resource. This tells Ed that his resolvers have not installed the new KSK and he will be negatively impacted by the KSK roll.

Geoff would like to do a large-scale test and provide the information back to Alice. He uses some mechanism such as causing users to go to a web page to cause a large number of users to attempt to resolve the three resources, and he then analyzes the results of the tests to determine what percentage of users will be affected by the KSK rollover event.

This description is a simplified example. It is not anticipated that Bob, Charlie, Dave, and Ed will actually look for the absence or presence of web resources; instead, the web page that they load would likely contain JavaScript (or similar) that displays the result of the tests, sends the results to Geoff, or both. This sentinel mechanism does not rely on the web: it can equally be used by trying to resolve the names (for example, using the common "dig" command) and checking which names result in a SERVFAIL.

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