

# Exploring the Overhead of DNSSEC

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**Abstract**— Even though the key ideas behind DNSSEC have been introduced quite some time ago DNSSEC has not yet seen large scale deployment. This is in large part due to the anticipated overhead of DNSSEC. While the overheads have been reduced by the introduction of the delegation signer model [1], it is still not clear if they are bearable.

Therefore, we in this paper examine the actual overheads of DNSSEC. We first examine how the packet sizes of a DNS trace increase if DNSSEC would be used. Then we explore the CPU and memory overheads imposed by DNSSEC by replaying a DNS client trace in a testbed initialized with roughly 100,000 zones.

## I. INTRODUCTION

Since the early days of the Internet people rely on the Domain Name System (DNS) [2], [3]. DNS maps human memorable hostnames to machine usable addresses. Its redundant and distributed design has made DNS an indispensable, yet from the users perspective transparent, component of the Internet. On the other hand the conventional DNS does not provide any mechanism to assure the authenticity of the retrieved information to its users. In the 1990's several real world attacks (e.g., [4], [5]) highlighted how easy it is to misuse DNS for attacking unsuspecting users (and administrators). This led to several proposals for enhancing or replacing DNS, of which an cryptographically enhanced version called DNSSEC is the current front runner. During the last 10 years several variations of DNSSEC have been discussed (e.g., [6]) yet the final decision is still outstanding. This is partly due to the ambitious goals of DNSSEC: full backwards compatibility as well as data integrity and data authenticity. Among the concerns hindering deployment are that it is unclear how much overhead DNSSEC introduces on the name servers, after all a critical part of the Internet architecture.

In this paper we explore the costs imposed by DNSSEC, in terms of network bandwidth as well as resource consumption on name servers, using a trace based analysis and by replaying a DNS query trace in a testlab. We find that deploying DNSSEC can result in substantially larger packets, depending on the cryptographic cypher, and therefore increased bandwidth usage and packet fragmentation. Furthermore, our experiments indicate that this may easily balloon memory usage on caching servers by a factor of four.

The remainder of the paper is organized as follows: in Section II we give an overview of DNSSEC highlighting possible overheads. Section III discusses the environment in which we collected the datasets for our study. Section IV presents our initial results regarding the per packet overheads

while Section V examines the overheads imposed on the name servers. Finally, in Section VI we summarize our experience.

## II. OVERVIEW OF DNSSEC

In this section we give a short overview of the DNS design and briefly discuss how DNSSEC extends it in order to guarantee integrity and authenticity.

**DNS:** DNS relies on a distributed database with a hierarchical structure. The root of the DNS system is centrally administered and serves its *zone* information via a collection of *root servers*. The root servers delegate responsibility for specific parts (zones) of the hierarchy to other *name servers*, which may in turn delegate the responsibility to other name servers. In the end each site is responsible for its own *sub-domain* and maintains its own database containing its information and operates an authoritative name server. An alternative view of this name space is one of a tree with labels at the nodes separated by dots. Information associated with any particular name is composed of *resource records* (RRs) which contain the type of the resource and data describing it.

The whole database is usually queried by end hosts using a local name server. If this name server receives a query for information that it does not have, it must contact another name server. If the server does not know how to contact the authoritative one for the zone it will contact one of the root servers. Those will usually not have an answer to the query but will *refer* the client to the authoritative server of the subtree the client's queried name lies in. For example the root zone *.* delegates the **org.** zone to another name server, so the client gets a referral from the root server to one for **org.** For efficiency reasons DNS relies heavily on caching. All information that a name server delivers to a client is cached on the client for a duration specified in the TTL field of the RR. Caching is usually not done on end hosts, so called stub resolvers, but rather on dedicated machines on the path, so called *caching resolvers* or *forwarders*.

**DNSSEC Extensions:** DNSSEC is an enhanced version of DNS which relies on public key cryptography. Surprisingly it turned out to be much harder than anticipated to integrate a "Public Key Infrastructure" into DNS which allows each client to verify the signatures. The first "established" model [7] used impractical key handling, caused significant administrative overhead, imposed unnecessary DNS traffic, and did not allow incremental deployment [8]. The Delegation Signer (DS) model [9] overcomes these limitations by, e.g., introducing

islands of security. Accordingly, our analysis is based on this approach [10], [11].

To verify an answer secured by DNSSEC an authentication chain from the DNS answer to a trusted key has to be built. Hereby it is assumed that the resolver has a well known trusted key for the root zone. Each zone guarantees for the correctness of the answer records using a digital signature. The chain is built from the bottom to the top, according to the DNS name hierarchy. The correctness of the zone’s key is guaranteed by a signature from the zone’s parent and so on, until the root zone is reached. If all authentication steps are successful, the DNS answer must be correct (unless one of the keys has been compromised).

To enable authentication the necessary signatures are associated with each name and are accessible via four additional RR types: *RRSIG* RRs include digital signatures for “Resource Record sets” (RRset). (*RRSIG* adds 46 bytes plus key size plus zone name length overhead for RSA and 70 bytes plus zone name for ECC.) An RRset is a set of RRs with the same name, the same class, the same type, and also the same TTL. *DNSKEY* RRs contain the public keys for the zone (adding 18 byte plus key size overhead). Each signed RRset has to provide such a key in order to enable the resolver to verify the signatures. *DS* RRs are configured at delegation points in the parent zone, if and only if the child-zone is secure. In effect these indicate to a resolver whether the child-zone is DNSSEC secured. The most important content of the DS RR is a cryptographic hash (digest) of the child-zone’s *DNSKEY*, where the child’s name and the DS RR’s name are identical, (add 36 bytes overhead.) Together with the DS record’s *RRSIG* RR the authenticity of the child zone’s *DNSKEY* can be verified. *NSEC* RRs provide a mechanism for verifying the nonexistence of records. Without authenticated nonexistence, an attacker may choose to answer a query with a referral, but not include a DS record. The resolver could interpret this as “zone exists, but is unsecured”. In this case delegation can easily be forged and the attacker did not even have to sign the zone data. (*NSEC* RRs add 23 bytes plus name length plus label length in overhead.) To provide space for all this overhead, DNSSEC capable name servers and resolvers must support the EDNS0 extension [12]. This implies that every DNSSEC packet contains an extra OPT pseudo record.

**Problems with DNSSEC:** Signing and verification are mathematically complex operations and consume processing power. In addition, the necessary DNSSEC RRs are relatively large. Therefore DNSSEC capable name servers have larger memory and network bandwidth requirements. To highlight this Table I summarizes some of the overheads imposed by DNSSEC for RSA as well as ECC [13]. This can result in significantly larger packets. While not per se a problem, larger packets might have to be fragmented or even truncated. In the worst case this could lead to a fallback from UDP to TCP during the query process. To avoid some of these problems, DNSSEC [10] requires that the minimum accepted answer size of every DNSSEC aware resolver is 1220 Bytes (instead of 512). It recommends a minimum accepted answer size of 4000 Bytes.

Type	Overhead	Comment
DNSKEY	18 + key size	RSA or ECC
DS	36	SHA-1 digest
RRSIG	46 + key size +  zone  70 +  zone	RSA ECC
NSEC	23 +  name  +  label	

TABLE I  
SIZE OF DNSSEC RRS IN OCTETS

Data	Dir.	Size	Queries	Answ.	Start	Dur.
TR02	out	5.4G	32.8M	23.0M	11/19/02	5.8d
TR04	out	6.0G	36.6M	31.0M	10/06/04	2.0d
QL05	all	39.8M	1.01M	-	01/21/04	44m

TABLE II  
SUMMARY OF THE DATASETS.

### III. DATASETS

Our analysis utilizes two different kinds of datasets collected from the “Münchener Wissenschaftsnetz” (MWN), a network that provides Internet access to two major universities, several research institutes and quite a few dormitories in Munich. Using a monitor port at the single upstream link between the MWN and the Internet we collected packet level traces of all DNS queries and answers. Second, we gained access to query logs for the main DNS forwarders inside the MWN. Hereby, it is important to note, that the MWN requires all resolvers inside the MWN to use one of three forwarders. This policy is enforced by blocking almost all outgoing traffic to port 53. Since the focus of this paper is on the overhead imposed by a representative sample population on the DNS infrastructure, all our analyses are based on client traces. We excluded DNS transactions that originate outside of our local network (that is queries for the zones served by the local nameservers).

An overview of the data used in this paper is given in Table II. TR02 and TR04 are packet level traces covering only UDP port 53 while QL05 is a query log from the main DNS forwarder. The trace TR02 contains almost six days of traffic starting on 11/19/2002 at 22:28 GMT and ending on 11/25/2002 at 16:34 GMT. While recording the trace, tcpdump reported 335 packets. A total 0.173% of all UDP packets were ignored: 61.8K queries as well as 34.5K answers were eliminated, since they are either irrelevant for Delegation Signer DNSSEC or due to decoding problems. Irrelevant queries include, e. g., 58.3K update queries and 1.4K notifications. Of the 33K answers with decoding problems 25K are from five single sources. A second trace TR04, captured under similar conditions, covers two weekdays, starting on 10/6/2004 at 10:06 GMT and ending on 10/08/2004 at the same time. But with 67.6 million packets and no dropped packets it is a bit larger than TR02. The 67.6M UDP packets split into 36.6M DNS queries and 31.0M replies. In this trace a total of 0.05% packets were excluded from further analysis.

The query log was captured directly from the main DNS forwarder, *dns1.lrz-muenchen.de*. Since the diversity of requests grows with the length of a trace and therewith the resource

requirements of our experiments we limited the analysis to a roughly 50 minute portion of the overall log from 01/21/2005 10:56 to 11:40 GMT containing 1,008,384 queries.

#### IV. DNSSEC: PER PACKET OVERHEAD

In this section we examine, based on our packet traces of DNS requests, how much the per query and response overhead is as well as how much the overall increase in bandwidth is for DNSSEC. For these analyses we simulate what happened if the whole world as seen from our network's perspective would use DNSSEC. This provides us with some kind of worst-case analysis that does not take configuration errors into account. The main idea is to transform every DNS packet from TR02 and TR04 into a DNSSEC packet with the same content. This transformation is based on the DS-DNSSEC RFCs [9], [10], [11], [14] and Internet-Draft [15]. Additionally we manually configured a BIND [16] server (version 9.3.0) and analyzed its reactions on different crafted queries in order to verify and tweak our transformation process. The approach of "literally" translating every single DNS packet to an equivalent DNSSEC packet assumes that in the real world DNSSEC is used to transmit the same content as today's DNS transactions. Although secure authentication of data might well change the ways the DNS system is used over time, we believe that in a first step operators will insist to deploy the authentication enabled system in the same manner as the traditional DNS system.

**Transformation of DNSSEC queries:** If the DNS query already contains an OPT pseudo record the DO bit has to be set and if necessary the acceptable answer size has to be adjusted to a minimum of 1220 bytes. Note, that this does not change the payload size. Otherwise an appropriate OPT pseudo record has to be added which increases the payload by 11 octets.

**Transformation of DNSSEC answers:** To derive DNSSEC answers from DNS ones several cases have to be considered: If the answer status is **Refused**, **FormErr**, or **ServFail** the answer contains no RRs. Accordingly no modifications are necessary. If the answer is **NotImpl** and the RRs are from the name server zone then the RRs have to be signed. Otherwise there is no change. In case of a **NXDomain** answer, two NSEC RRs have to be constructed and signed: one for denying the existence of the exact name, one for denying the existence of a suitable wildcard (see Section II). For the **NoError** answers the kind of answer contained in the packet determines the necessary adjustments. If the packet contains a final answer, the answer, authority and additional sections of the DNS answer are signed. Otherwise if the answer section of the NoError answer is empty, but the authority section contains NS RRs, the packet contains a referral. In this case a DS RR is added to the authority section. Note that only the DS RR has to be signed as the NS RRs belong to the child zone. Otherwise the packet contains a negative answer. In this case, a NSEC RR is added and the packet is signed. In a final step an OPT RR is added unless the answer already contains one.

Signing a packet always entails adding RRSIGs for every RRset for the purpose of authentication. Note that only RRsets for which the answering name server is authoritative, can be signed. Our assumption in this experiment is, that the originating name server is authoritative for a RRset, if and only if its domain equals the query domain. We assume that each zone deploys a two level hierarchy of keys [15], [17]: a key-signing key (KSK) and a zone-signing key (ZSK). An authoritative nameserver may include both keys using DNSKEY RRs in its response or omit them if the packet grows too large, which may lead to an additional request for these keys by the verifying resolver. Following [10] and BIND's implementation we added two DNSKEY RRs (KSK and ZSK) to all packets except referrals. The reasoning behind this optimization is that the public key information is likely to be cached especially for the top level domains. For the RSA experiments we choose a KSK/ZSK key length of 1200/1024 bits [15] for all zones, for ECC a key length of 144/136 bits [13]. For more details see [10]. In our transformations we do not address the fact, that in a real-world deployment of DNSSEC different zones would naturally use different key lengths and/or different algorithms, resulting in a different distribution of packet sizes. Another issue in real world application of DNSSEC is key expiry and rollover. The ZSK as well as the KSK should expire regularly (e.g., weeks or months respectively) which requires a rollover mechanism. Some rollover scenarios envision to send two DNSKEY RRs (the old one and the new one) during the rollover phase. In our transformation we ignore such rollovers which leads to smaller packets and/or fewer requests. The final payload increase results from applying the necessary transformations to a packet, summing up the individual overheads, see Table I.

**Results:** Table III summarizes the increase in UDP payload for TR02. We consider queries and answers separately and sub-classify answers into "noErr" (successful) and "NXDomain". Furthermore the successful answers are separated into "final answers", "referrals" and "empty answers". In addition we had 1.6M packets with error-code "FormErr", 1.7M "ServFail", 5K "NotImpl", and 0.3M "Refused". The column "DNS size" is computed by summing the UDP payloads of the corresponding packets. The DNSSEC size (not shown) is computed by transforming the DNS packets. Instead the last column "Factor for DNSSEC" captures the increase in the payloads relative to the DNS size. While the "raw" trace captures the influence of the popularity of each name we also considered a "normalized" version which eliminates duplicate queries. We consider a query as a duplicate if its key, consisting of the IP address of the servers, the queried name, its type, and the query/answer flag, is a duplicate. The assumption underlying this approach is that all answers for a queried name from one host are the same except for ordering.

Table III highlights that the overhead is highly dependent on the packet type. Generally the size increase is much more moderate when using the less-well established ECC signatures [13]. As neither query packets nor answer packets of type Refused and FormErr are signed the overhead consists

Type	Count		DNS Size		DNSSEC factor		
	all	norm	all	norm	RSA		ECC
					all	norm	all
Query	32.8M	5.1M	1.5G	0.3G	1.1	1.1	1.1
noErr	20.0M	4.2M	3.7G	0.7G	4.1	5.3	2.3
Final	6.8M	2.5M	1.2G	0.5G	6.2	5.7	3.0
Ref.	10.9M	1.3M	2.3G	0.2G	2.0	2.6	1.6
Empty	2.2M	390K	.2G	44M	11.7	10.6	5.2
NXD.	1.4M	500K	.2G	57M	12.7	12.9	6.2

TABLE III  
TR02: DNS SIZE VS. DNSSEC SIZE.

	Size $\leq$	NXD	noErr	Final	Ref.	Empty
RSA	1,228	.005	.790	.701	1	.633
RSA	1,480	.231	.951	.921	1	.996
RSA	2,056	.999	.997	.991	1	.999
RSA	4,008	1.000	.999	.999	1	1.000
ECC	1,228	.998	.999	.998	1	.999
ECC	1,480	.999	.999	.999	1	.999

TABLE IV  
SIZE THRESHOLDS: FRACTION OF SMALLER ANSWER PKTS.

of at most an additional OPT section. This results in an average overhead factor between 1.1 and 1.2. Empty answers and NXDomain packets are on the other end of the spectrum. Initially they did not contain any RR. But when signed one, respectively two NSEC, two DNSKEY RRs, and the RRSIG RRs are added. This bloats the DNS packets by a factor up to twelve. Final answers are also subject to major increases as their RRs have to be signed. On the other hand the increase for referrals is moderate, since the DS model does not include the key of the parent zone. This reduces the overhead significantly (e.g., by 684 bytes for 1200/1024 bit RSA keys). On the other hand this can lead to additional queries to retrieve the DNSKEYs resulting in a minimum delay of one round-trip.

That the results for the “raw” trace are similar to the ones for the “normalized” trace highlights that the overhead of DNSSEC is intrinsic. However there is a major difference in the overall factors: 3.4 for “raw” vs. 4.6 for “normalized”. This is due to a shift in the composition of the traces. Referrals contribute 42.1% of the volume for “normalized”, but only 18.0% for “raw”.

Although the distribution among the packet types is significantly different in TR04 the DNSSEC factors are similar. TR04 contains more erroneous answer packets (error-code NXDomain and ServFail) whereas the especially expensive NXDomain packets (DNSSEC factor of 14.0 in TR04) result in an overall size increase factor of 4.2 for the raw and 5.8 for the normalized trace.

While the overall increase is of interest to determine bandwidth demands and size the memory requirements of servers it is even more interesting to inspect the distributions. Figure 1, left shows a comparison of DNS vs. DNSSEC sizes for referrals from TR02. The shapes of the probability density

functions over the packet sizes are very similar just shifted to the right for DNSSEC. After all DNSSEC always adds an additional DS RR to these packets. For final answers the size increase depends on the number of RRsets for which the server is authoritative as well as the length of the zone name. Furthermore RRsets differ in size. Figure 1 (right) shows a scatter plot of DNS packet size vs. DNSSEC packet size for all final answer packets in TR02. The identifiable lines have a slope of 1 and are due to the content of the original DNS packets: The parallel lines have a vertical distance of 174 bytes; the size of a RRSIG RR. Accordingly all packets within a line have the same number of authoritative RRsets.

The last plot already shows that some DNSSEC packets may become subject to fragmentation and/or truncation even though the minimum DNS message size has been increased from 512 bytes to 1220 bytes. Further inspection shows that Query, FormErr, ServFail, and Refused packets are never limited by the maximum packet sizes. After all they do not contain any answers. Such packets account for more than 60% of all packets, but less than one third of the DNS size and one tenth of the DNSSEC size. The other packets – especially answers with noError or NXDomain error code – can become quite big. Table IV examines what percentages exceed certain important thresholds: 1220 octets (1228 UDP size) is the minimum message size supported by every DNSSEC aware resolver. IP networks often use a MTU of 1500 bytes. This implies that only UDP packets of size  $\leq 1480$  bytes can be sent without IP fragmentation. The tool `dig` uses a default maximum DNSSEC answer size of 2056 bytes (incl. UDP header). Finally 4008 octets is recommended as a lower bound for the maximum answer size [18]. (BIND’s default is 4096 octets.)

Our evaluation shows for RSA signatures, that virtually all DNSSEC packets, derived from both of our traces, are smaller than 4008 bytes. Moreover most (99.8%) are smaller than 2056 bytes. Yet about 77% (TR02) and 72% (TR04) of the noErr and NXDomain packets will require IP fragmentation. One might assume that empty and NXDomain answers have a real problem if the answer size were to be limited to 1220 bytes. However the name server can choose to drop one or both DNSKEY RRs as is done for referrals. This reduces the packet size by 684 octets for RSA, ensuring that the name servers are *not required* to set the truncation bit (TC) [10] but in case the receiving client does not have the appropriate DNSKEY RR cached it has to issue an additional query. When using ECC signatures instead of RSA ones almost all packets are smaller than 1,228 bytes, regardless of their type, see Table IV.

## V. DNSSEC: MEMORY AND CPU OVERHEAD

In order to evaluate how much CPU as well as memory overhead DNSSEC imposes on name servers and caches we replayed the DNS query trace, QL05, against DNS as well as DNSSEC name servers in a testlab. The DNSSEC experiments rely on RSA signatures only, since ECC is not yet implemented in the latest version of BIND.

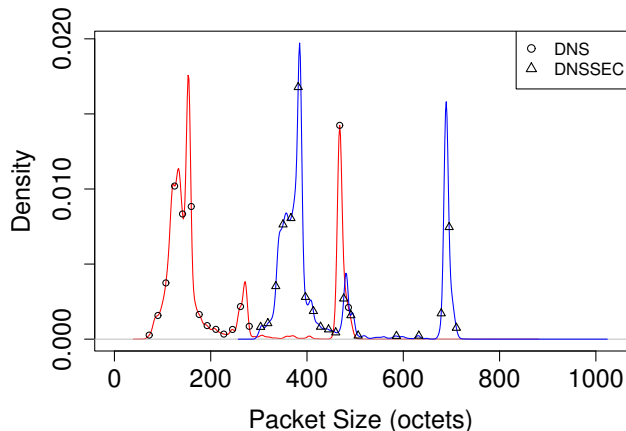
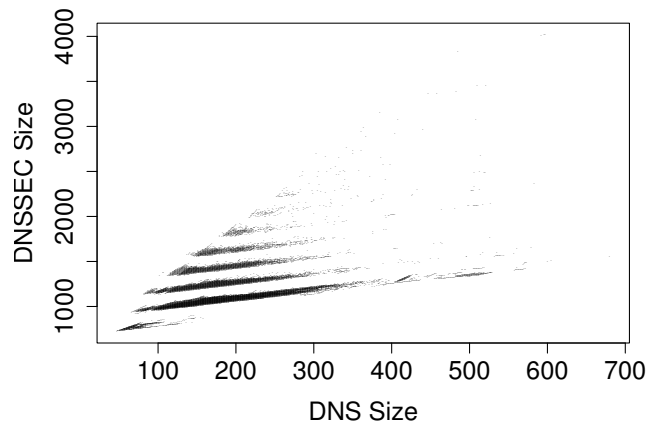


Fig. 1. DNSSEC NAME RESOLUTION (TR02): INCLUDING THE RELEVANT RRS FOR RSA SIGNATURES



**Methodology:** Our testbed setup, see Figure 2, includes three name servers, (*ns1*, *ns2*, *ns3*, Athlons XP1800+, Debian). Each of these is authoritative for some subset of the zones, using BIND [16] (version 9.3.0). The basic zone data for the experiment is derived from the query log QL05, by iteratively resolving the contained queries. The RRs from the answer and the authority sections are used to initialize the zone database. Flawed RRs, e.g., NS RRs with IP addresses in the RDATA part are dropped. (The additional section also turned out to be problematic [19].)

The resulting zone files are ready for use in the DNS experiments. For DNSSEC they have to be signed first. We used the `dnssec-keygen` and `dnssec-signzone` tools that come with BIND. After creating the Key Signing Key (1200 bit length) and the Zone Signing Key (1024 bit length), the corresponding zone is signed. In addition to the signed zone, `dnssec-signzone` creates a key set file for the zone. When signing the parent zone the existence of this key set file is used by `dnssec-signzone` to determine if the child zone is secure, and if so to calculate the DS RR for the delegation. Therefore, to get a completely signed DNSSEC hierarchy, the deepest zones have to be signed first.

In a next step the zones are distributed across the set of available name servers in our testbed. We decided to assign each level of the DNS hierarchy to a different name server process, listening on an IP address of its own, to ensure that all iterative queries have to traverse the full hierarchy. Since zones at the same level are more or less independent they can be placed on the same name server. Each zone is hosted only on one (“primary”) name server process, there are no “secondaries”. This implies that the records have to be adjusted appropriately. The time to live fields are set according to the needs of the individual experiments. We distributed the more than thirty name server processes onto our three machines in a way that all server instances are able to keep their zone data in main memory: We choose to put the largest level, level two,

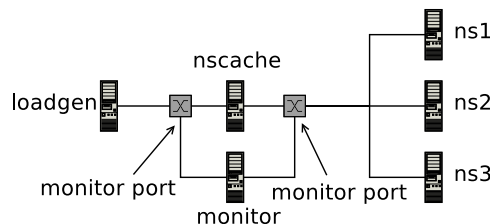


Fig. 2. TESTBED SETUP

on a machine of its own, *ns2*. The next largest zone, level five, together with the root zone and the top-level zones are put on another machine, *ns1*. The other levels, 3, 4, 6 to 33, ran on *ns3*.

We generated the queries on *loadgen* using the tool `dig` in batch mode. Memory and CPU usage for the authoritative name servers as well as for the caching name server *nscache* are determined leveraging the Linux per process accounting information from the `proc` filesystem at periodic intervals, i.e., after every 1000 queries.

**Memory usage increase:** Part of sizing a DNSSEC server respectively a caching name server is to determine the memory footprint of the application. We find that the penalty for authoritative servers is only a factor of two; much smaller than what one may expect given the results of Section IV. For example, the level two server for 55K zones occupied 290 MB for DNSSEC as compared to 156 MB for DNS. To determine the overhead for a caching name server we examine the memory usage of the BIND process on *nscache*. Its increase is rather dramatic, e.g., from 93 MB for DNS to 432 MB for DNSSEC for a workload that consisted of 218K unique queries spread over the complete zone-information using TTL values of 24 hours. This choice of TTL values effectively disables cache expiration. A necessity, as the used version of BIND had a bug which caused the memory occupied by expired DNSSEC

Level	#DNS	CPU-time DNS	#DNSSEC	CPU-time DNSSEC
0	5.0K	1.0 s	6.4K	2.03 s
1	61.8K	11.56 s	65.4K	13.85 s
2	176.1K	23.80 s	249.1K	39.71 s

TABLE V  
CPU-TIME ON AUTH. SERVERS FOR 1M QUERIES

cached	CPU-time DNS	CPU-time DNSSEC	delay DNS	delay DNSSEC
no	292.8 s	665.4 s	1.8 ms	3.9 ms
yes	37.1 s	45.9 s	0.2 ms	0.2 ms

TABLE VI  
CPU-TIME ON *nscache* FOR 218K QUERIES

cache entries not to be freed or reused.

**CPU usage increase:** In our experiments we identify two sources of increased CPU usage due to DNSSEC. For authoritative name servers the overhead only stems from the larger data volume that has to be sent, as they do not have to perform any cryptographic operations. Table V shows the CPU usage, averaged over five experiments, for those queries (columns “#DNS” and “#DNSSEC”) that the servers for levels 0, 1, and 2 have to answer when sending one million requests to *nscache*. Comparing the CPU times for DNS to those of DNSSEC we observe that DNSSEC introduces an overhead of a factor of 1.1 to 2. However, if we consider the average CPU usage per query the factor is roughly 1.3 to 1.6 for all level 0-2 authoritative servers.

Since our client issues all queries to the caching name server, *nscache*, with the DO bit unset, *nscache* verifies any information before stripping off all DNSSEC RRs and sending the result to the client. That implies that the BIND process has to verify all signatures for all answers that it receives from the authoritative name servers unless it has the information already cached. In a first experiment we confront *nscache* with 218K unique queries to ensure that it for every query (at a minimum) has to verify the signature of the queried name itself. We used TTLs of 24 hours in order to enable BIND to cache referrals for the duration of the experiment. The goal of a second experiment is to enable *nscache* to serve all information from its cache. Recall that if the name server takes the information from its cache it does not have to perform any cryptographic verification. Therefore we repeated the same set of queries before the TTL expired. Table VI shows the resulting CPU usages (averaged over five experiments). The CPU time for DNSSEC on *nscache* for the first run increases by a factor of 2.3 if compared to DNS. A fairly small factor given the task at hand. Roughly the same factor applies to the mean delay between queries and answers as experienced by the stub resolvers. On the other hand the numbers indicate that the absolute delay introduced by the additional verifications is hardly perceivable by the end user as long as the name server does not operate at its limit. (The delays are computed from packet level traces collected by the *monitor*, see Figure 2.)

## VI. SUMMARY

In this paper we evaluate the costs a wide spread DNSSEC deployment would impose in terms of network bandwidth as well as resource consumption on name servers. We base our analysis on real world data from a large client population. For RSA signatures we find that DNS packets grow on average by a factor of 3.4 and 12.7 in the worst case. The less well-established ECC signatures outperform RSA: ECC signatures only impose an average overhead factor of 2.0 and 6.2 in the worst case.

In our testlab we found that DNSSEC operating with RSA signatures leads to significantly higher memory requirements: more so for caching name servers but also for authoritative name servers. CPU usage does not seem to be a show stopper for DNSSEC: although the CPU usage increases, modern hardware should be able to handle the extra processing without impacting the end user performance significantly. Overall we are not able to identify a principle performance hurdle for the deployment of DNSSEC, except that the necessary software changes for DNSSEC, e.g., BIND, are not yet fully matured.

## ACKNOWLEDGMENT

The authors would like to thank the Leibnitz Rechenzentrum and in particular Hans Bezold for his cooperation for acquiring the data used in this paper.

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