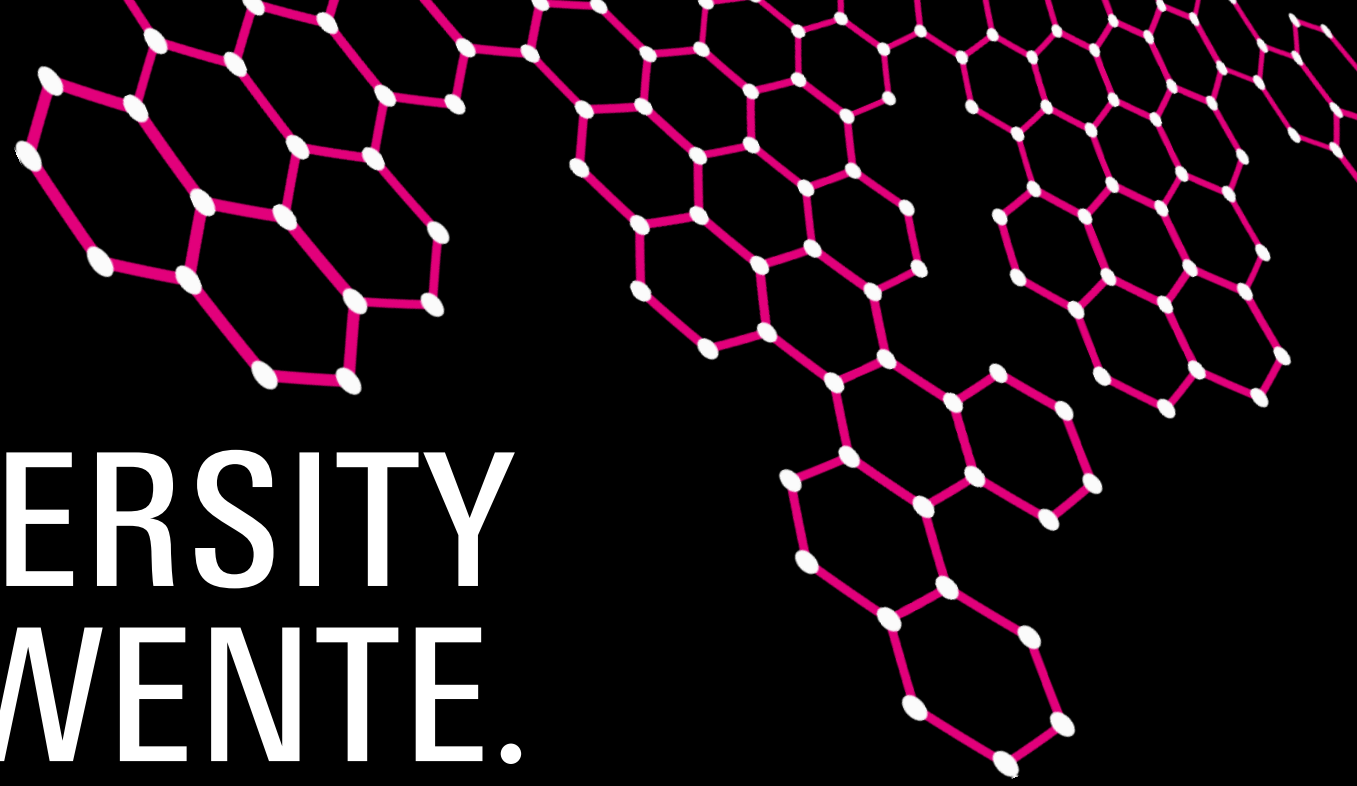
FACULTY OF ELECTRICAL ENGINEERING, MATHEMATICS AND
COMPUTER SCIENCE



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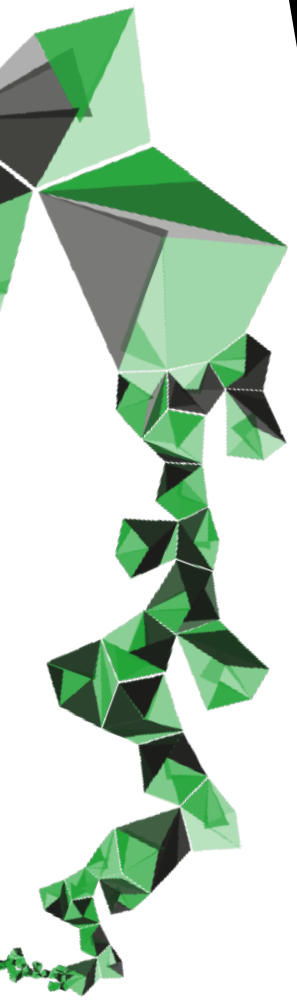
THE CHALLENGES IN USING PQC FOR DNSSEC

Prof. dr. ir. Roland van Rijswijk-Deij

Design and Analysis of Communication Systems group

University of Twente

WHO AM I?



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- Interested in DNSSEC operations research

THIS TALK

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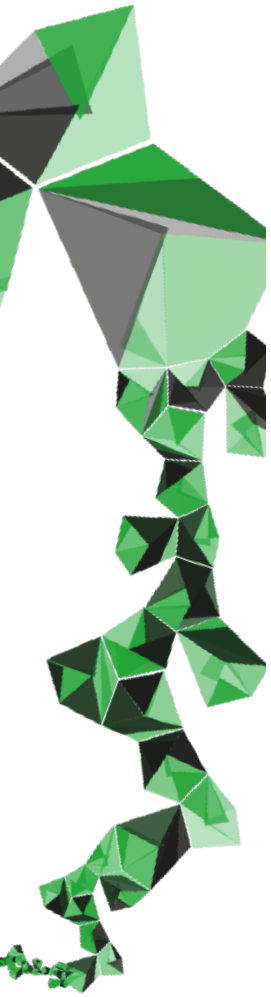

- Quick primer: DNS + DNSSEC

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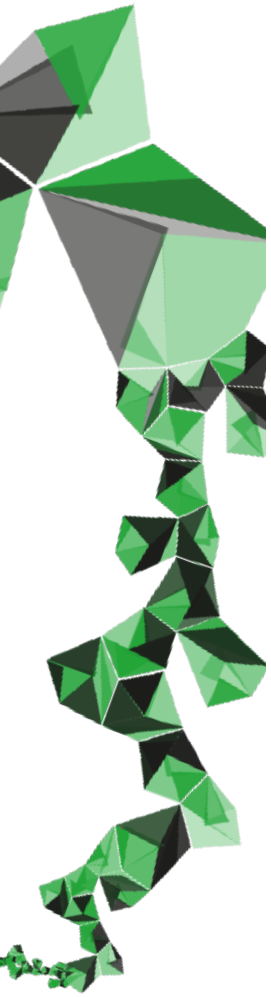

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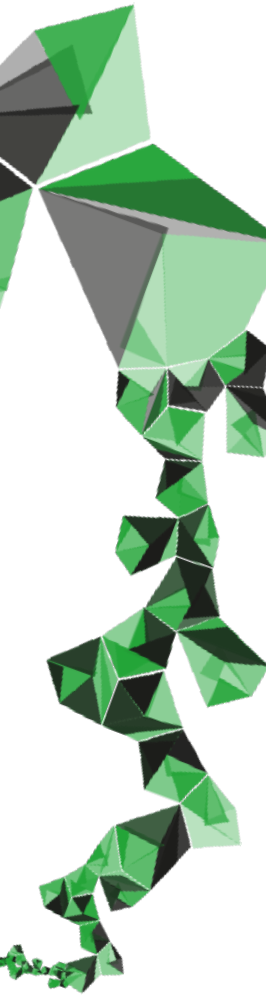

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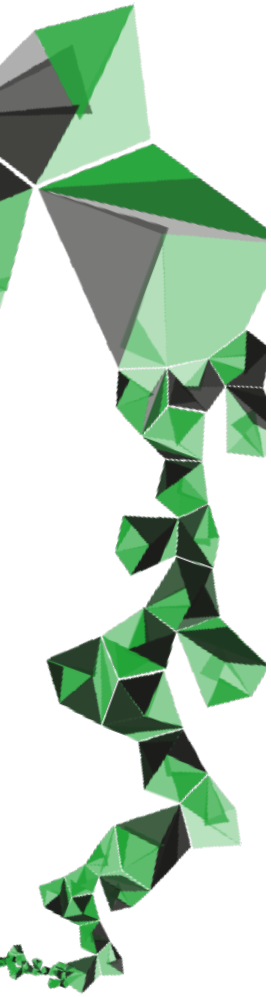

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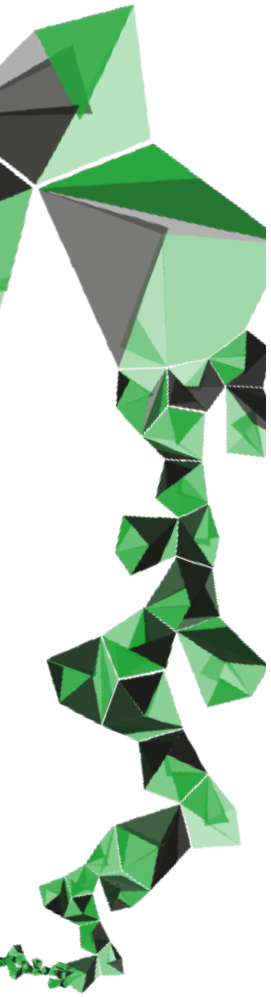

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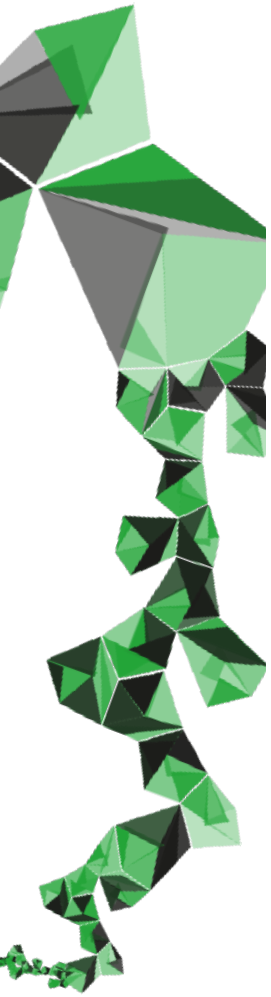

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A QUICK PRIMER: THE DNS

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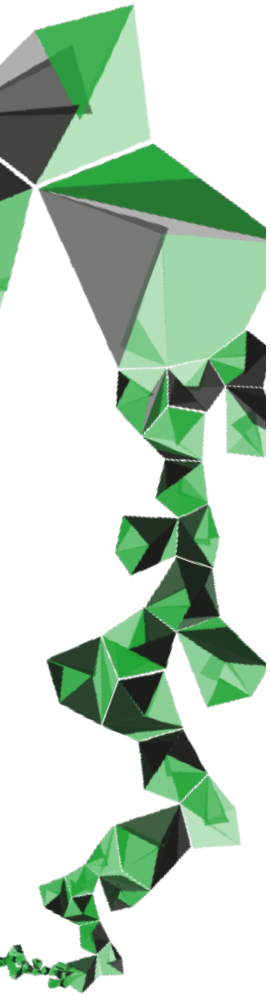

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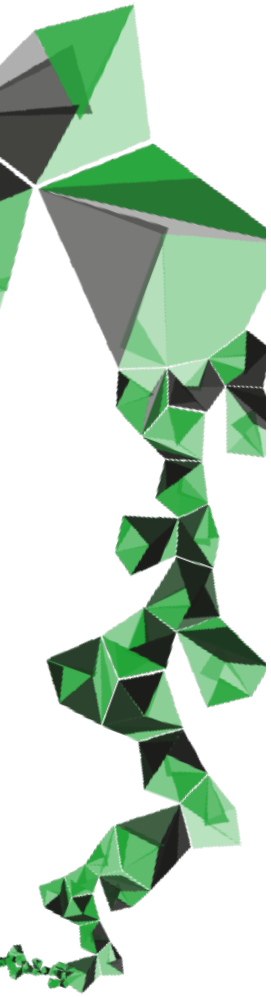

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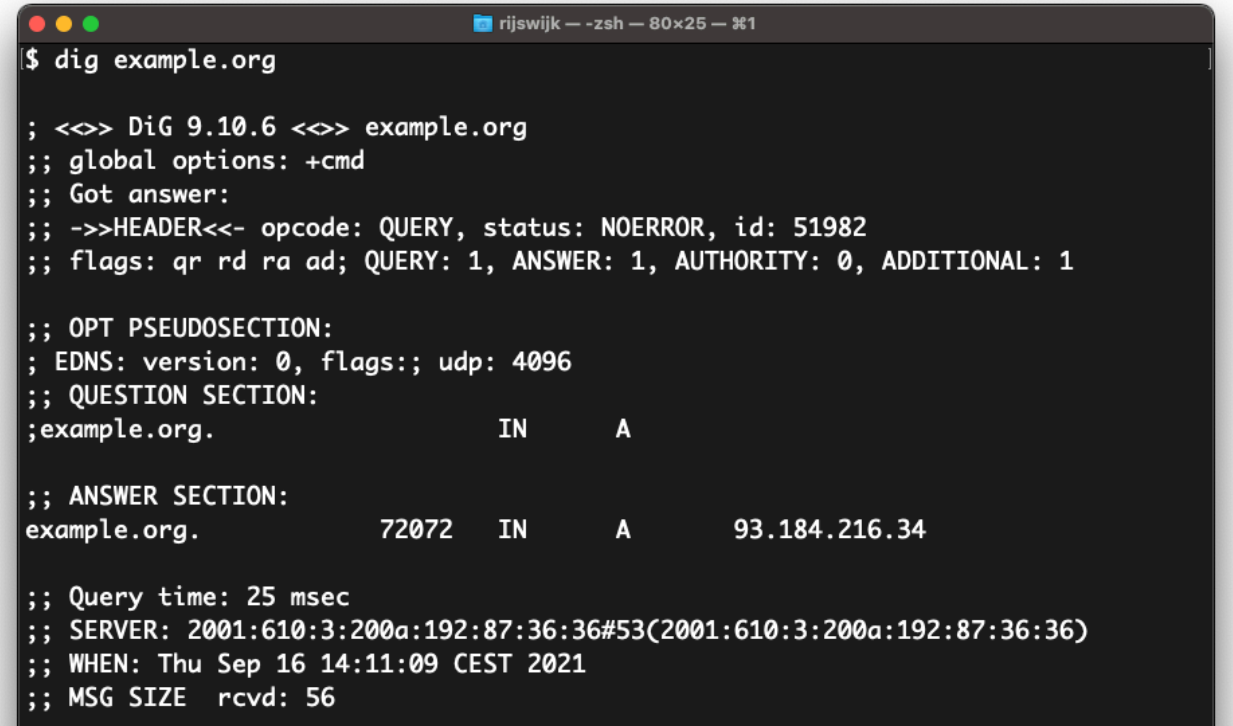
- Human-readable names to machine readable information

A QUICK PRIMER: THE DNS

- You use the Domain Name System every day
- Human-readable names to machine readable information
- Most common use: mapping names to IP addresses:



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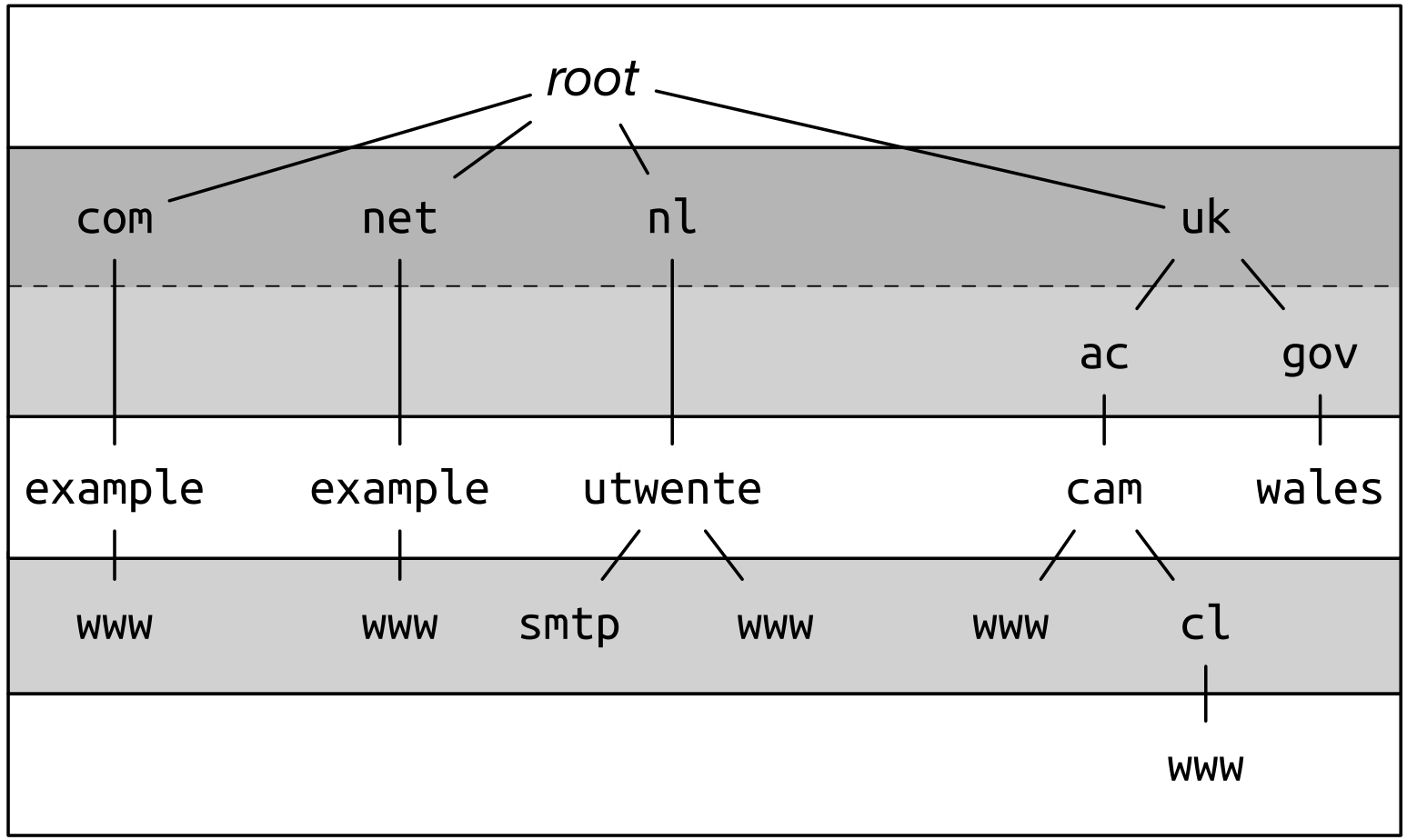
HIERARCHICAL NAME SPACE



root level

top level domains

public suffixes

second level domains

third level domains

further levels

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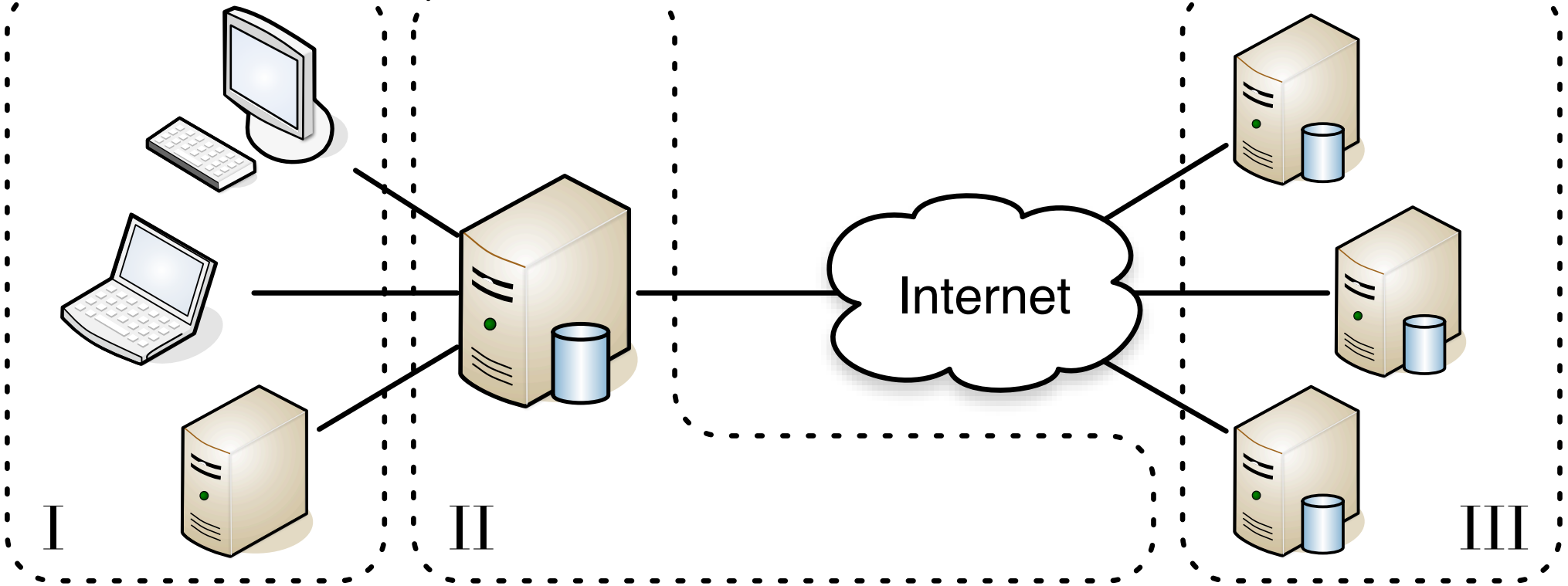
DNS ROLES



clients **recursive caching name server** (a.k.a. 'DNS resolver') **authoritative name servers**

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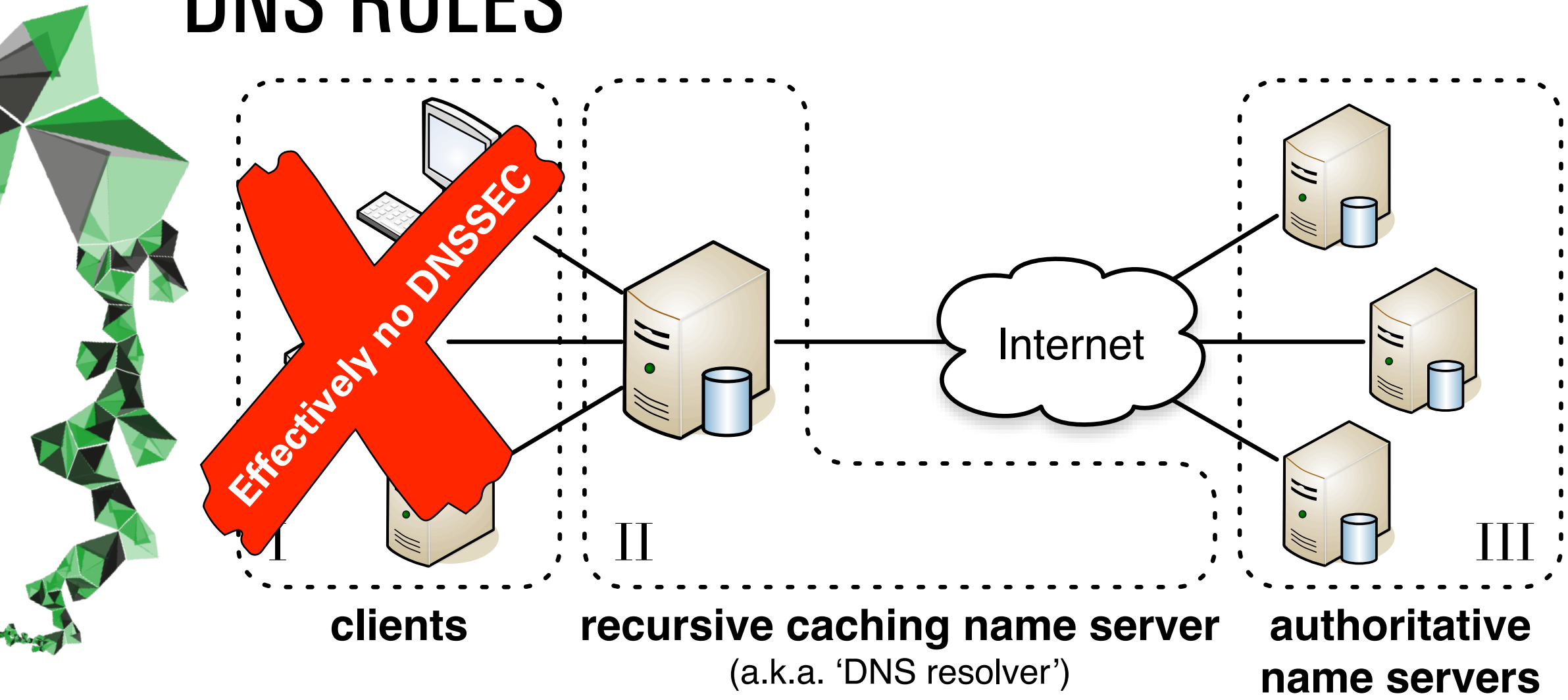

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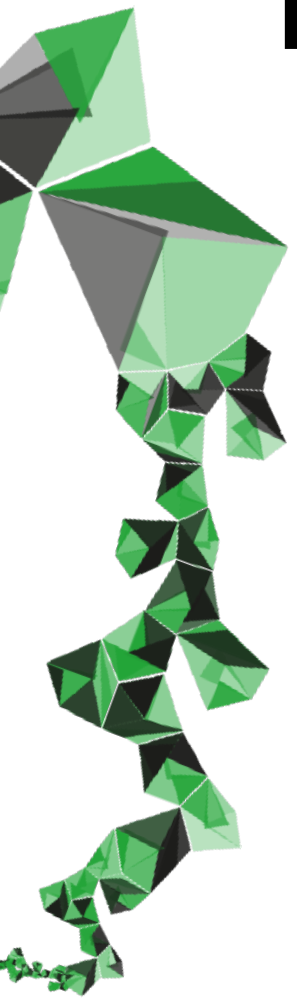
PROBLEMS WITH THE DNS



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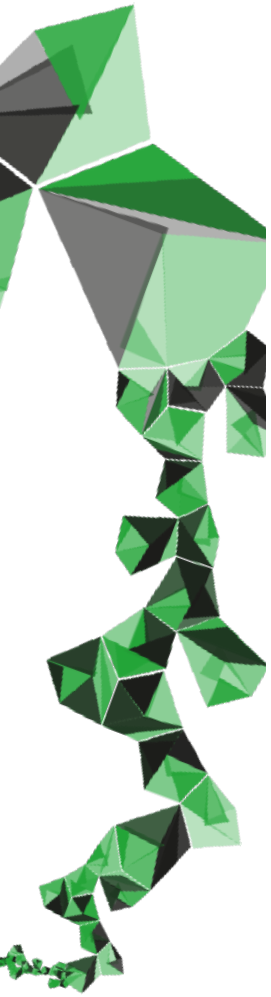

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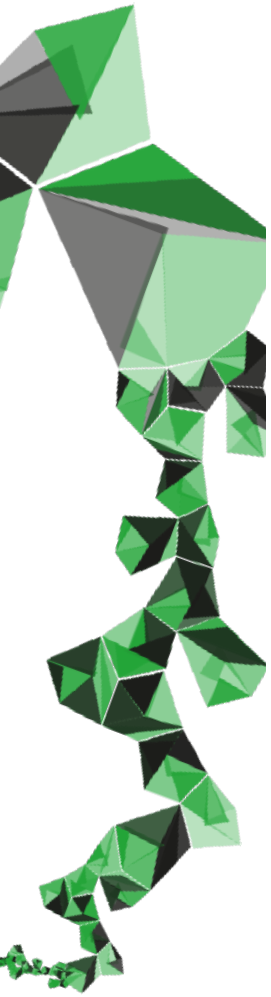

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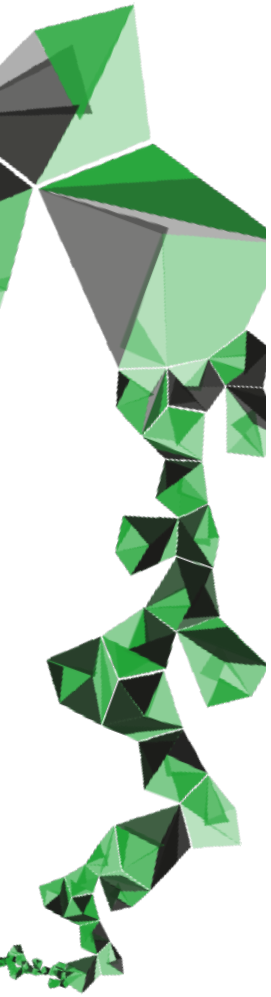

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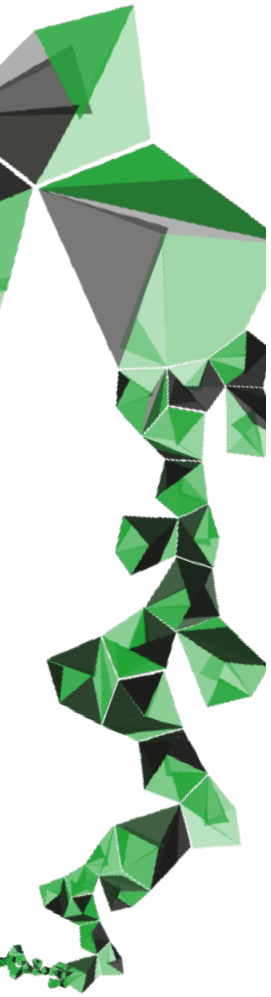

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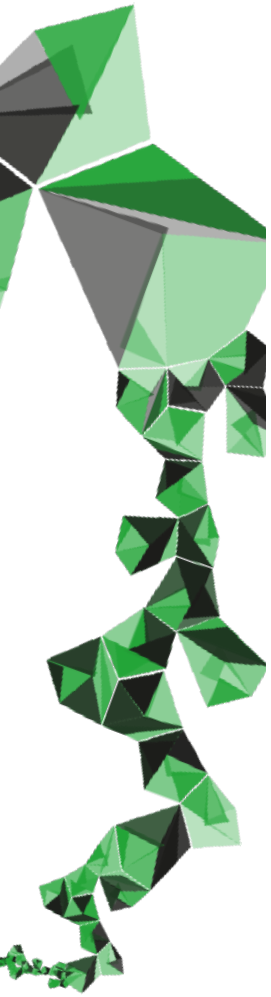

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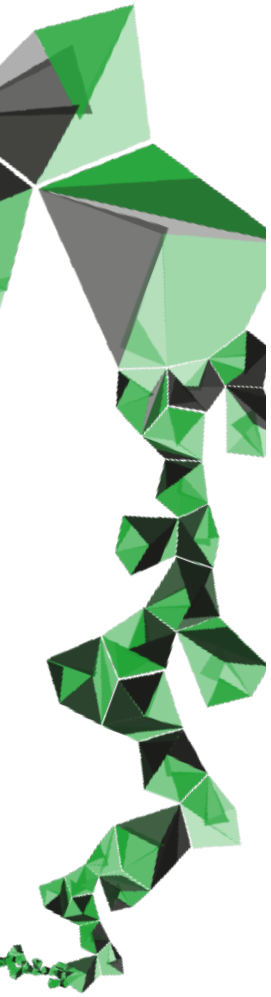

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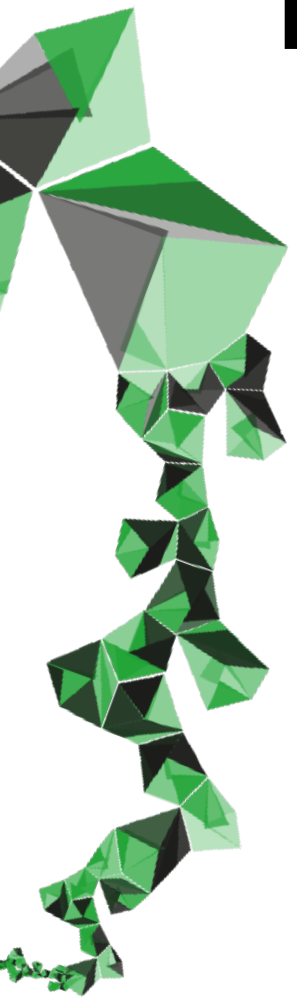
- Root cause: no mechanisms for authenticity and integrity

ENTER DNSSEC



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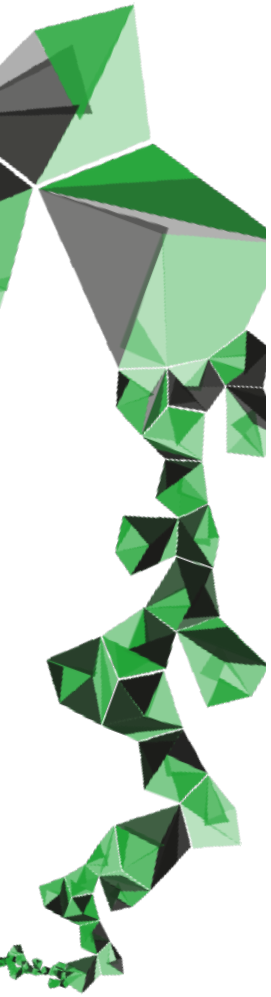

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  Note: DNSSEC does not add confidentiality

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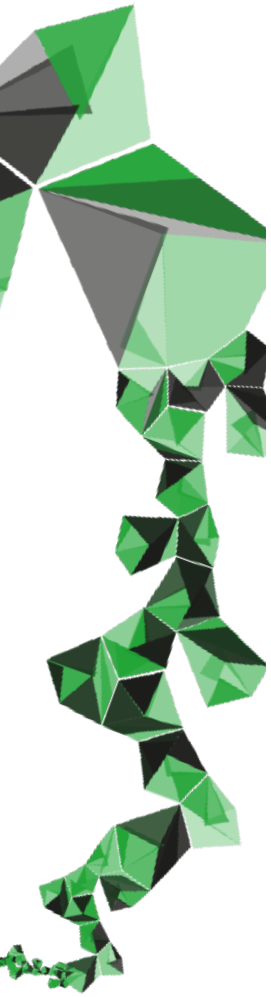

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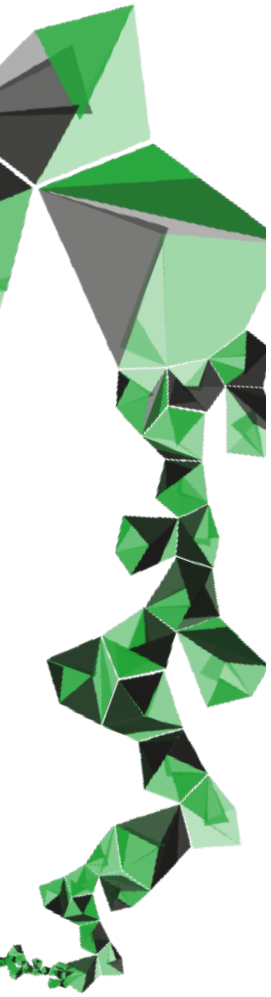

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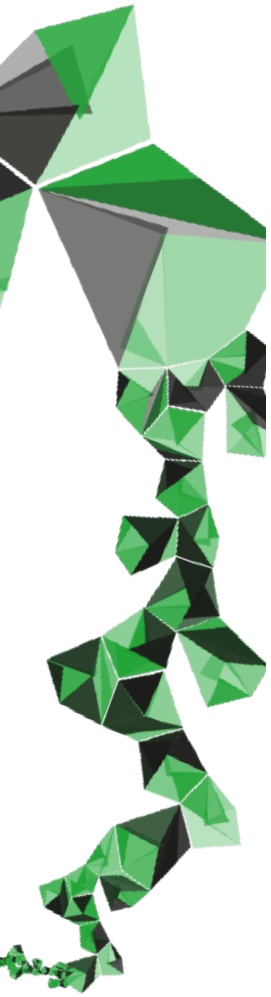

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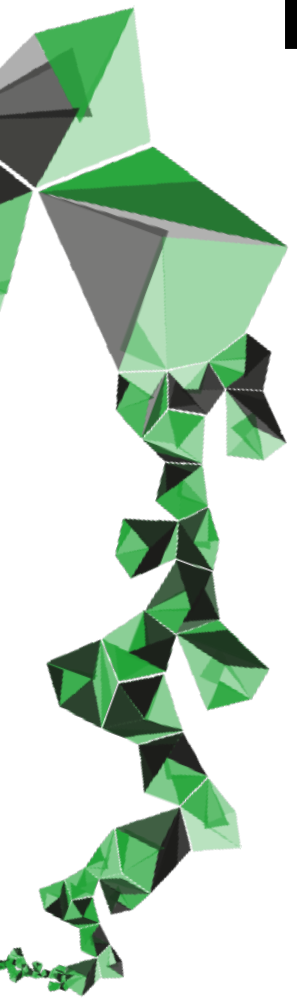
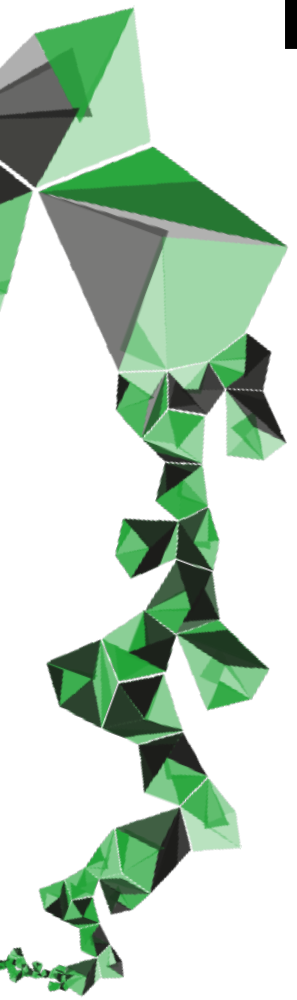
- Single root of trust (DNS root zone), validation along chain of trust (explained later)

DNS ZONE



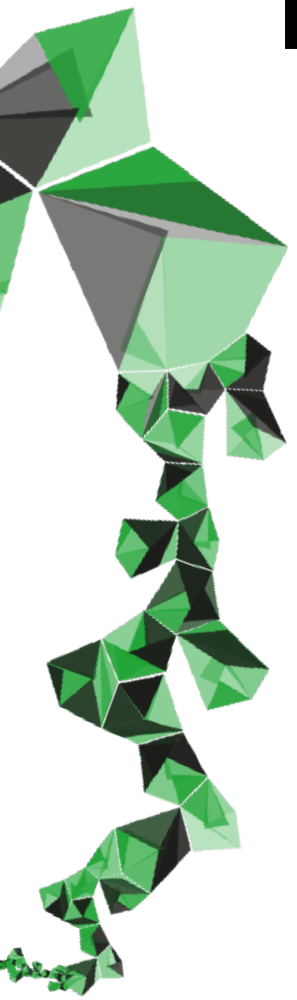
```
1  $ORIGIN example.com.
   ...
   domain name   TTL    class  type   value
2  @             86400  IN     A      93.184.216.34          ← RRset #1
3  @             86400  IN     AAAA   2606:2800:...:1946     ← RRset #2
4  @             86400  IN     NS     a.iana-servers.net.    ← RRset #3
5  @             86400  IN     NS     b.iana-servers.net.
6  www           86400  IN     CNAME  example.com.           ← Alias
7  sub            3600  IN     NS     ns1.example.org.       ← Delegation
8  sub            3600  IN     NS     ns2.example.org.
9  lorem.ipsum   86400  IN     A      127.0.0.1              ← Results in empty non-terminal
10 *.dolor         300  IN     TXT    "Sed ut perspiciatis   ← Wildcard
                                      unde omnis..."
```

DNSSEC-SIGNED ZONE



	domain name	*TTL*	*class*	*type*	*value*	
1	example.com.	86400	IN	A	93.184.216.34	← RRset #1
2	example.com.	86400	IN	RRSIG	A 8 2 86400 ...	← signature for RRset #1
3	example.com.	86400	IN	AAAA	2606:2800:...:1946	← RRset #2
4	example.com.	86400	IN	RRSIG	AAAA 8 2 86400 ...	← signature for RRset #2
5	example.com.	86400	IN	NS	a.iana-servers.net.	← RRset #3
6	example.com.	86400	IN	NS	b.iana-servers.net.	
7	example.com.	86400	IN	RRSIG	NS 8 2 86400 ...	← signature for RRset #3
8	example.com.	3600	IN	DNSKEY	257 3 8 AwEAAdCU...	← Set of public keys
9	example.com.	3600	IN	DNSKEY	256 3 8 AwEAAZ0a...	
10	example.com.	3600	IN	RRSIG	DNSKEY 8 2 3600 ...	← signature over DNSKEY set

DNSSEC-SIGNED ZONE



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6	example.com.	86400	IN	NS	b.iana-servers.net.	
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8	example.com.	3600	IN	DNSKEY	257 3 8 AwEAAdCU...	← Set of public keys
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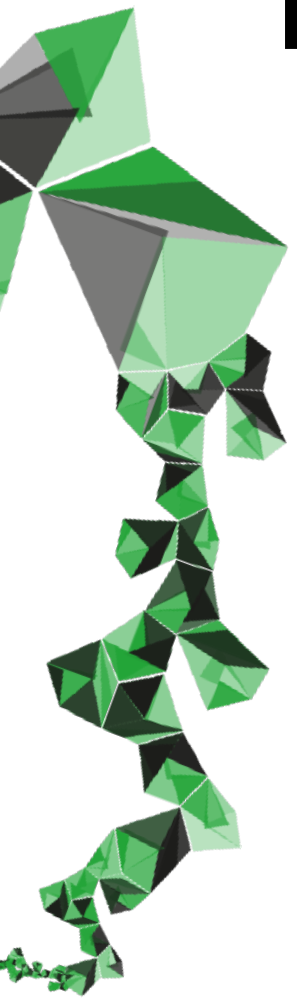
DNSSEC-SIGNED ZONE



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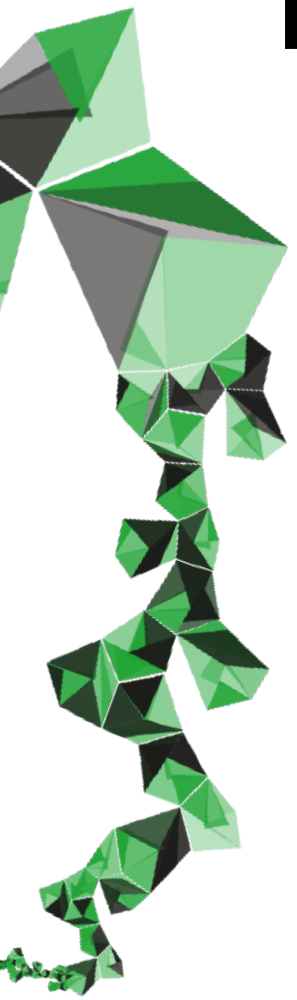
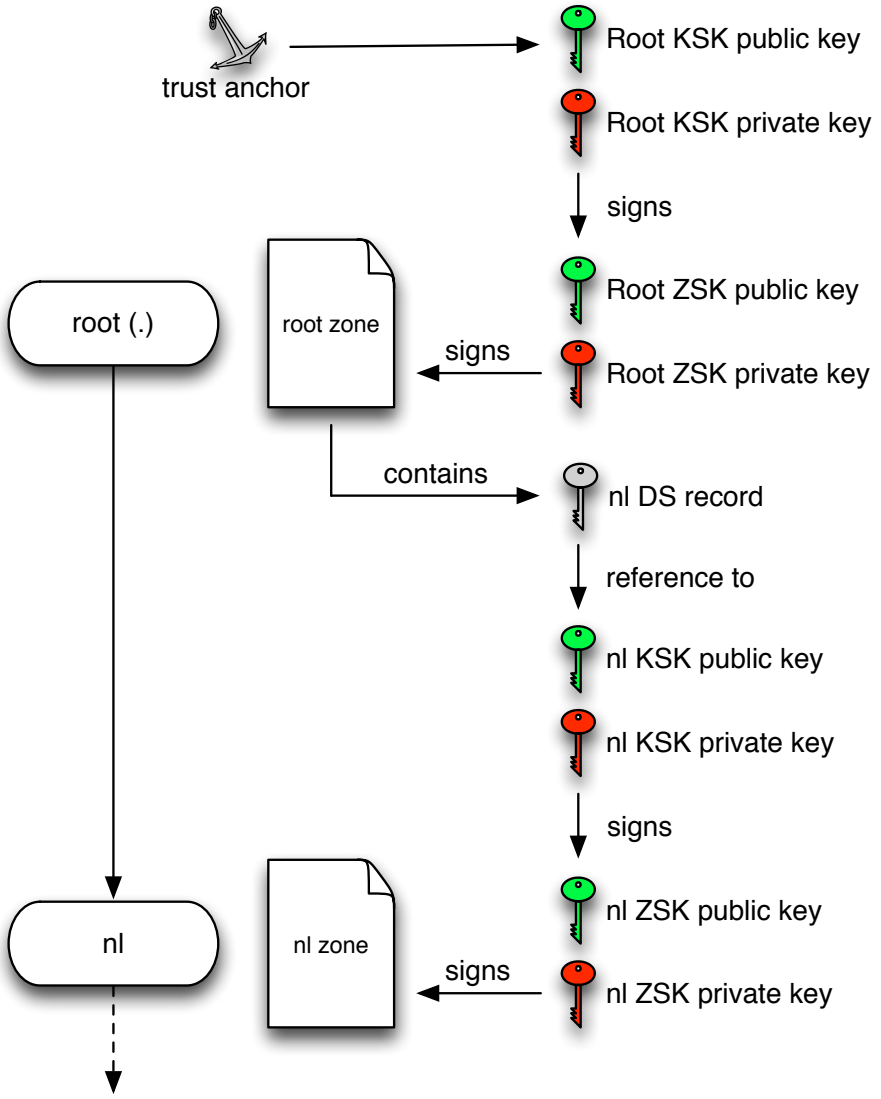
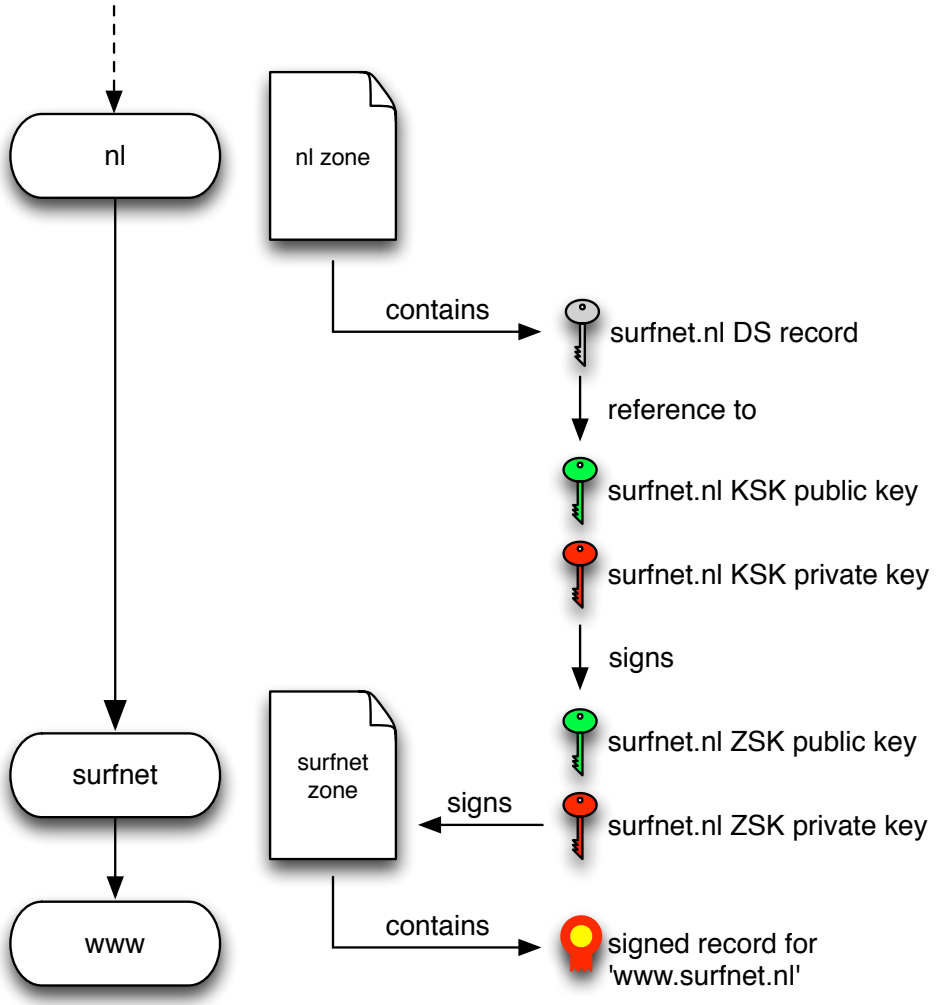
DNSSEC VALIDATION







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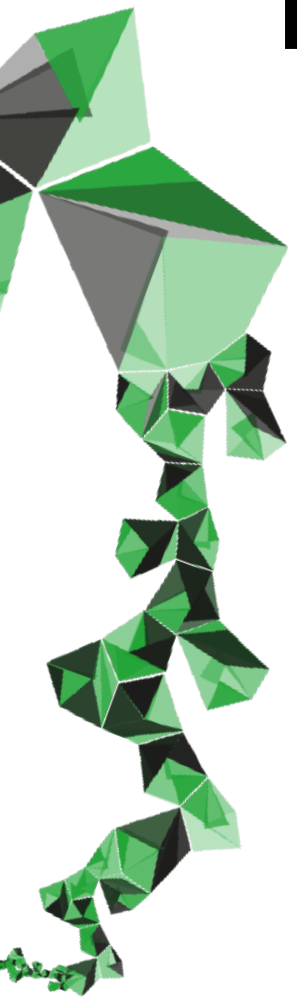
DNSSEC TRANSPORT



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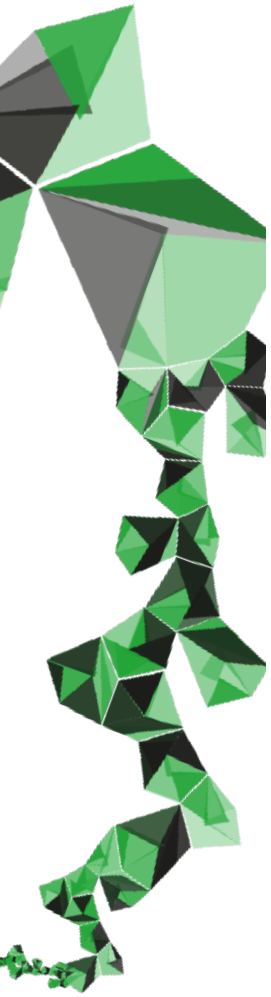

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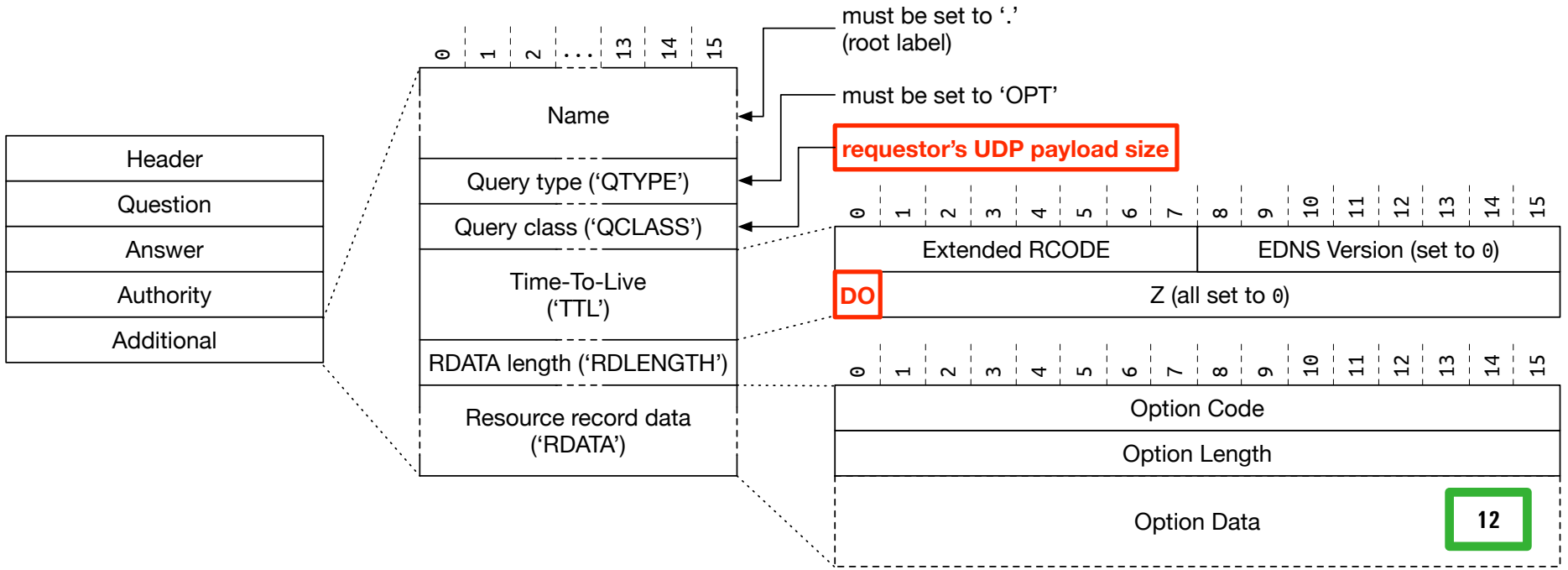
- The original DNS specification allows a maximum message size of 512 bytes — too small for DNSSEC (keys + signatures!)
- Protocol extension EDNS0 solves this:



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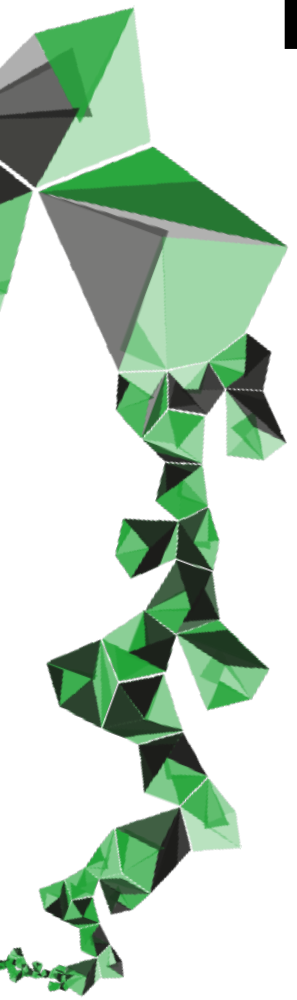
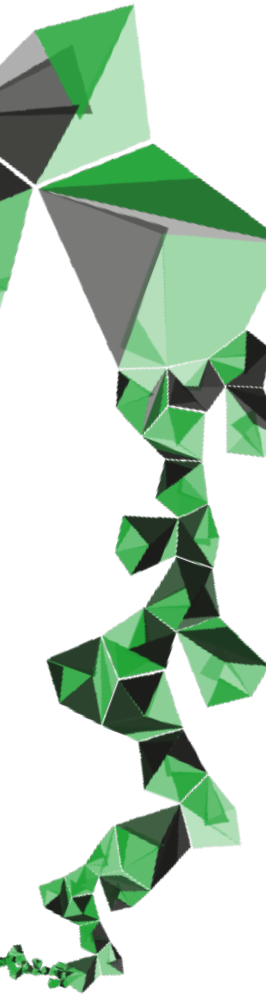
EDNSO AND FRAGMENTATION

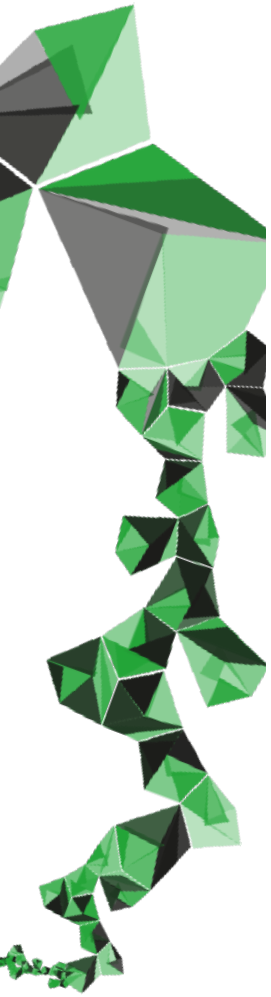


EDNS0 AND FRAGMENTATION



- EDNS0 allows for UDP payloads of almost 64KB

EDNS0 AND FRAGMENTATION



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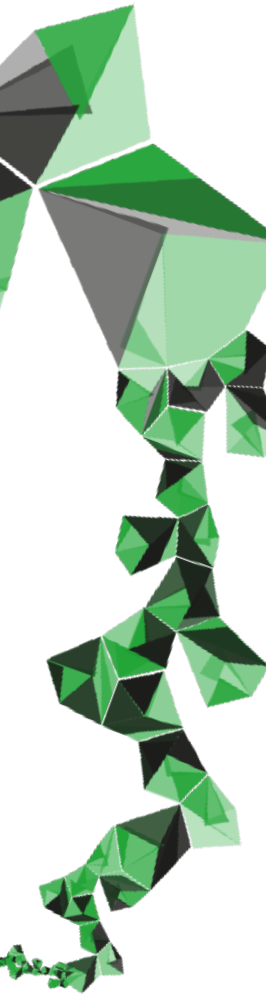

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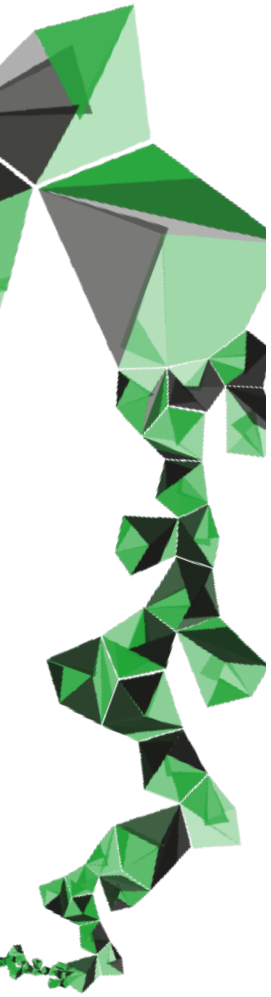

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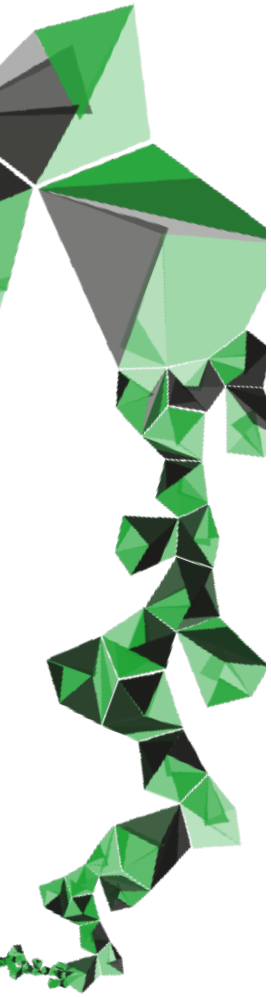

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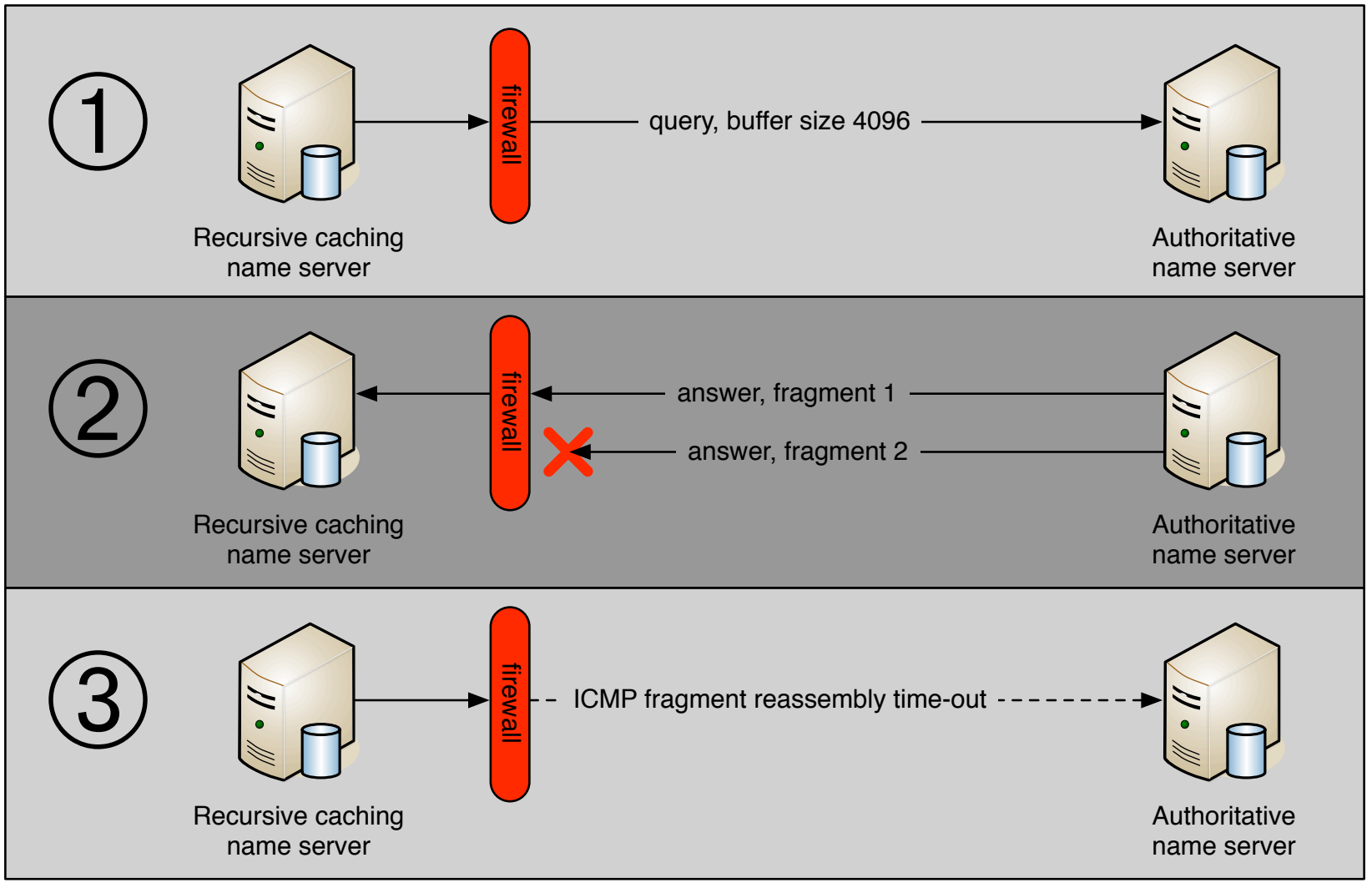
- Fragmentation causes two problems (next two slides)

UNREACHABILITY



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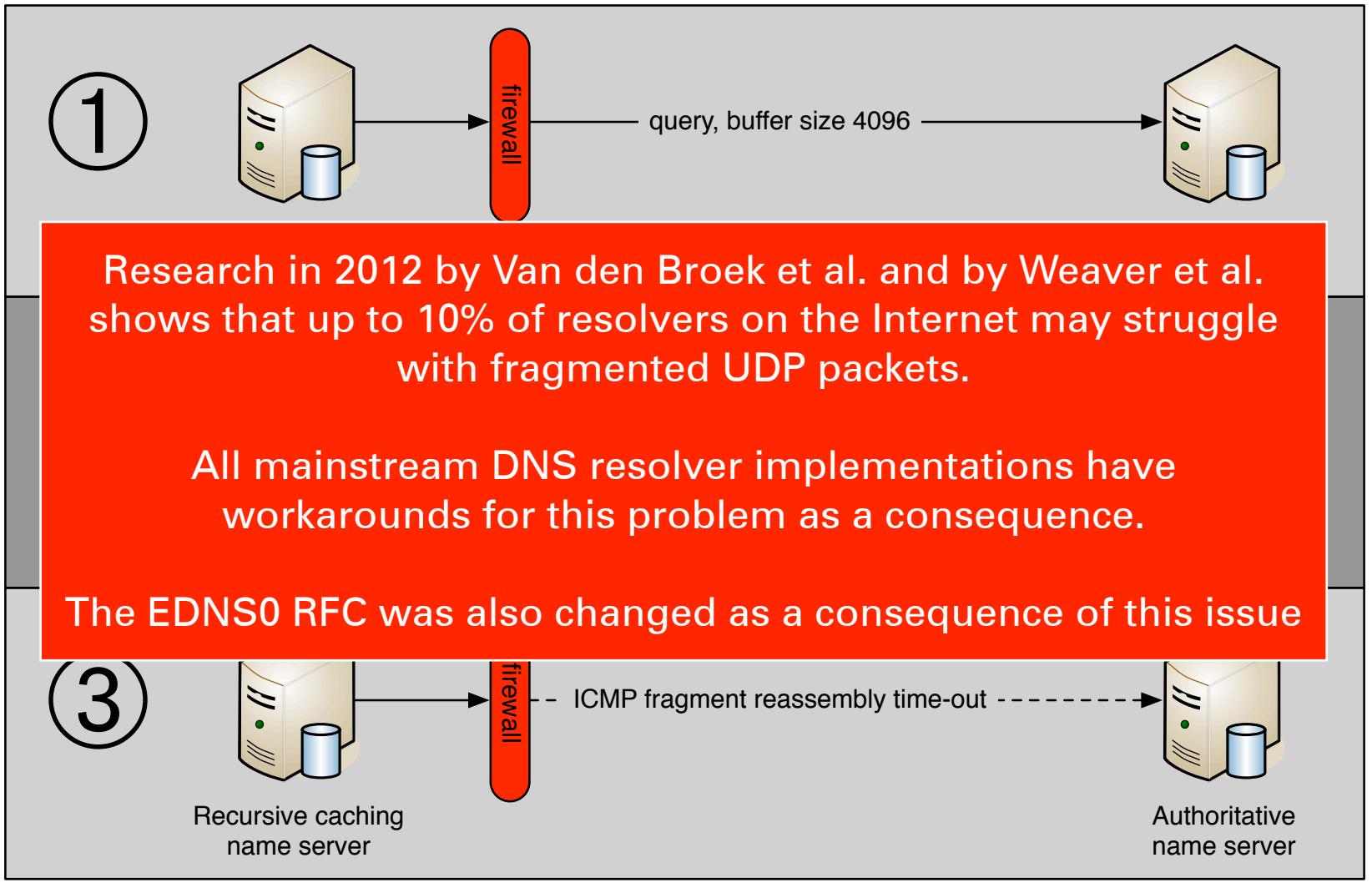
UNREACHABILITY

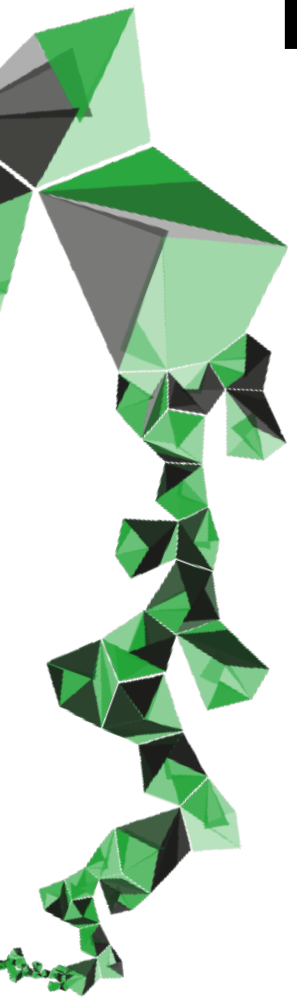


Research in 2012 by Van den Broek et al. and by Weaver et al. shows that up to 10% of resolvers on the Internet may struggle with fragmented UDP packets.

All mainstream DNS resolver implementations have workarounds for this problem as a consequence.

The EDNS0 RFC was also changed as a consequence of this issue

FRAGMENT CACHE POISONING



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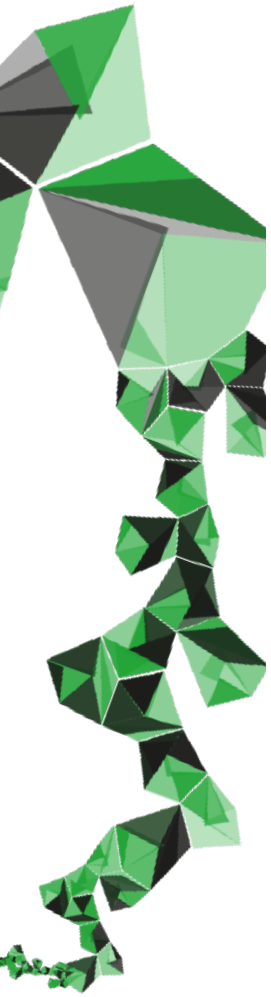

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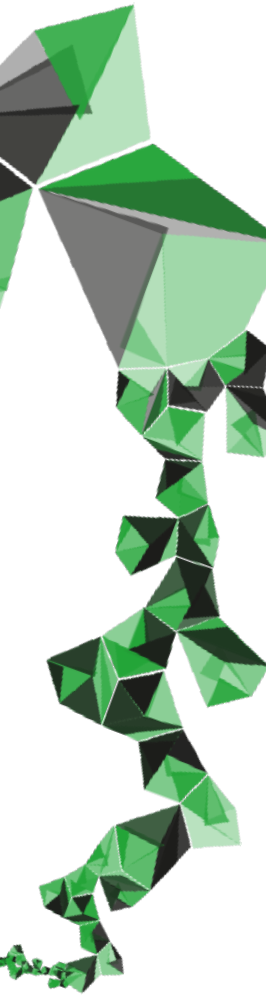

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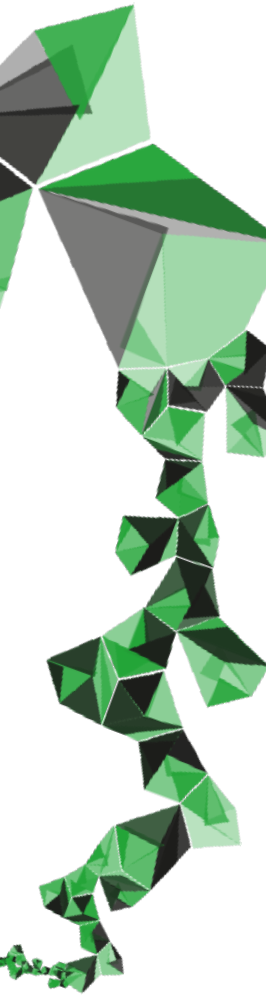

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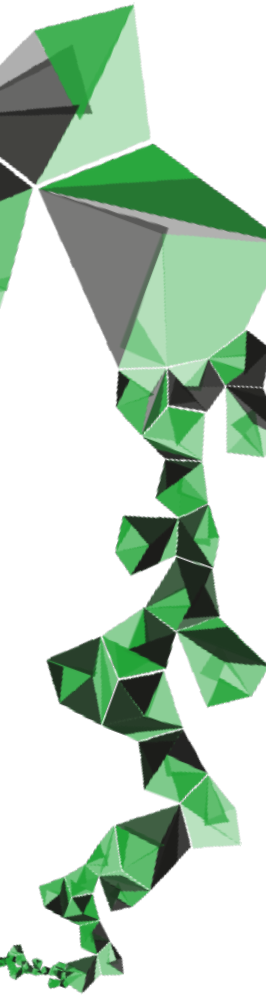

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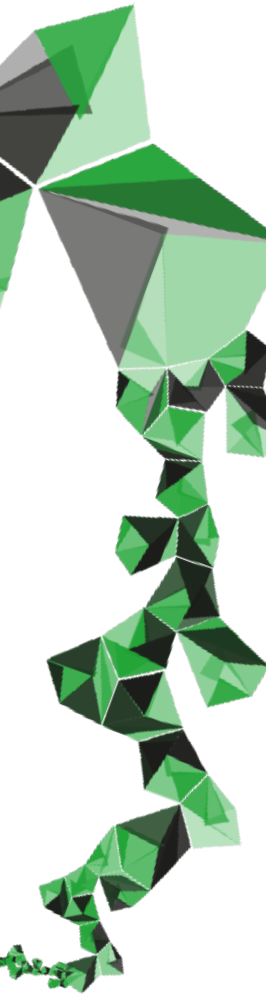

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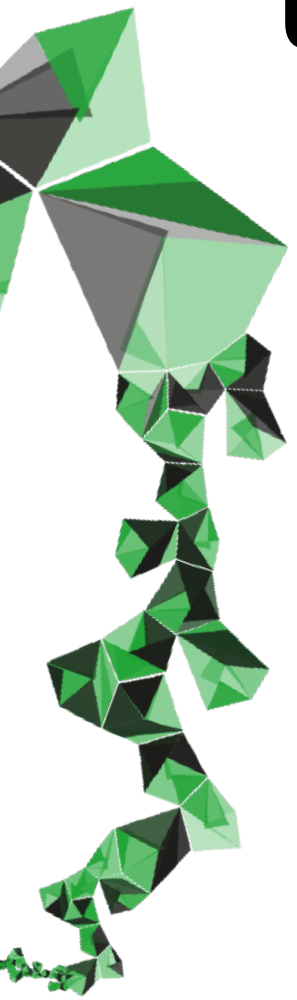
- Irony: DNSSEC's large responses help facilitate this attack on non-validating DNS resolvers

CONSEQUENCE: AVOID FRAGMENTATION!



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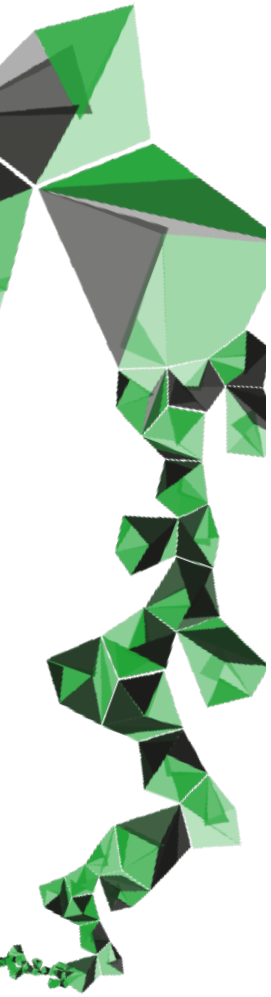

- The DNS community wants to avoid fragmentation

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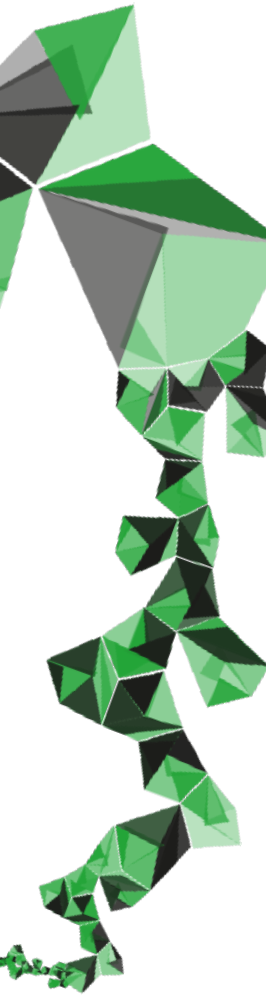

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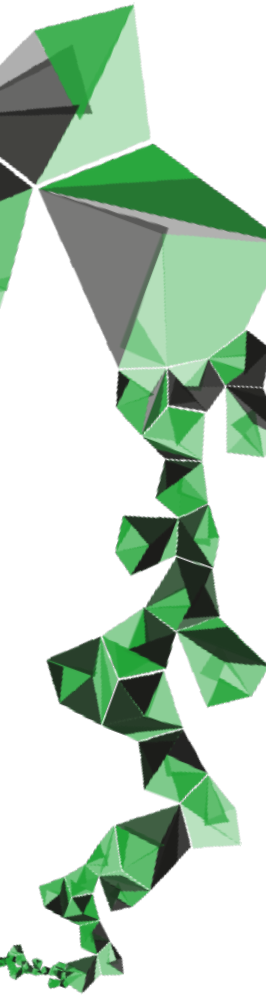

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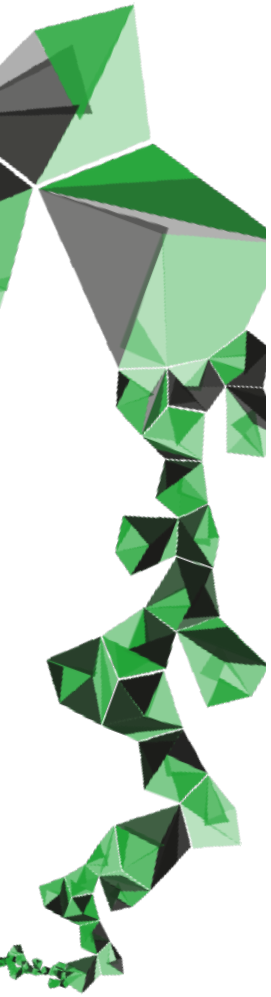

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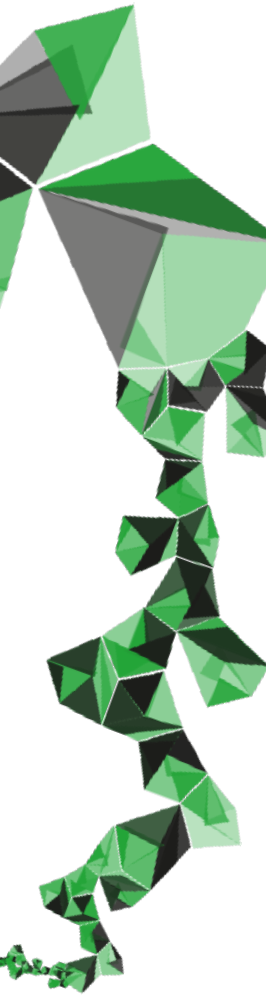

- The DNS community wants to avoid fragmentation
- Three strategies:
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  - Different cryptographic algorithms (ECC)
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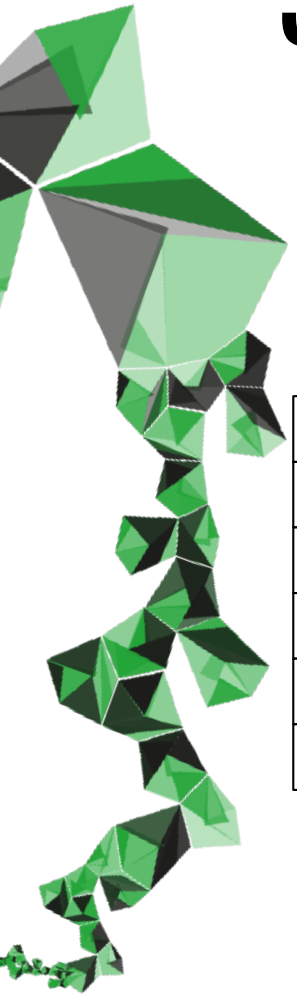
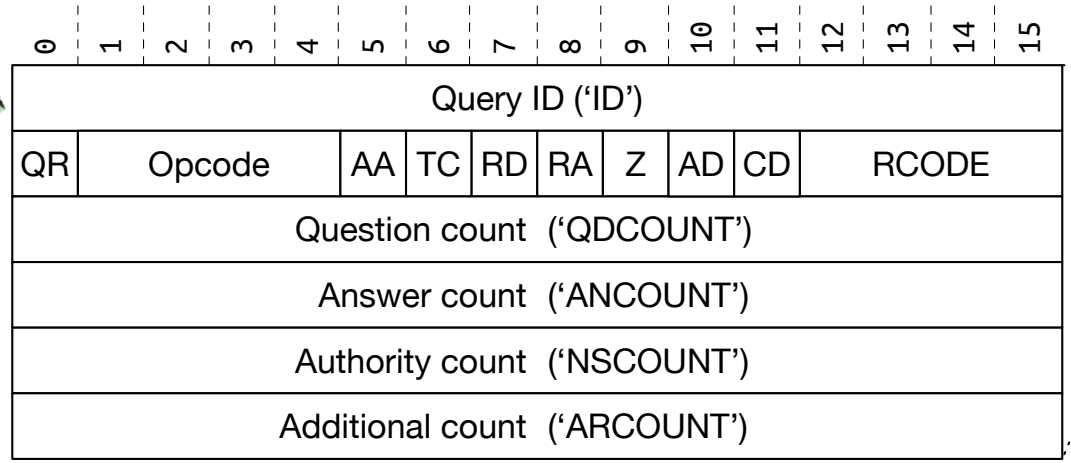
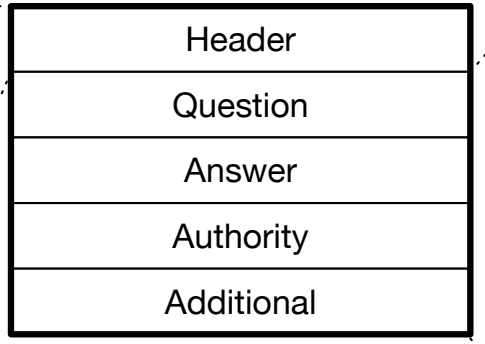
  - Collaborate on EDNS0 parameters that avoid fragmentation
    DNS Flag Day (discussed later)

STRIPPING OPTIONAL RECORDS





DNS message header



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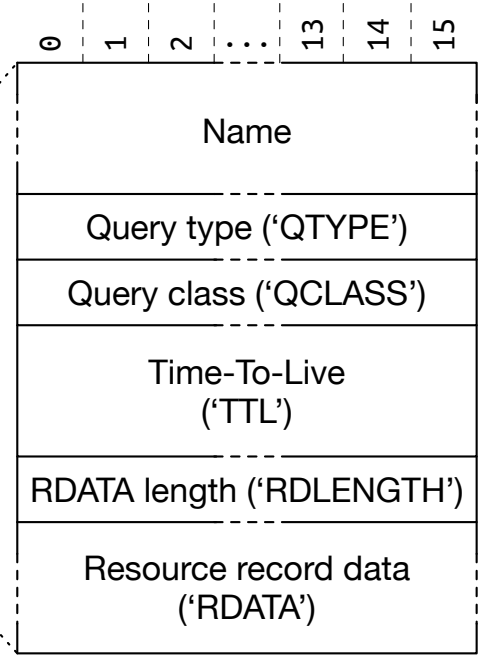

DNS message body

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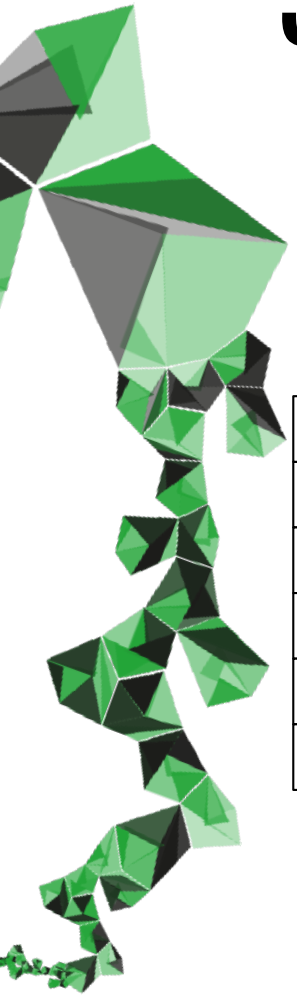

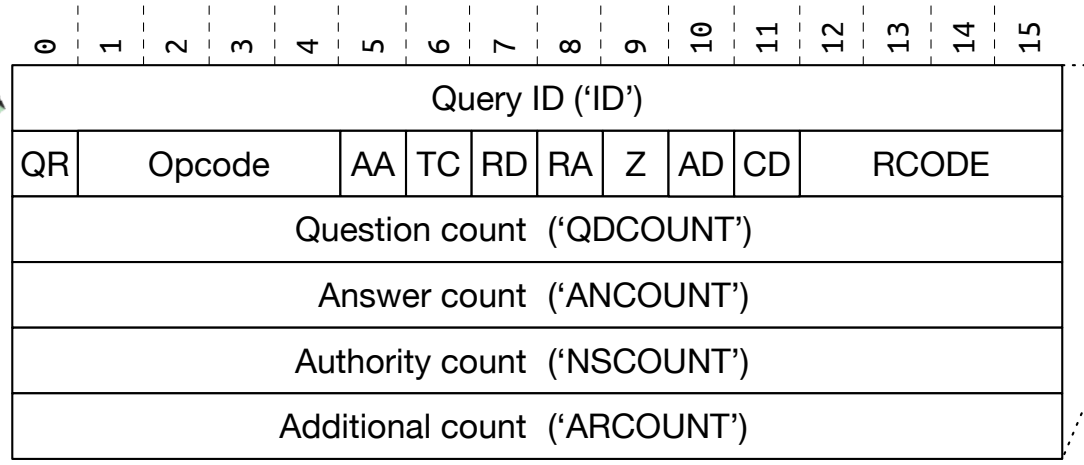

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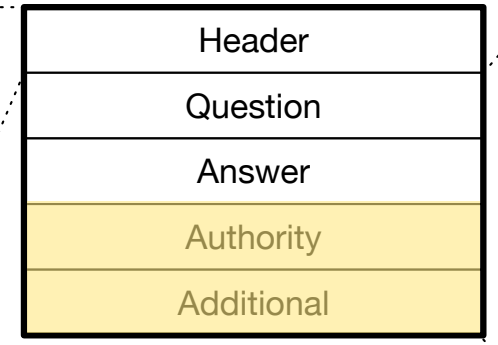

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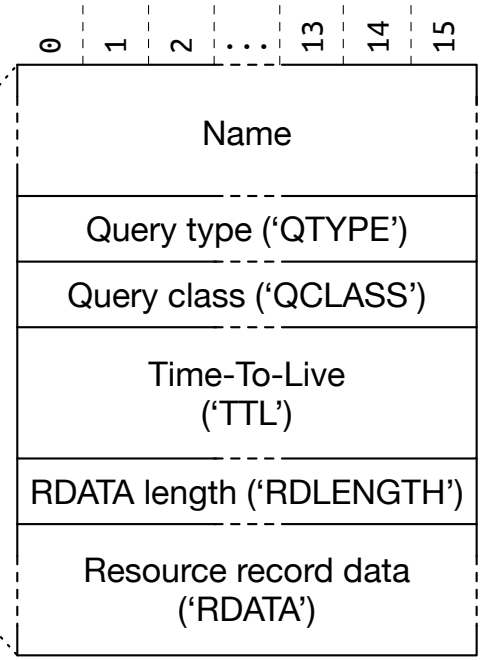

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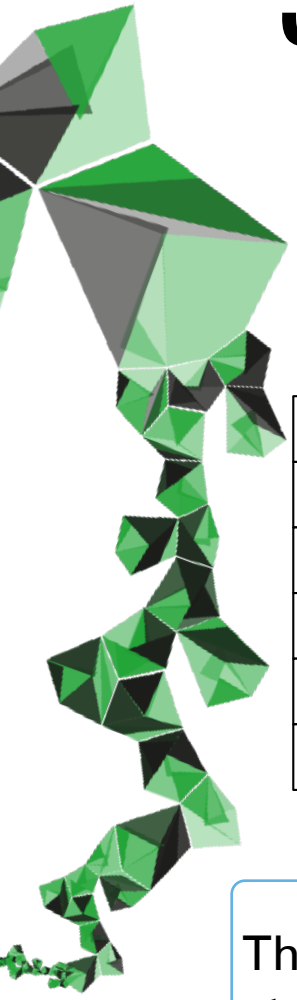

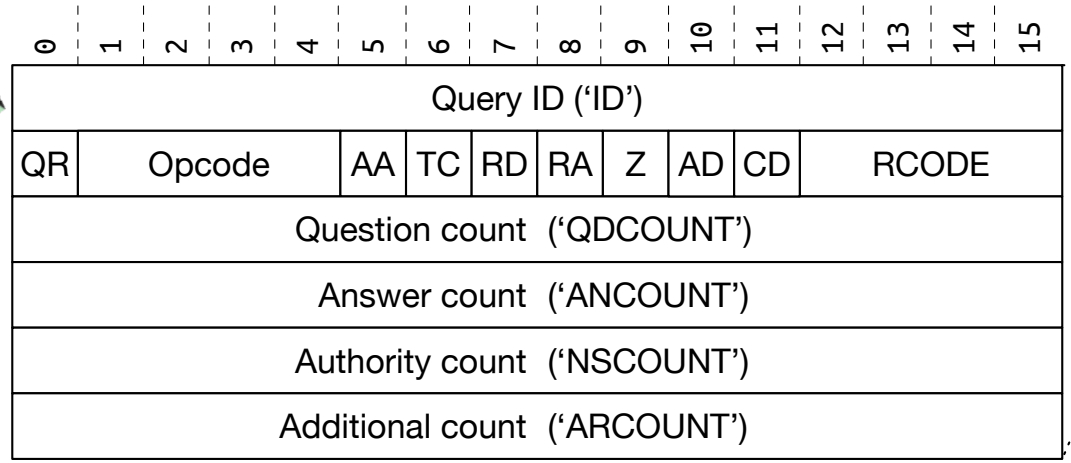

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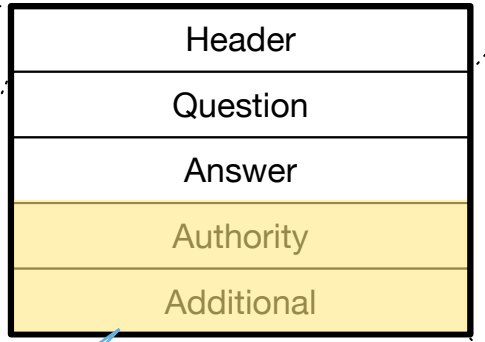

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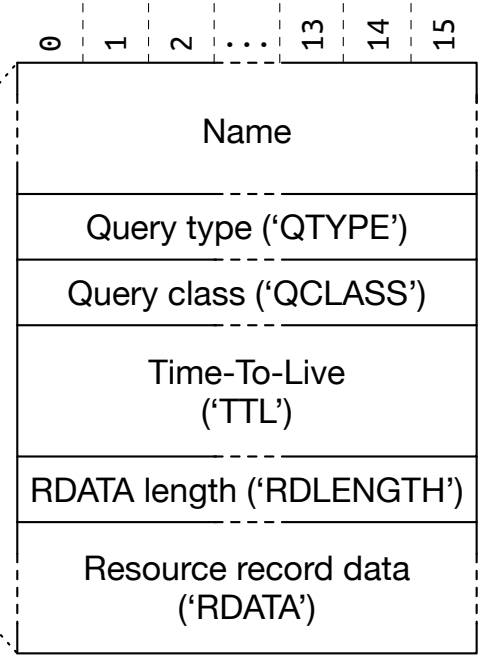

DNS message body

These sections are optional in many responses, stripping them reduces fragmentation significantly, as it removes records *and* signatures

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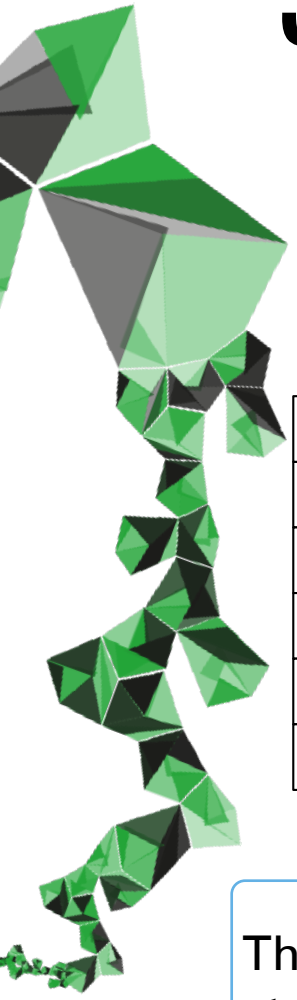

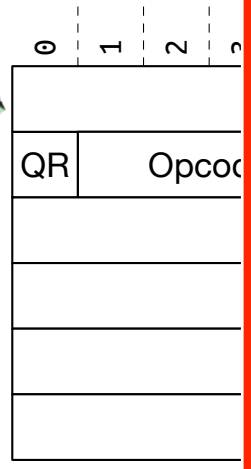

These sectio
stripping the
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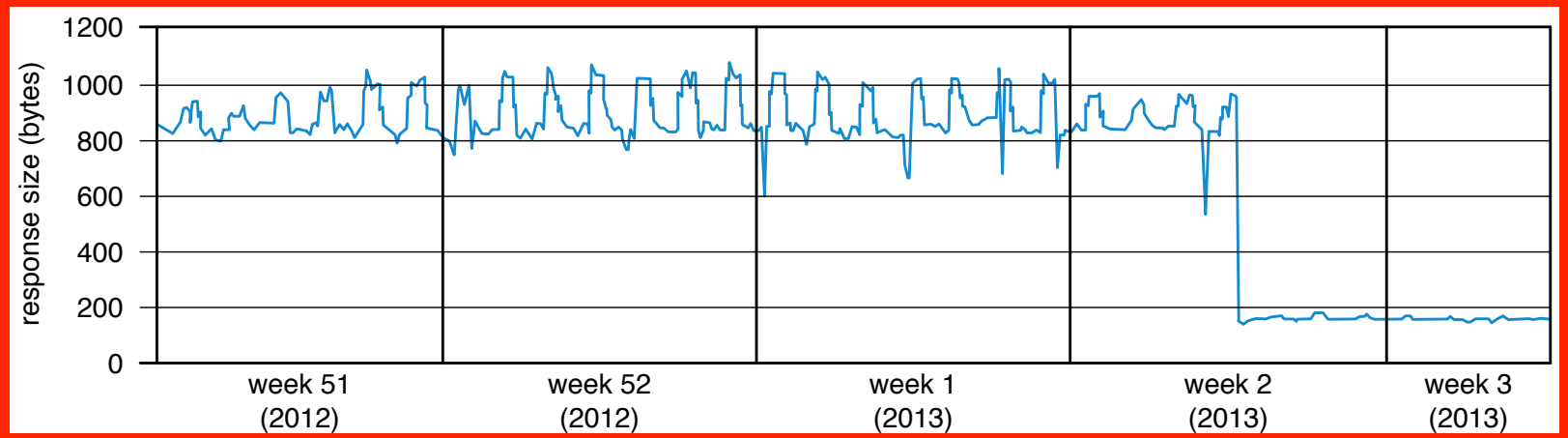
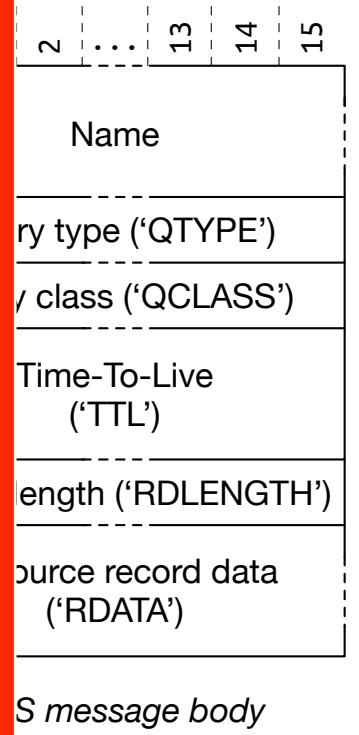
Stripping these records vastly reduces response sizes



But there is also a performance impact
(that is not well understood)



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SWITCHING TO ELLIPTIC CURVE CRYPTO

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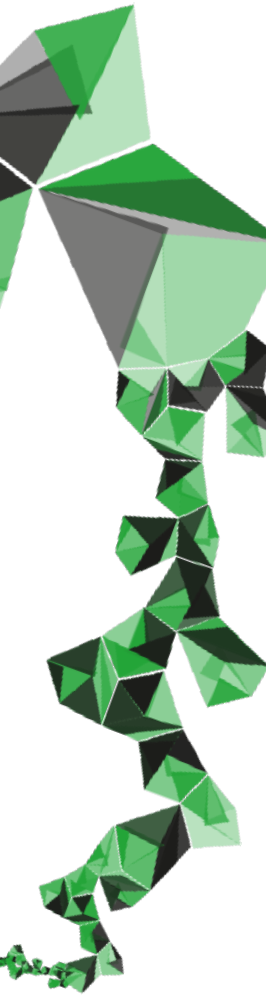

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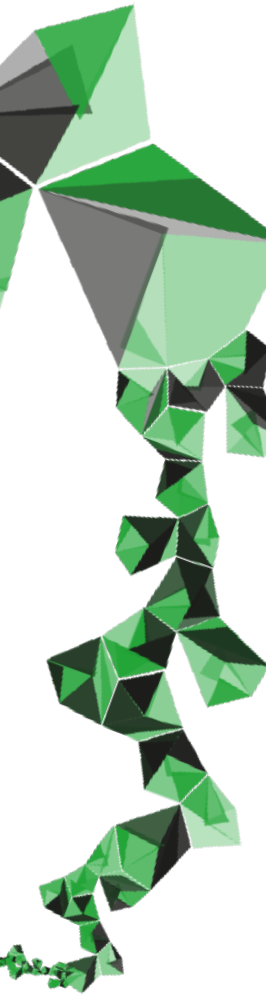

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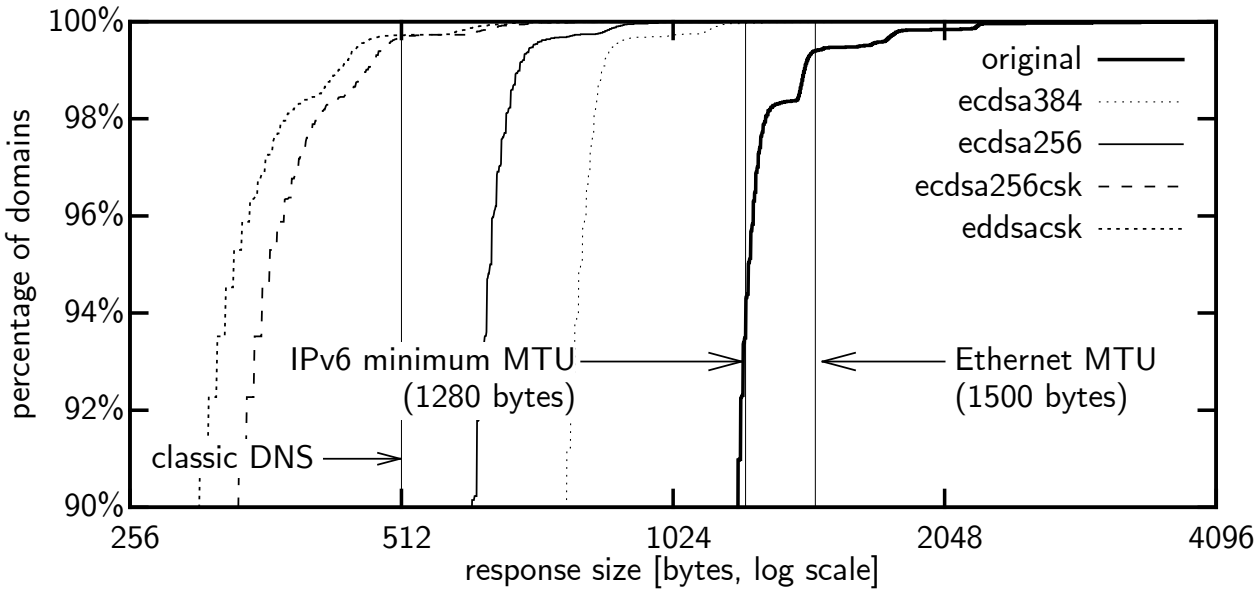

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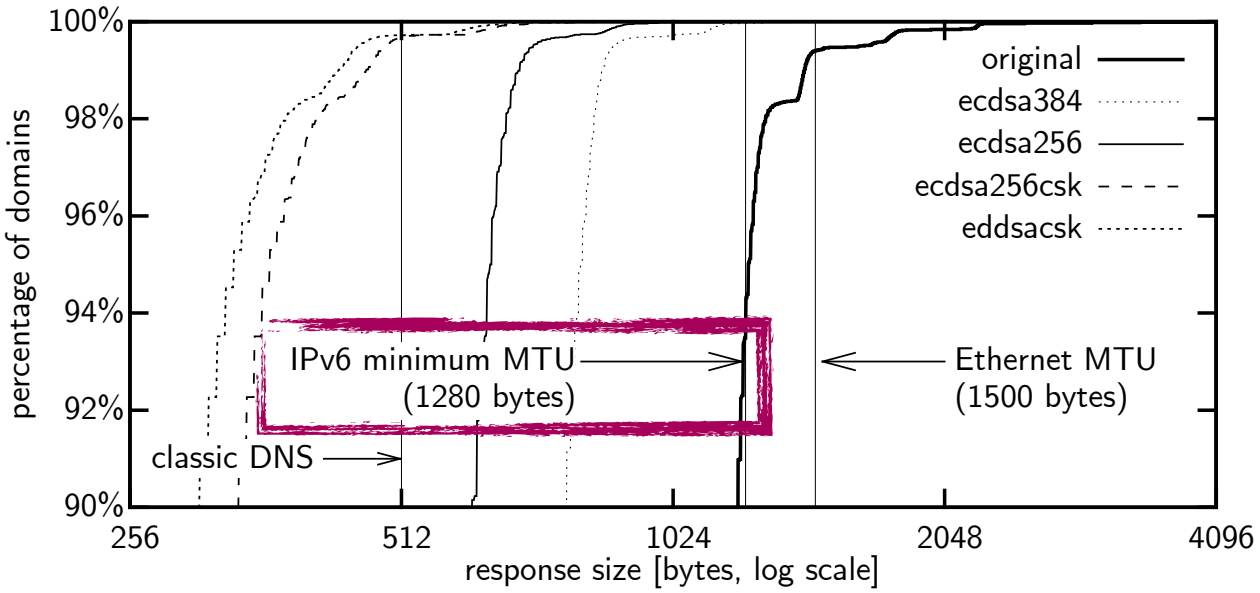

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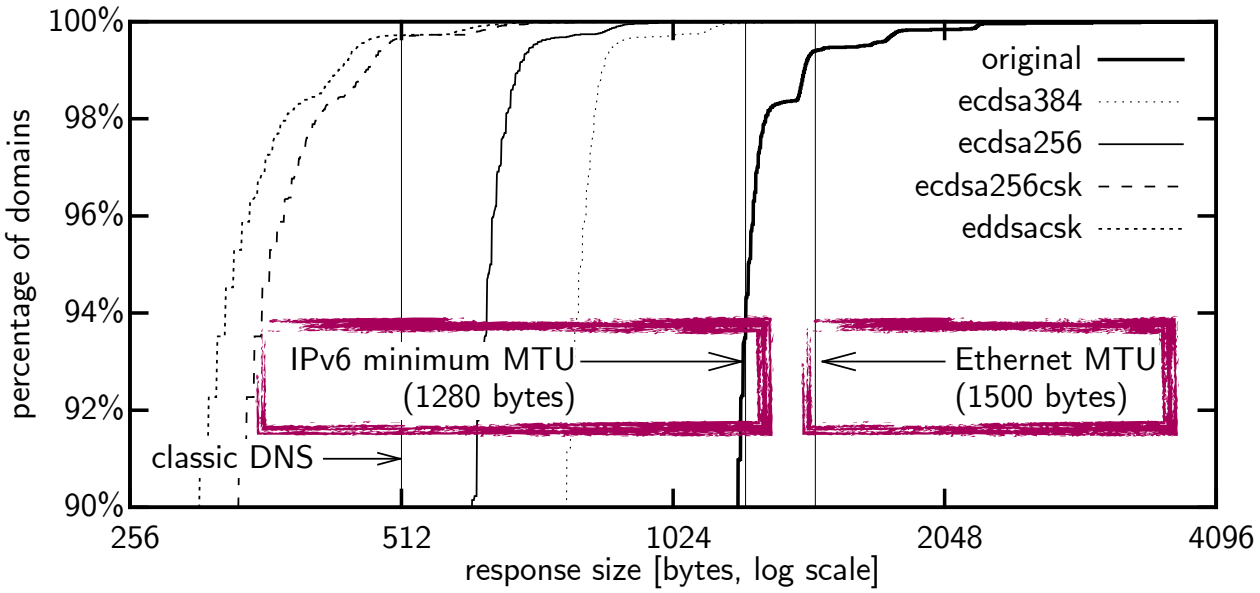

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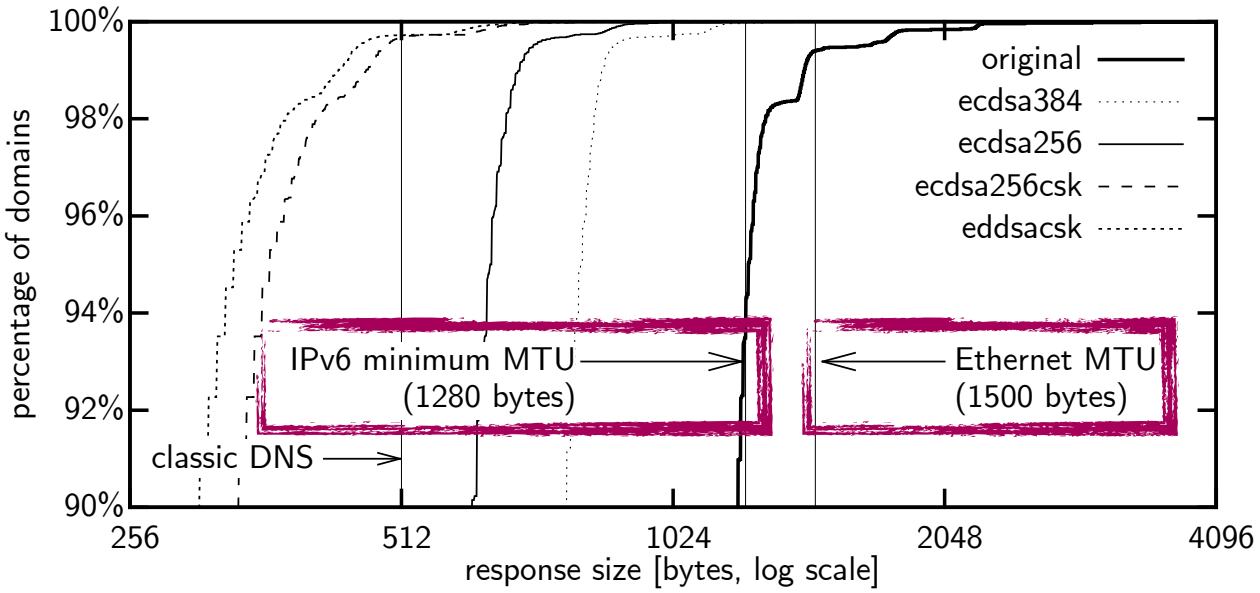

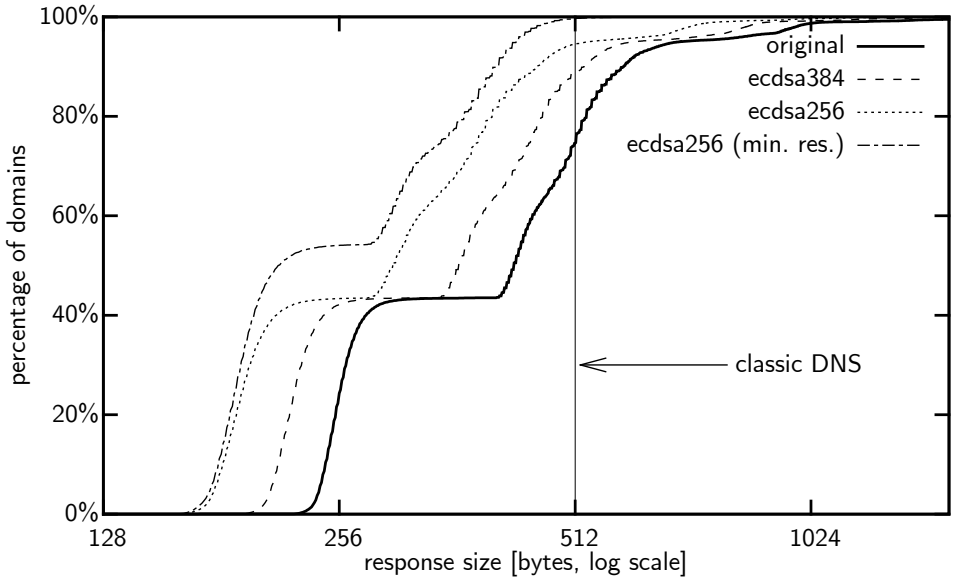

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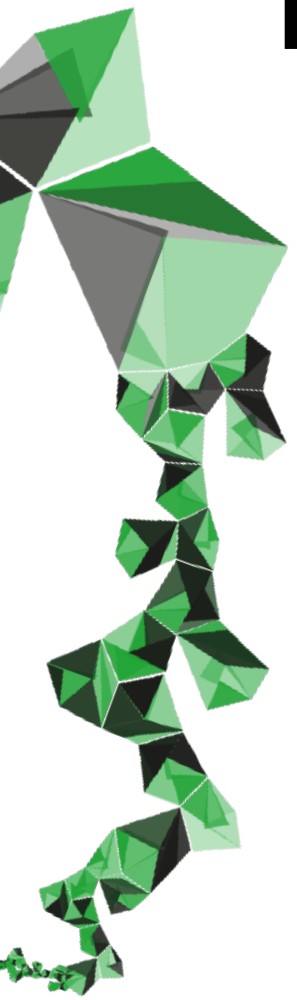
ECC CHALLENGE: VALIDATION SPEED



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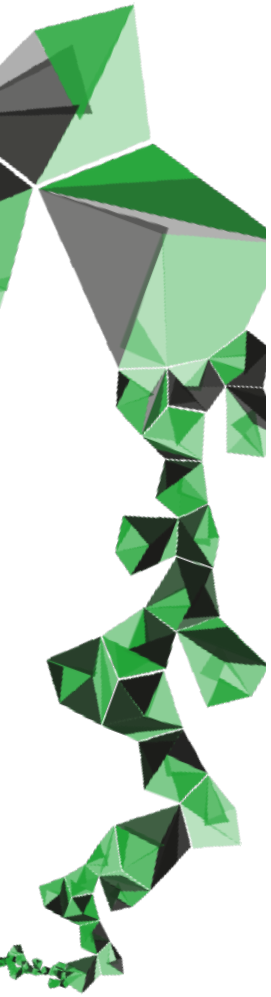

- ECC signature verification is much slower than RSA

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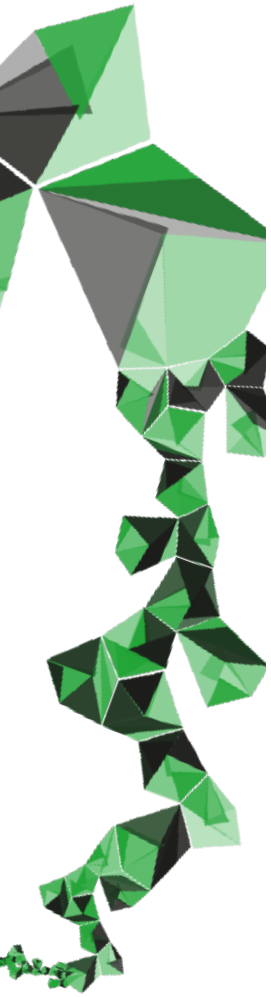

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- Verification occurs way more frequently than signing in DNSSEC → *what is the impact on operations?*

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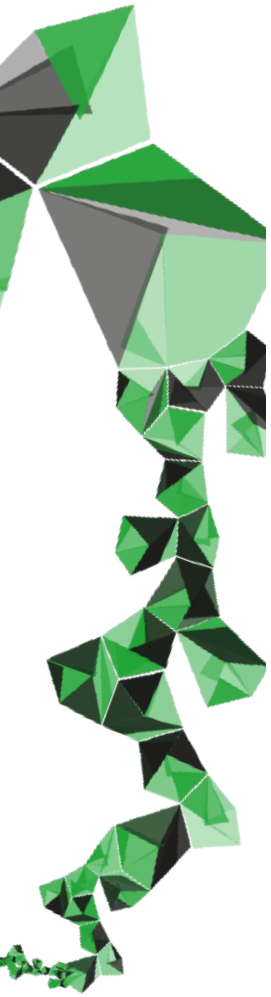

- ECC signature verification is much slower than RSA
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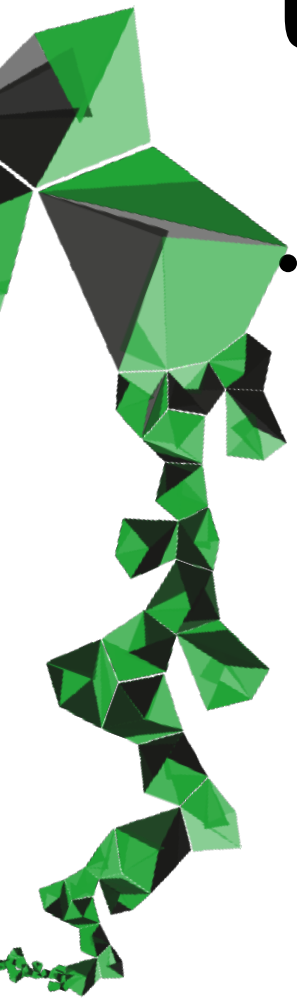
ECC algorithm	OpenSSL version†	Compared to⋆			
		RSA		ECDSA	
		1024	2048	P-256	P-384
ECDSA P-256	0.9.8zh	27.5	8.4	-	-
	1.0.1f	26.0	7.9	-	-
	1.0.2e	11.5	3.6	-	-
ECDSA P-384	0.9.8zh	57.7	17.6	-	-
	1.0.1f	77.6	23.4	-	-
	1.0.2e	87.3	27.2	-	-
Ed25519	(1.0.2e)‡	7.9	2.5	0.7	0.1
Ed448	(1.0.2e)‡	23.4	7.3	2.0	0.3

⋆the number means that the ECC algorithm is x times *slower*
†comparison of the ECC and RSA primitives for this OpenSSL version
‡independent implementations compared to this OpenSSL version

OPERATIONAL IMPACT



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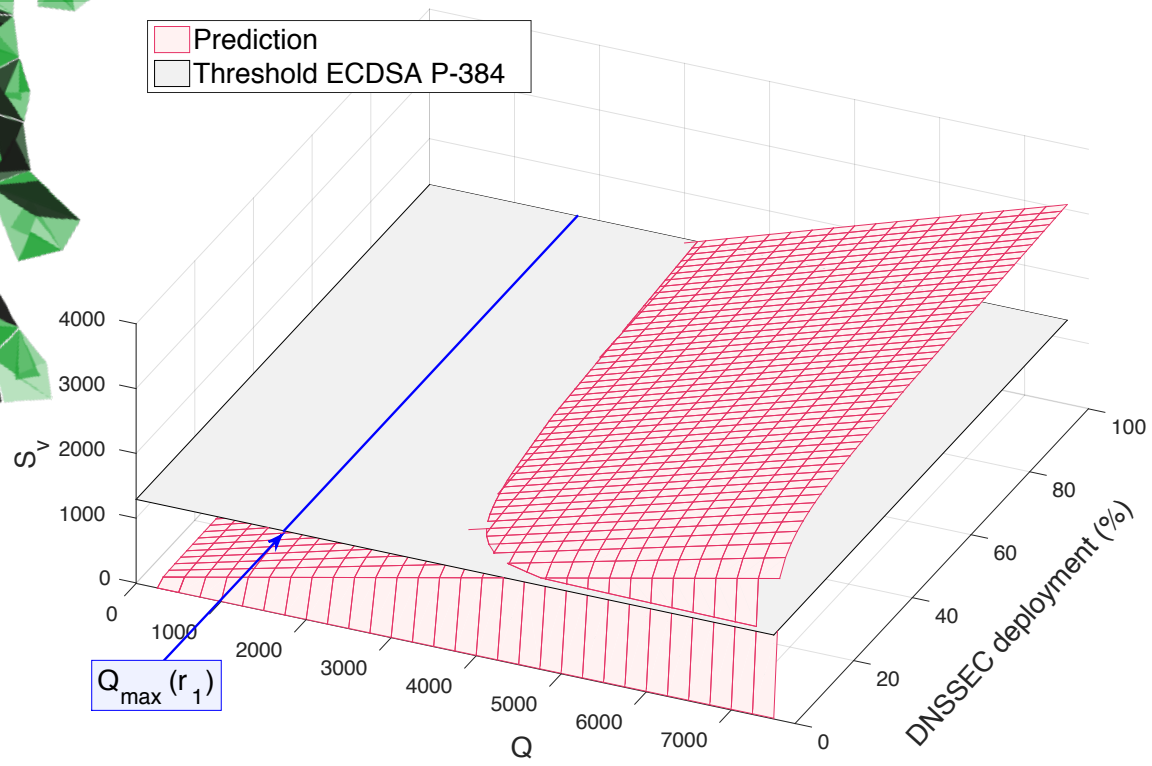

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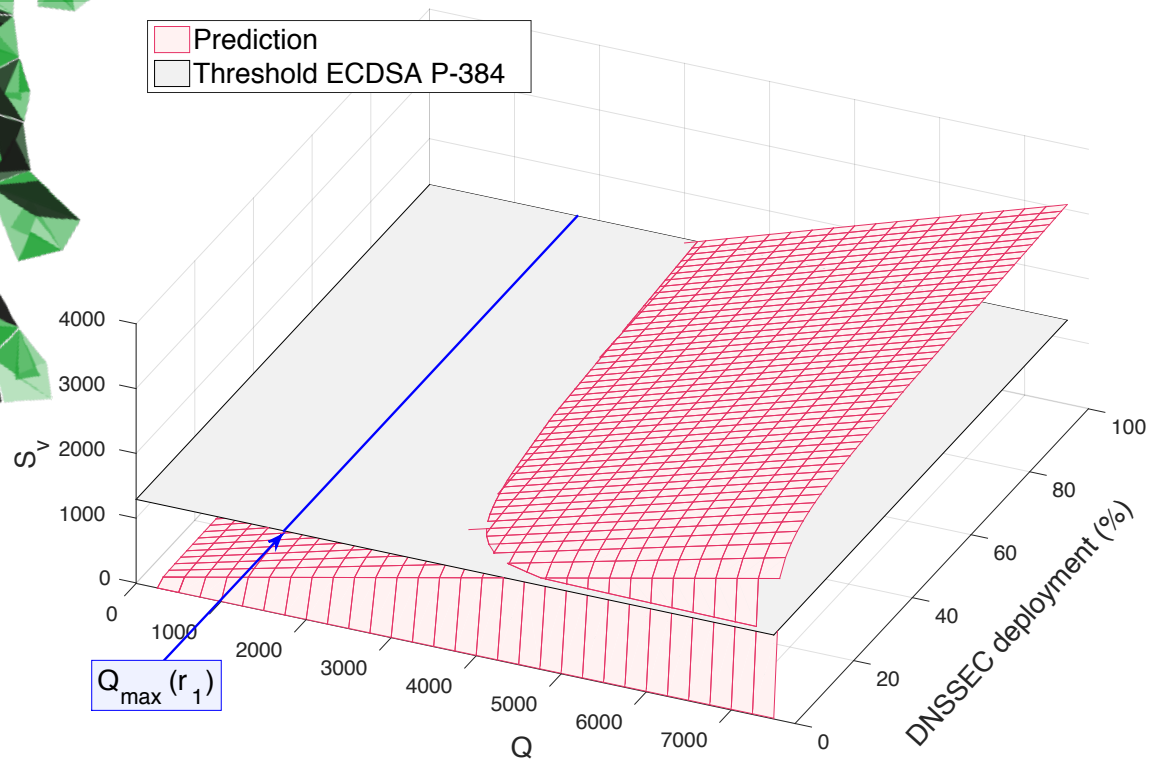
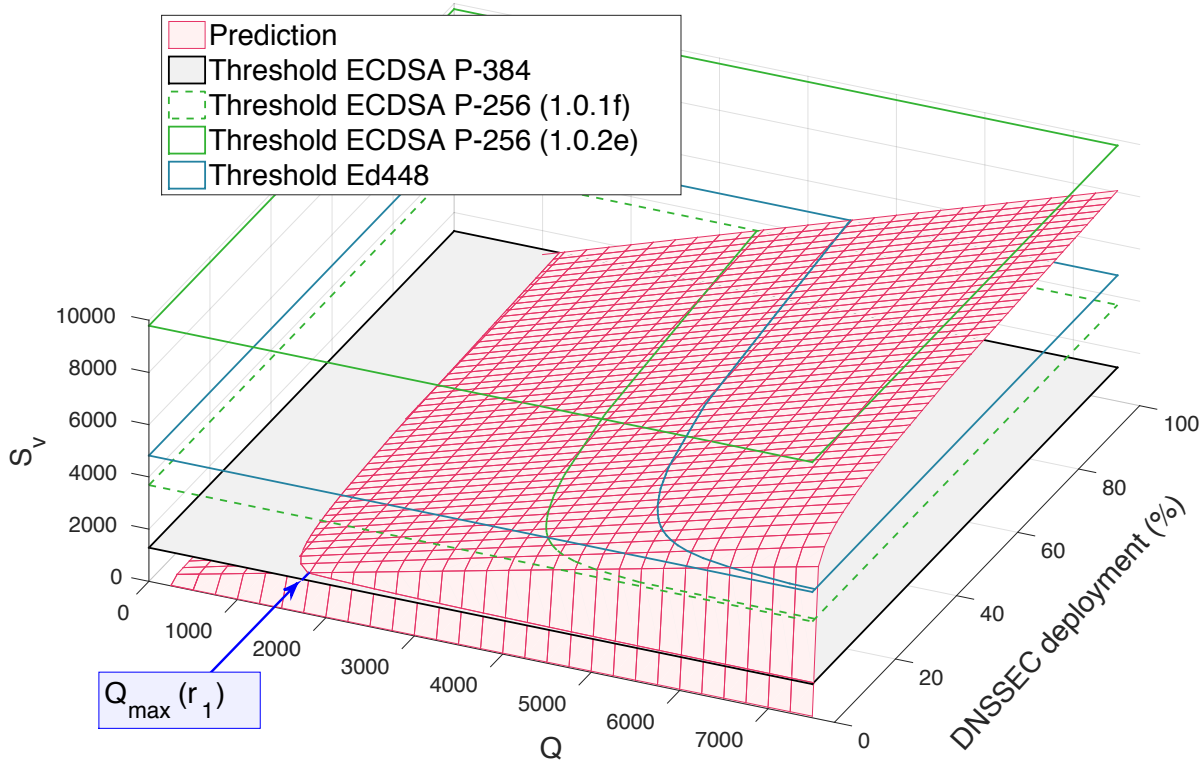
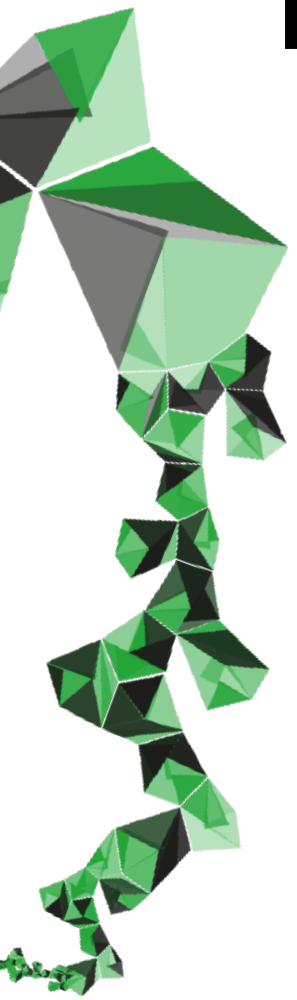




DNS FLAG DAY 2020



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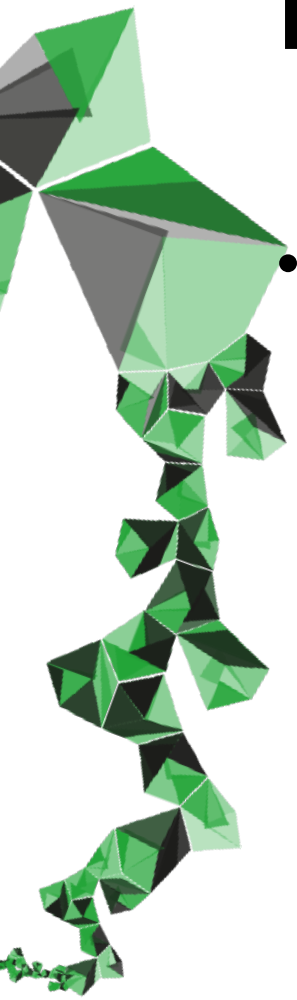

- Due to the operational problems with fragmentation, DNS vendors decided to work together

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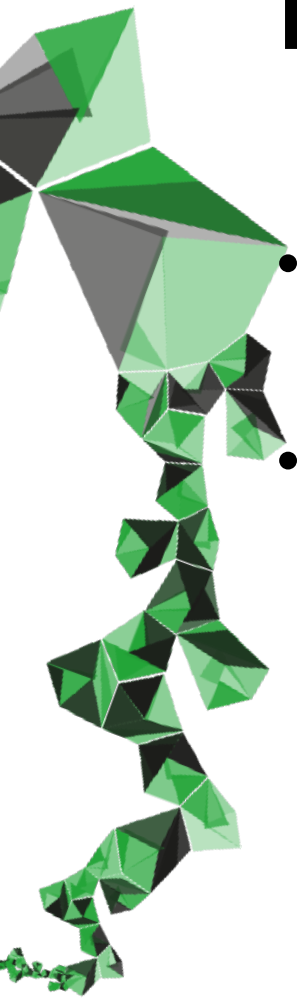

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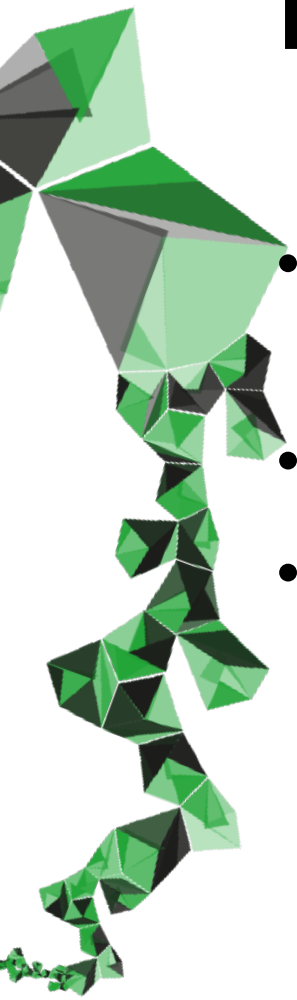

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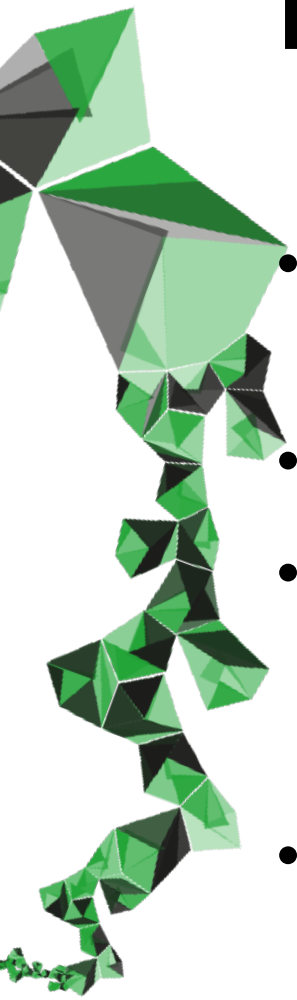

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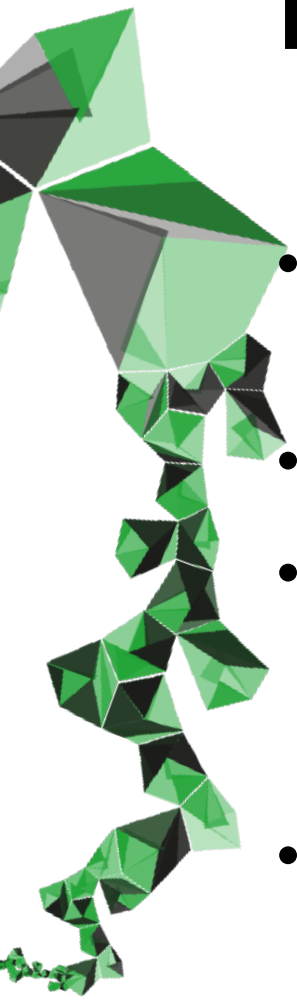

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- Fallback to TCP otherwise

TAKEAWAYS UNTIL NOW

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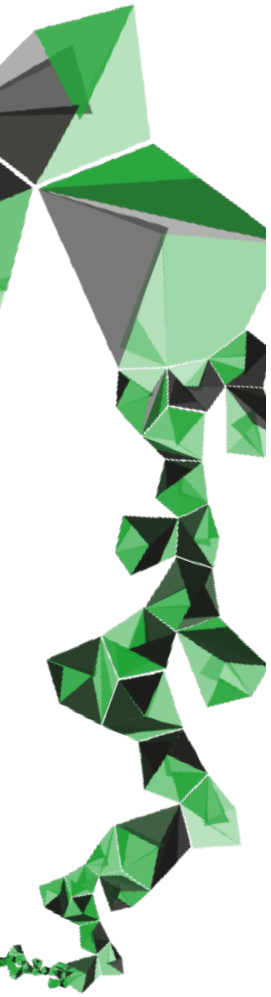

- DNSSEC increases the size of DNS messages

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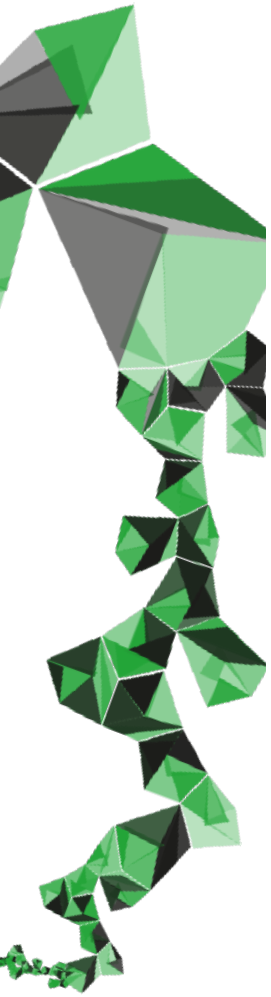

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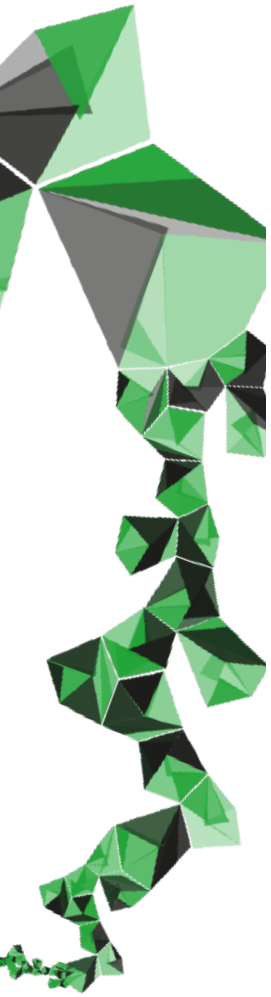

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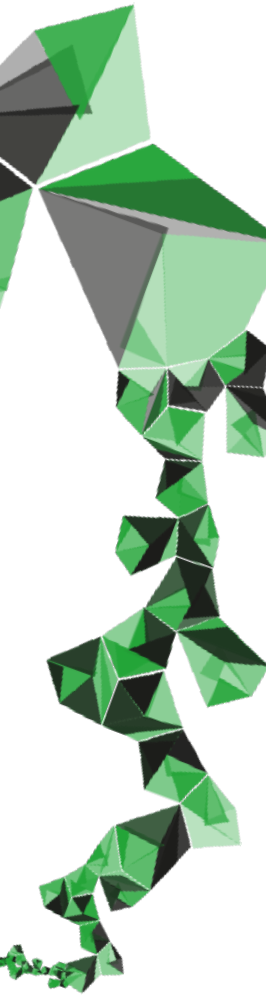

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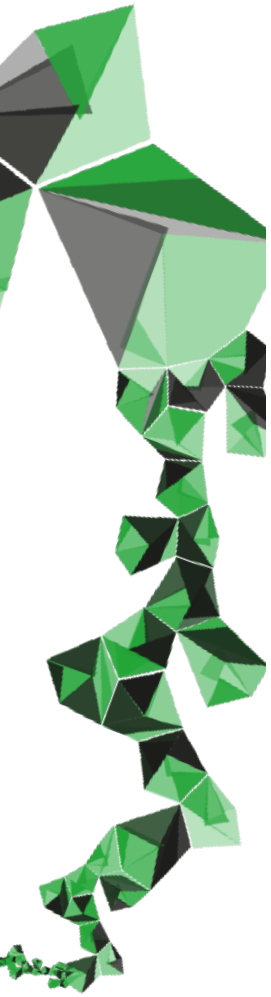

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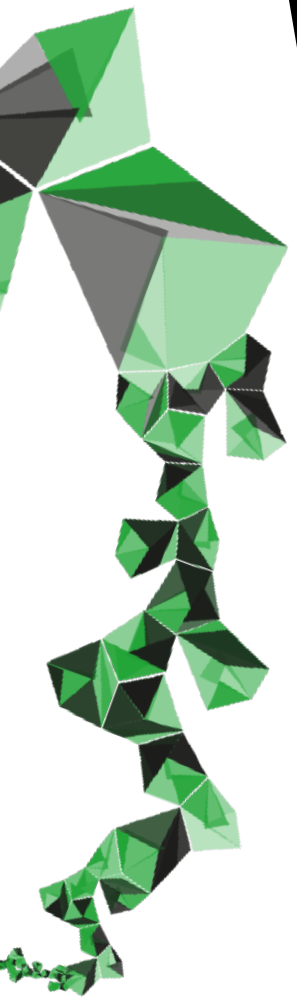
- **Consequence: a switch to quantum-safe algorithms has to take this mindset into account**

WHAT ABOUT PQC IN DNSSEC?



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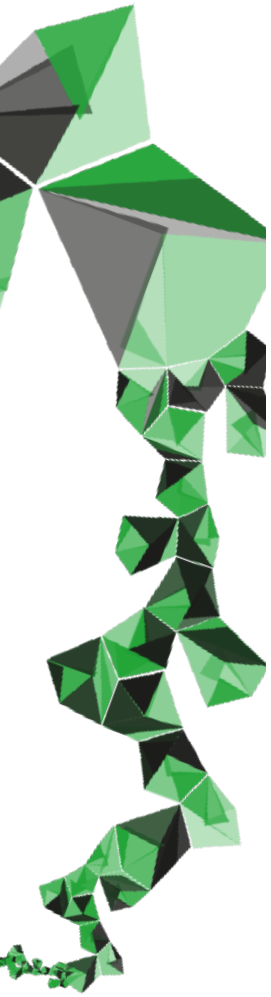

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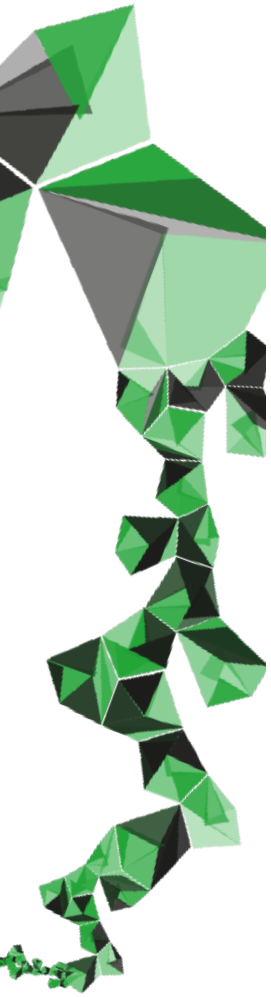

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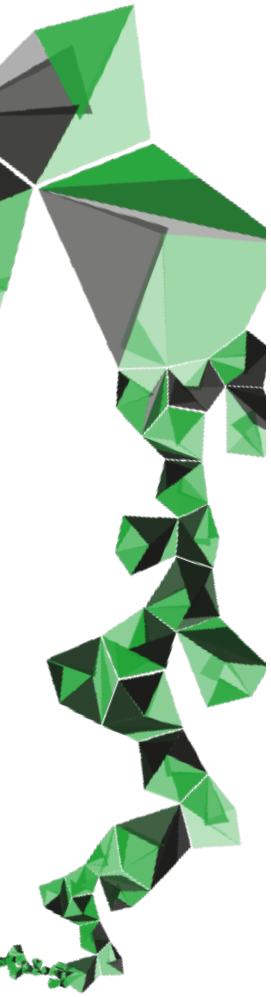

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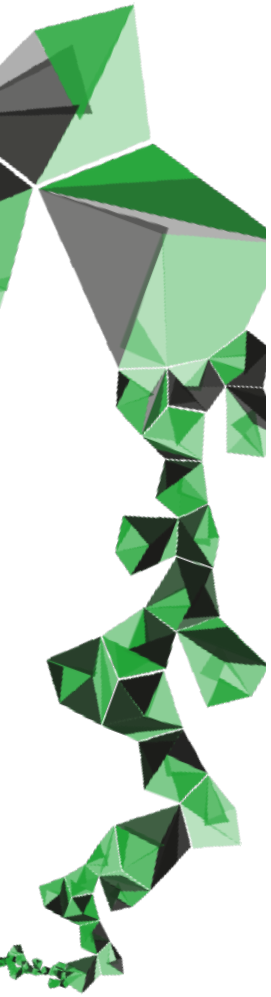
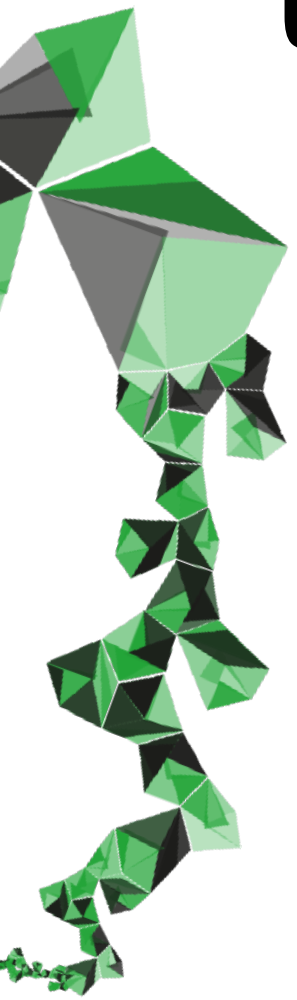


- I hope I convinced you signature size, public key size and verification speed are an issue
- Dealing with larger signatures or keys may be unavoidable
- Higher computational load for verification should be avoided
- We need to balance out any changes in favour of a lower workload for DNS resolvers

GREEN, ORANGE AND RED LINES



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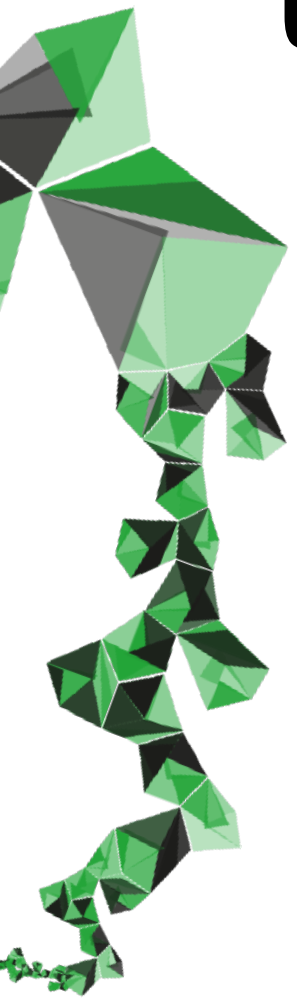

Signature size

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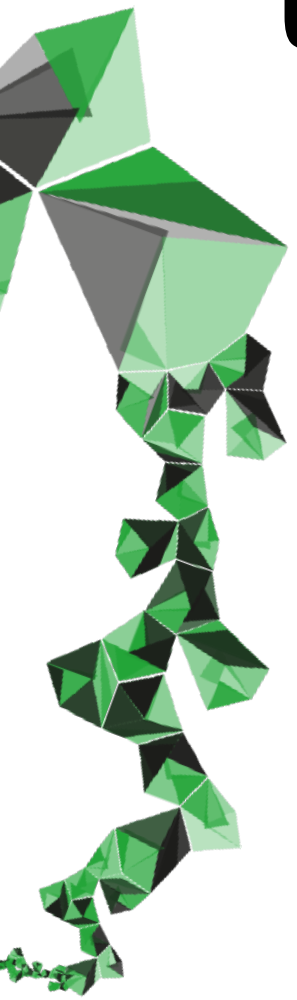

Signature size	≤ RSA 2048

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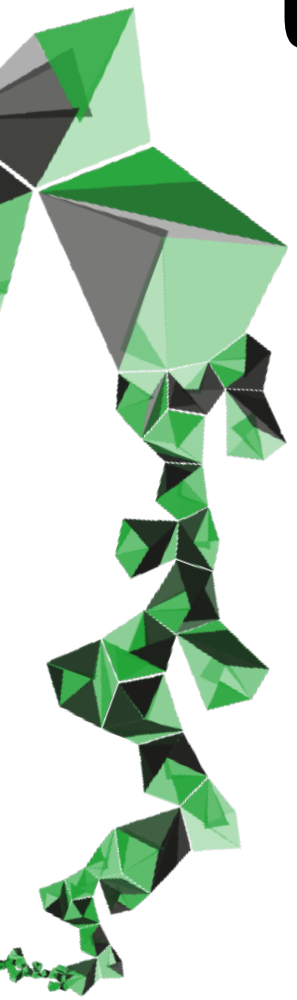

Signature size	≤ RSA 2048	≤ RSA 4096

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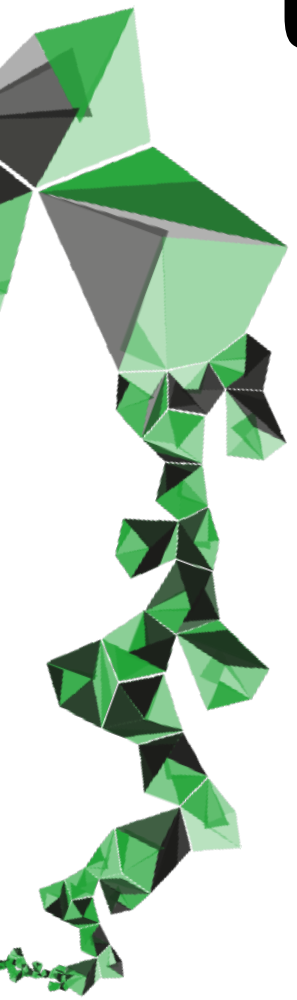

Signature size	≤ RSA 2048	≤ RSA 4096	≥ RSA 4096

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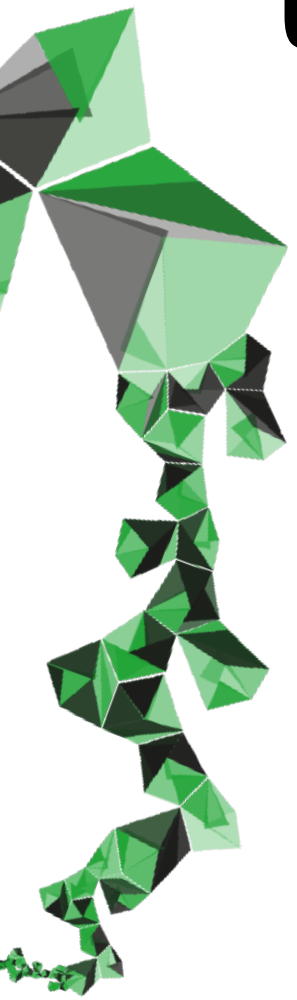

Signature size	≤ RSA 2048	≤ RSA 4096	≥ RSA 4096
Public key size			

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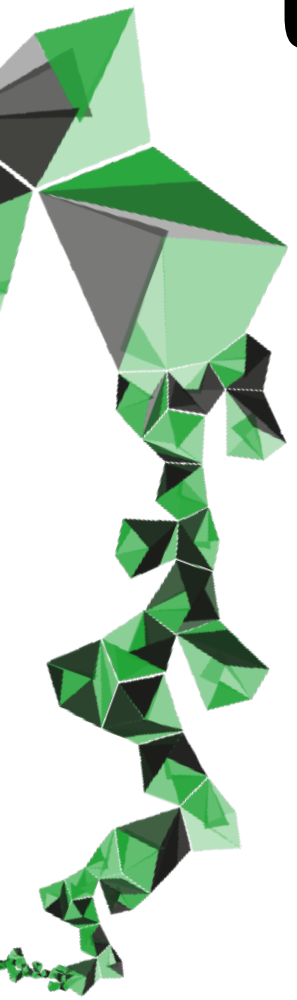

Signature size	≤ RSA 2048	≤ RSA 4096	≥ RSA 4096
Public key size	≤ RSA 2048		

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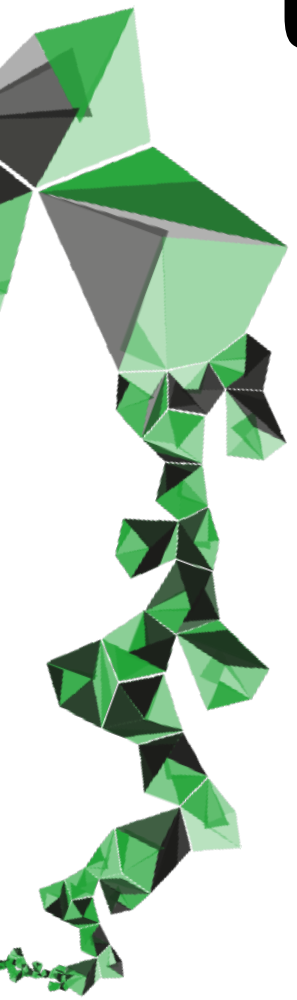

Signature size	≤ RSA 2048	≤ RSA 4096	≥ RSA 4096
Public key size	≤ RSA 2048	≤ RSA 4096	

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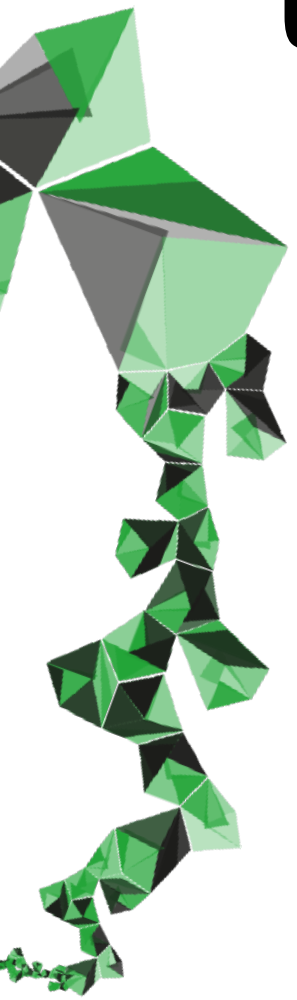

Signature size	≤ RSA 2048	≤ RSA 4096	≥ RSA 4096
Public key size	≤ RSA 2048	≤ RSA 4096	≥ 1 MByte*

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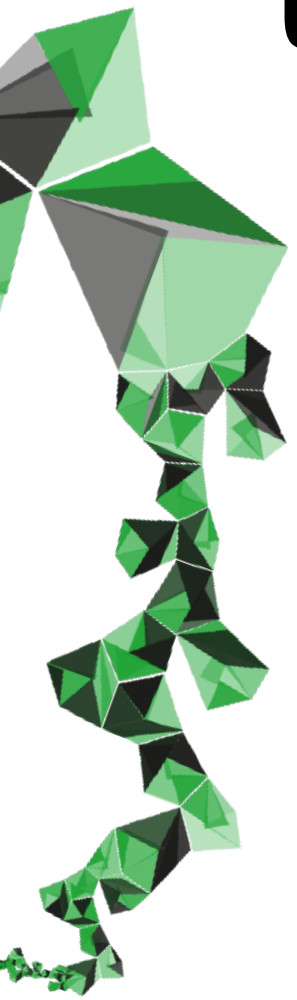

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Signing speed *(single CPU core)*			

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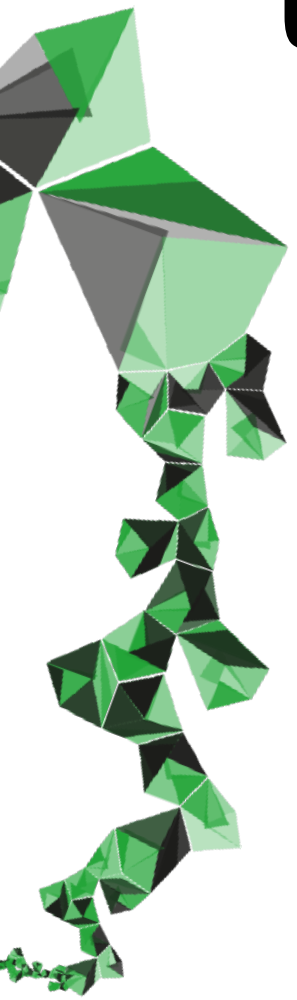

Signature size	≤ RSA 2048	≤ RSA 4096	≥ RSA 4096
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Signing speed *(single CPU core)*	≤ RSA 2048		

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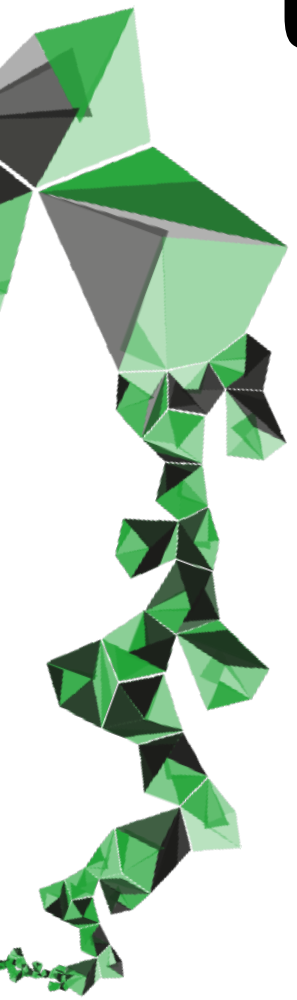

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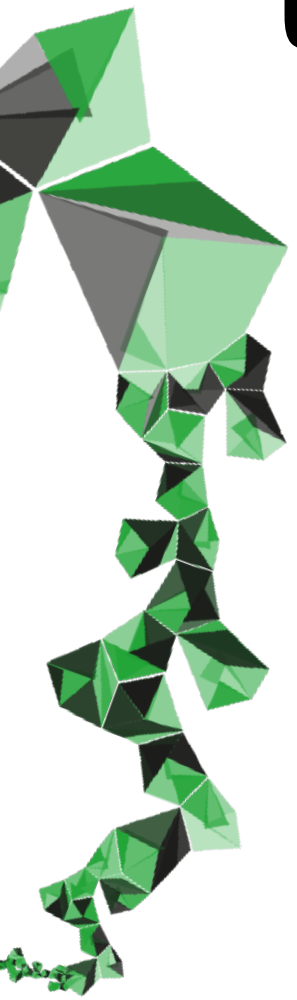

Signature size	≤ RSA 2048	≤ RSA 4096	≥ RSA 4096
Public key size	≤ RSA 2048	≤ RSA 4096	≥ 1 MByte*
Signing speed *(single CPU core)*	≤ RSA 2048	≤ RSA 4096	≥ 50ms*

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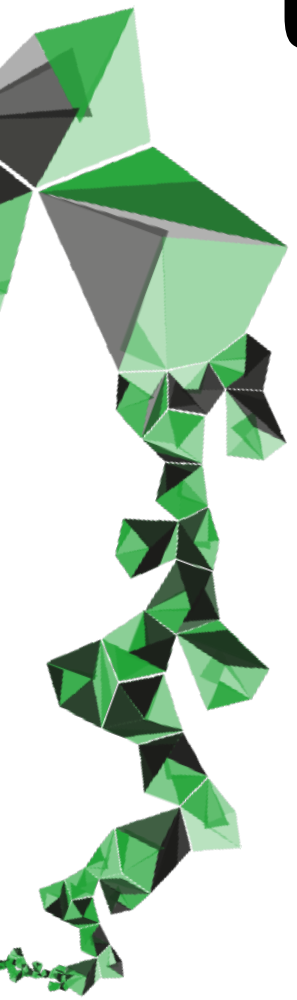

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Validation speed *(single CPU core)*			

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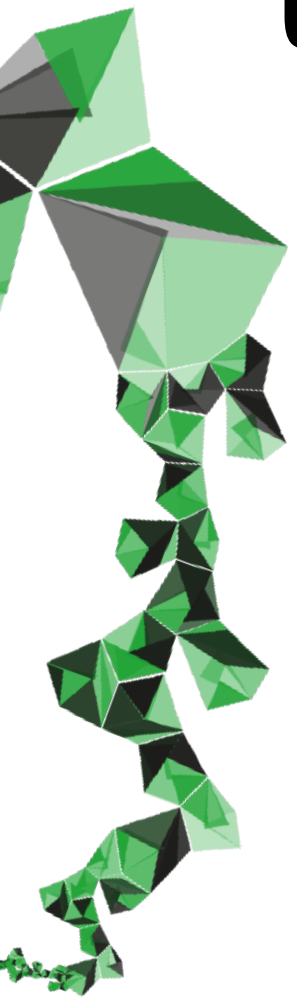

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Validation speed *(single CPU core)*	≤ ECDSA P-256		

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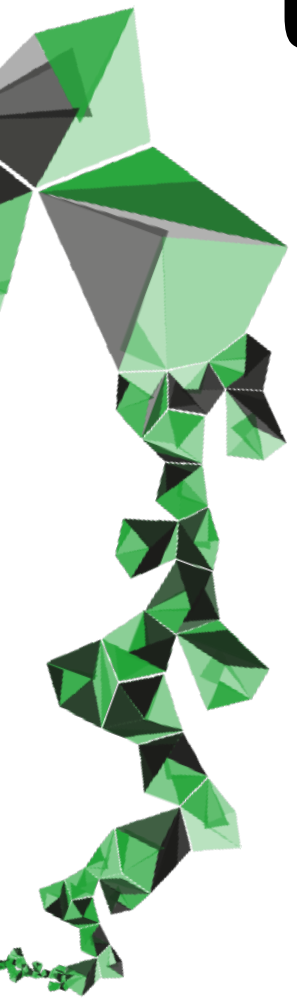

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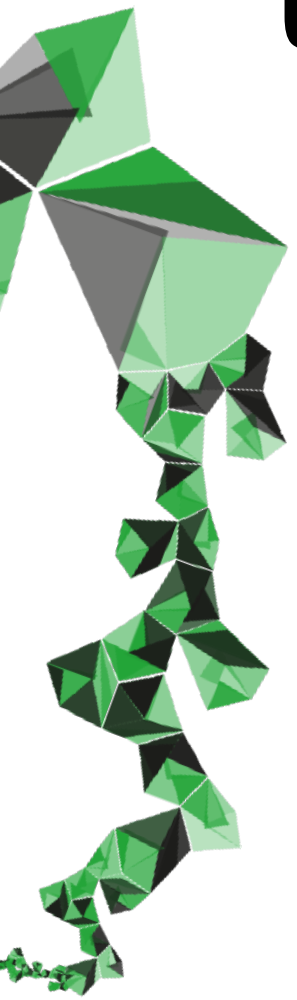
Validation speed *(single CPU core)*	≤ ECDSA P-256	≤ ECDSA P-384	

GREEN, ORANGE AND RED LINES



Signature size	≤ RSA 2048	≤ RSA 4096	≥ RSA 4096
Public key size	≤ RSA 2048	≤ RSA 4096	≥ 1 MByte*
Signing speed *(single CPU core)*	≤ RSA 2048	≤ RSA 4096	≥ 50ms*
Validation speed *(single CPU core)*	≤ ECDSA P-256	≤ ECDSA P-384	≥ ECDSA P-384

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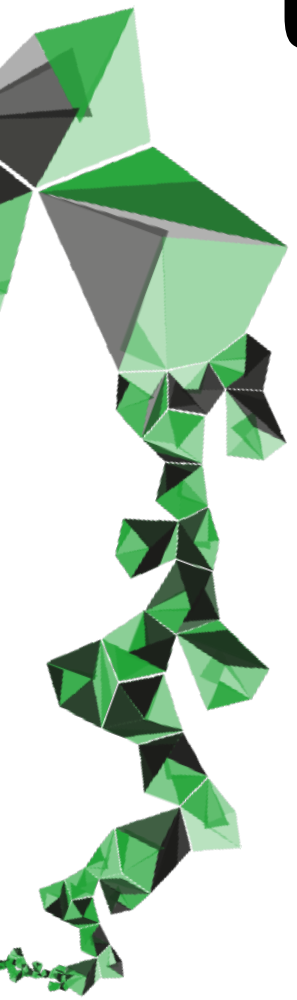

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Other restrictions			

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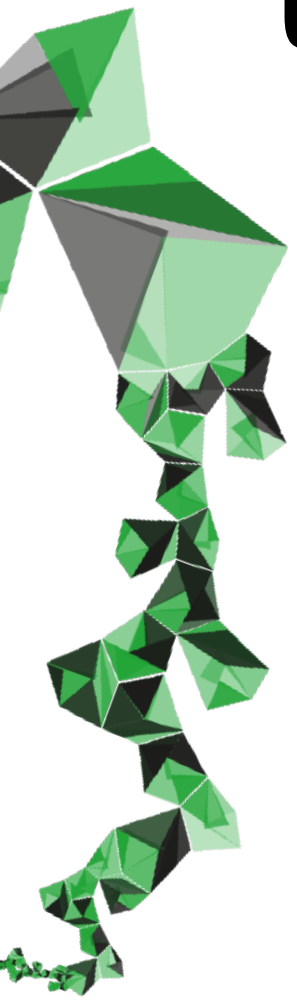

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Other restrictions		Stateful signing	

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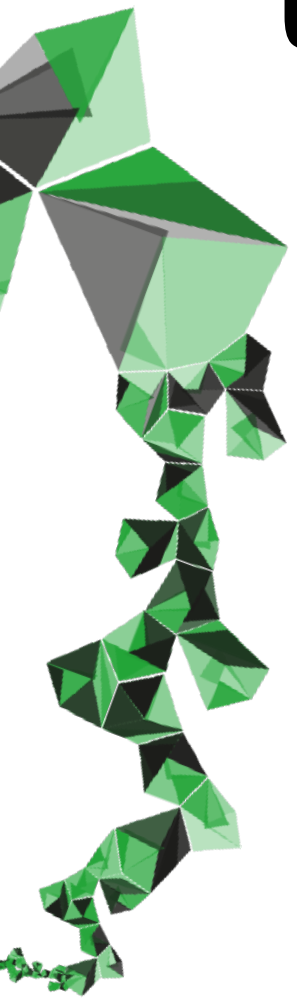

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Validation speed *(single CPU core)*	≤ ECDSA P-256	≤ ECDSA P-384	≥ ECDSA P-384
Other restrictions		Stateful signing	Specialised hardware

STUDY OF NIST ROUND 3 ENTRIES

Prio	Requirement	Good	Accepted Conditionally
#1	Signature Size	$\leq$ 1,232 bytes	—
#2	Validation Speed	$\geq$ 1,000 sig/s	—
#3	Key Size	$\leq$ 64 kilobytes	$>$ 64 kilobytes
#4	Signing Speed	$\geq$ 100 sig/s	—

SUITABLE ROUND 3 ALGORITHMS

Algorithm	NIST Verdict	Approach	Private key	Public key	Signature	Sign/s	Verify/s
Crystals-Dilithium-II [29]	Finalist	Lattice	2.8kB	1.2kB	2.0kB		
Falcon-512 [31]	Finalist	Lattice	57kB	0.9kB	0.7kB	3,307	20,228
Rainbow-I_a [56]	Finalist	Multivariate	101kB	158kB	66B	8,332	11,065
RedGeMSS128 [16]	Candidate	Multivariate	16B	375kB	35B	545	10,365
Sphincs$^+$-Haraka-128s [11]	Candidate	Hash	64B	32B	8kB		
Picnic-L1-FS [17]	Candidate	Hash	16B	32B	34kB		
Picnic2-L1-FS [17]	Candidate	Hash	16B	32B	14kB		
EdDSA-Ed22519 [12]		Elliptic curve	64B	32B	64B	25,935	7,954
ECDSA-P256 [12]		Elliptic curve	96B	64B	64B	40,509	13,078
RSA-2048 [12]		Prime	2kB	0.3kB	0.3kB	1,485	49,367

TAKEAWAYS NIST ROUND 3 ENTRIES

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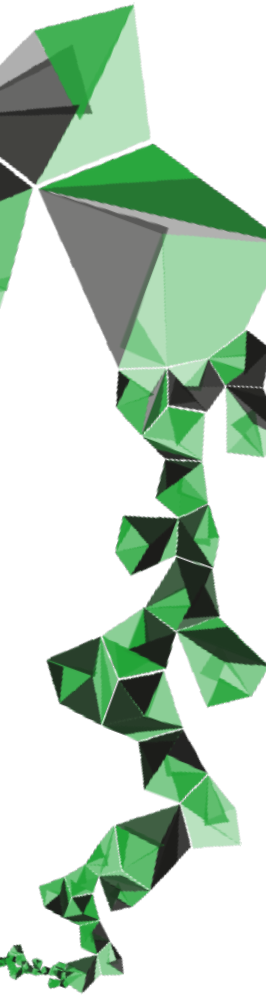

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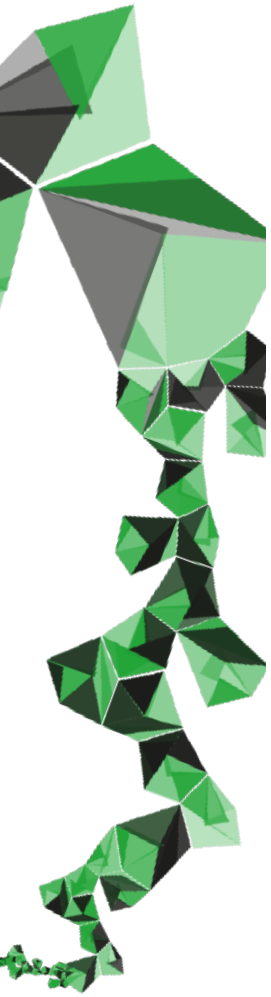

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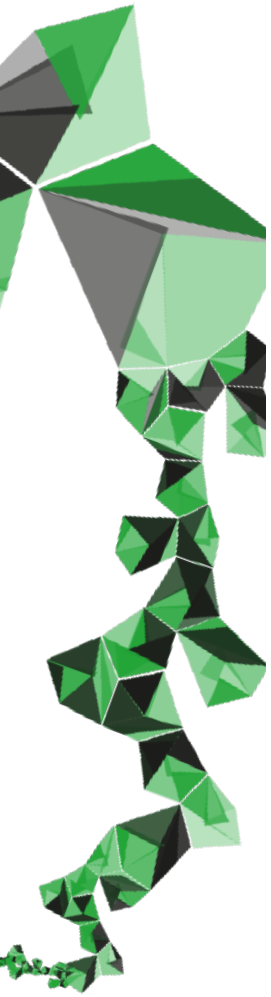

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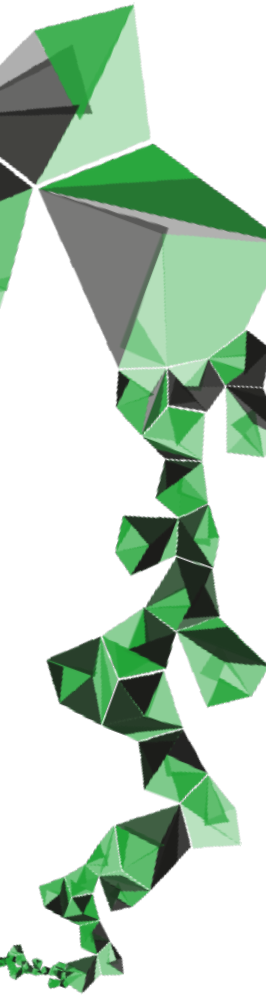

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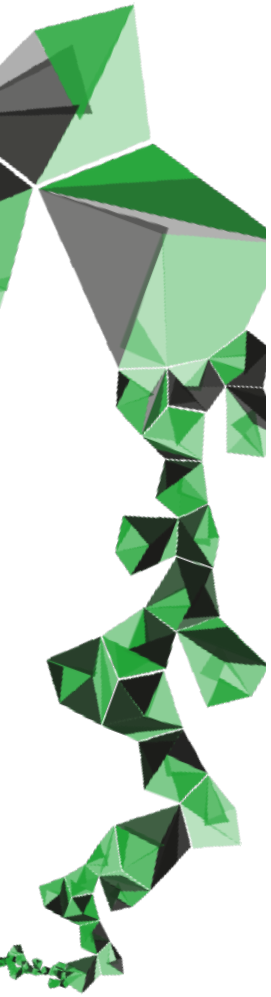

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- If we consider signature size as highest priority, two most suitable candidates are ~~Rainbow~~ and RedGeMSS
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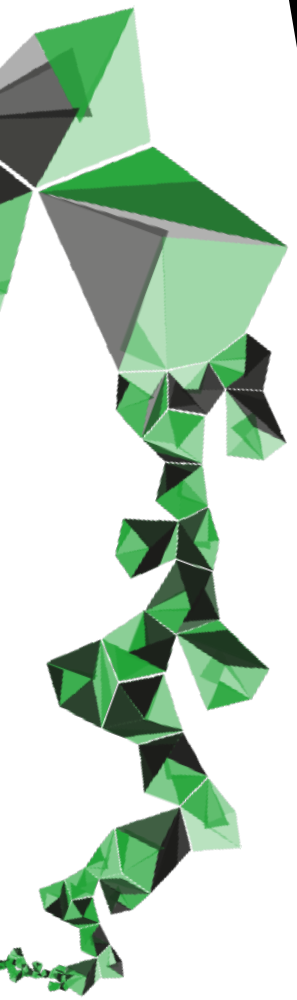
- *And* we only considered level 1 security (128-bit)

WHAT ABOUT ISOGENIES?



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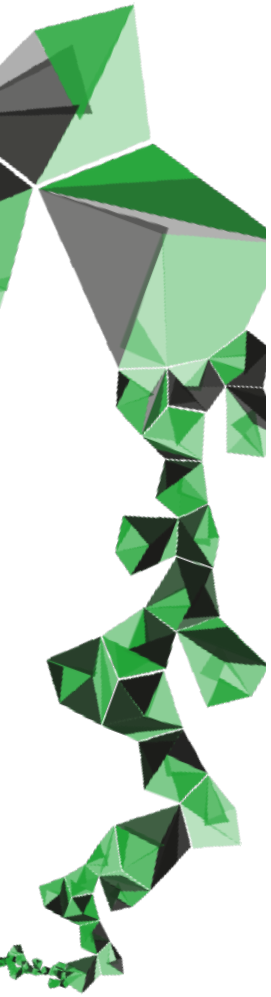

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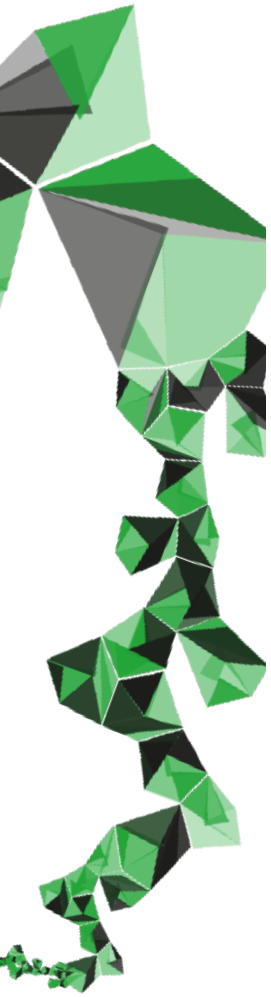

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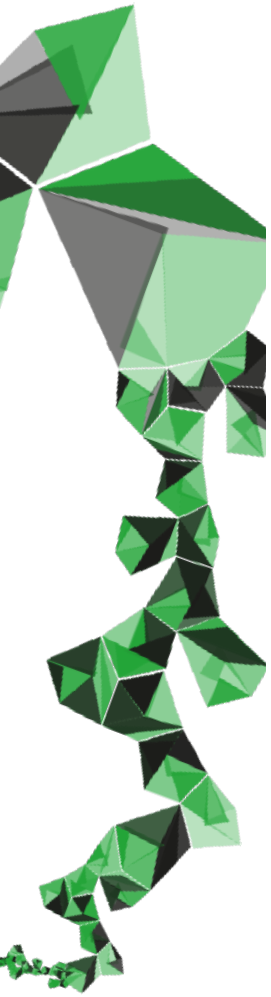

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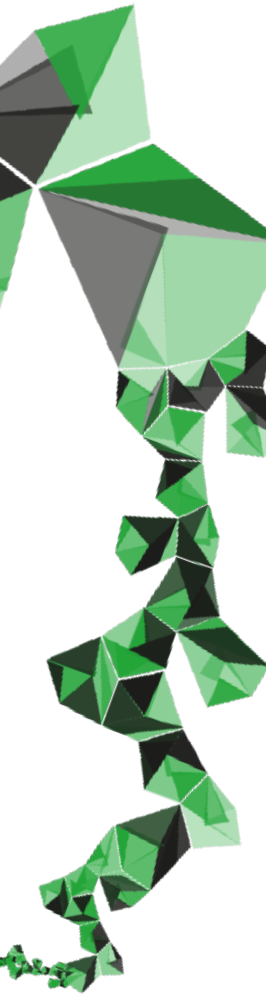

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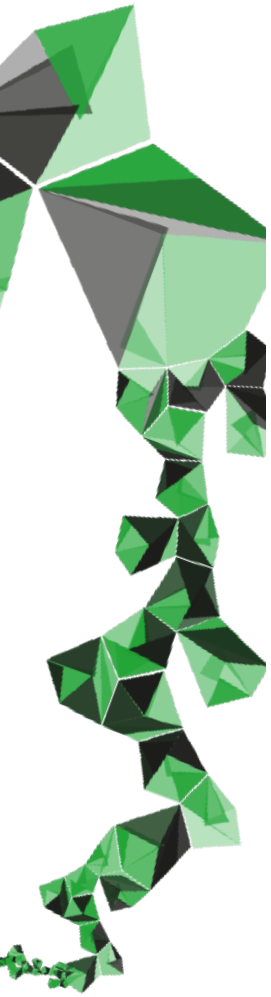

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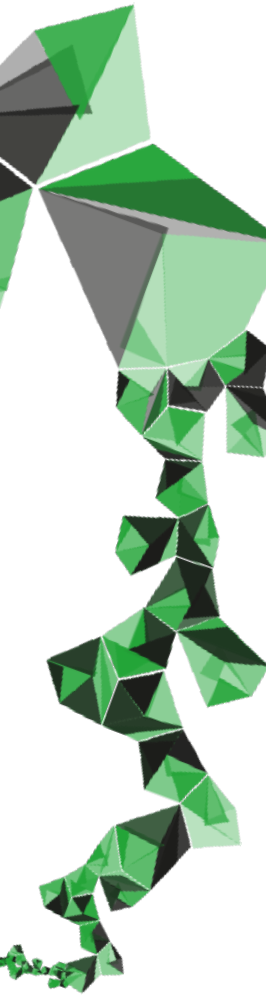

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  - It all feels “very new”
    → sufficiently cryptoanalysed for “the big screen”?
  - CSIDH, CSI-FiSh, SeaSign, SQISign, where are we headed?

STUMBLING AROUND IN THE DARK

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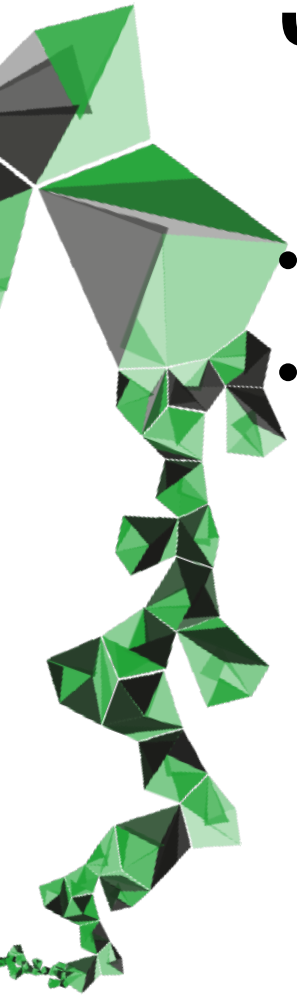
- I looked at one scheme with “DNSSEC glasses on”

STUMBLING AROUND IN THE DARK



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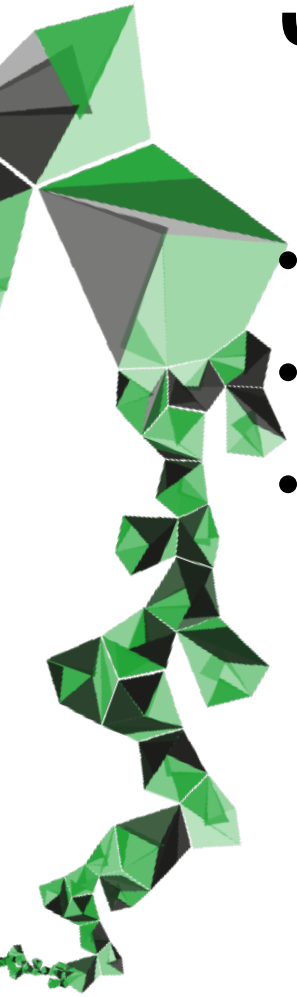

- I looked at one scheme with “DNSSEC glasses on”
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- Key and signature size at NIST level 1 look good!

Signature size	204 bytes
Public key size	64 bytes

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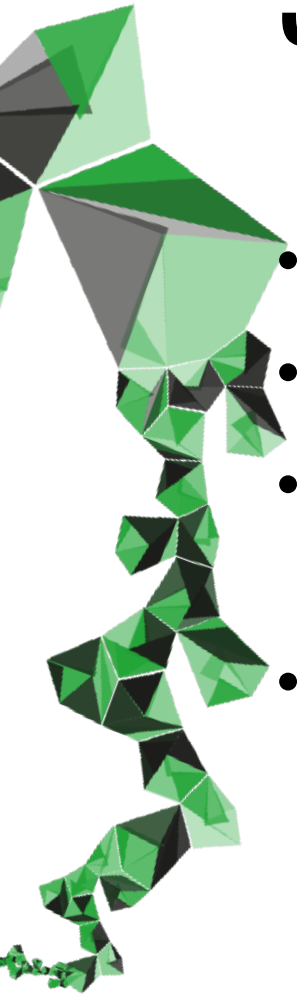

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Signing speed *(single CPU core)*	2.3s

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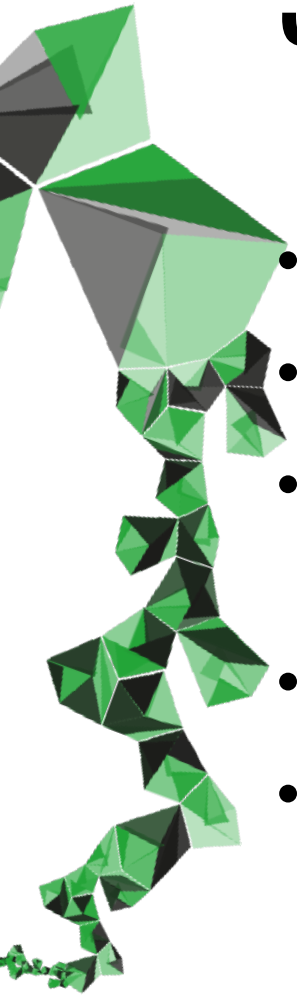

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- Validation is ~40x slower than ECDSA P-384 (so too slow)*

Signature size	204 bytes
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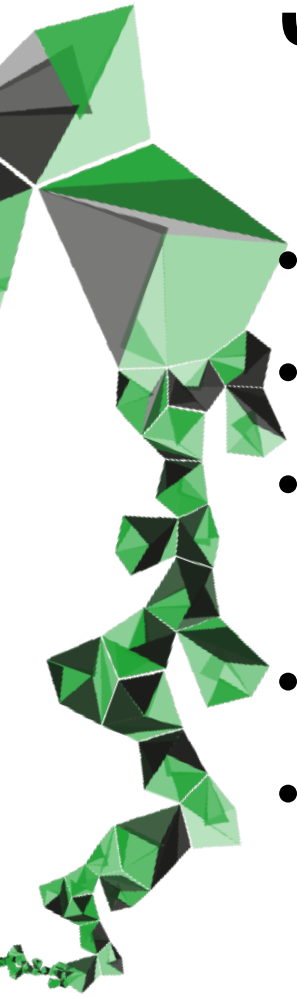

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**may work for DNS root*

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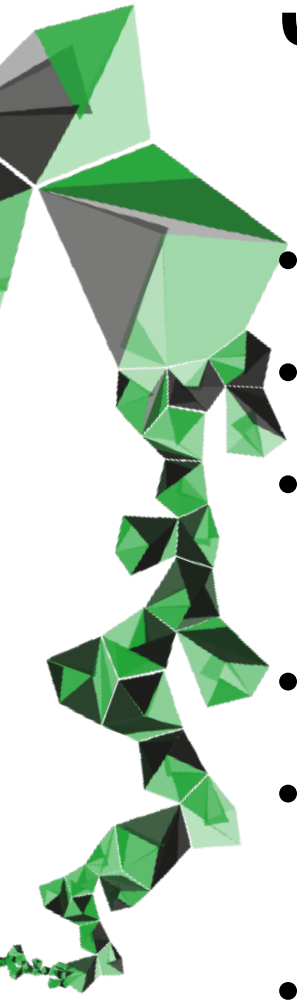

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- Key and signature size at NIST level 1 look good!
- Signing speed is a disaster*
- Validation is ~40x slower than ECDSA P-384 (so too slow)*
- Will this improve?

Signature size	204 bytes
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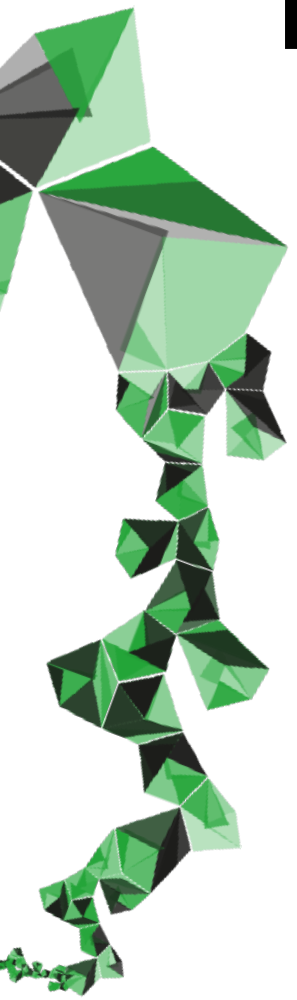
**may work for DNS root*

DO WE NEED A “FALLBACK OPTION”?



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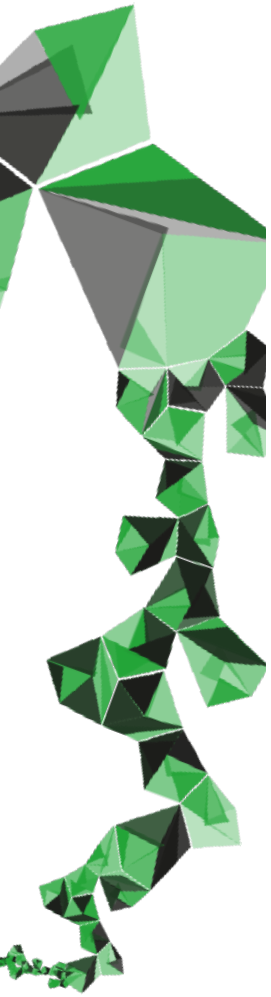

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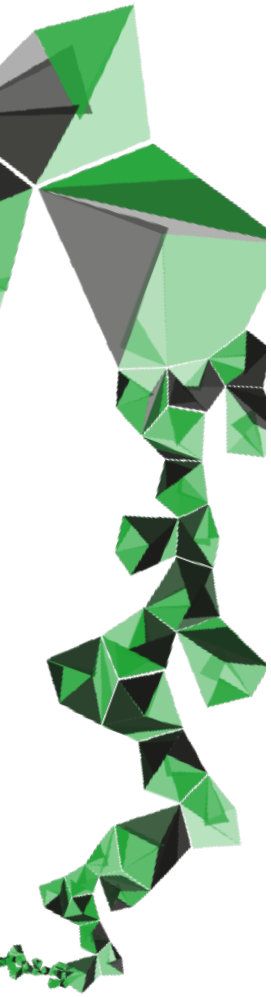

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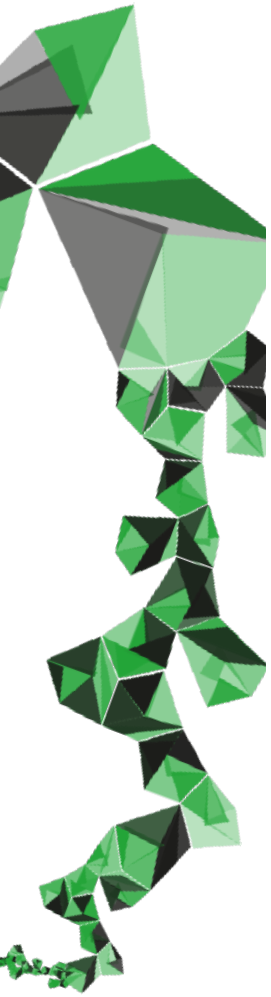

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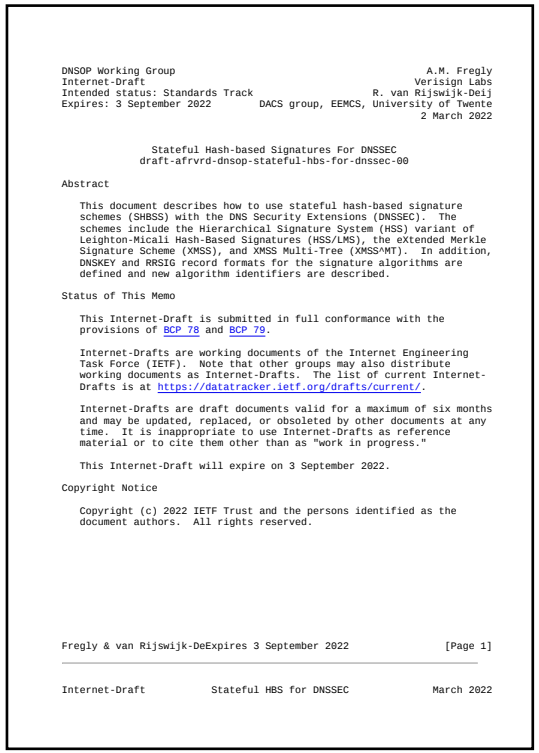
- Given how long it takes to introduce new algorithms, should we introduce a “fallback option”
- We believe so*



DNSOP Working Group
Internet-Draft
Intended status: Standards Track
Expires: 3 September 2022

A.M. Fregly
Verisign Labs
R. van Rijswijk-Deij
DACS group, EEMCS, University of Twente
2 March 2022

Stateful Hash-based Signatures For DNSSEC
draft-afrvrd-dnsop-stateful-hbs-for-dnssec-00

Abstract

This document describes how to use stateful hash-based signature schemes (SHBSS) with the DNS Security Extensions (DNSSEC). The schemes include the Hierarchical Signature System (HSS) variant of Leighton-Micali Hash-Based Signatures (HSS/LMS), the eXtended Merkle Signature Scheme (XMSS), and XMSS Multi-Tree (XMSS^MT). In addition, DNSKEY and RRSIG record formats for the signature algorithms are defined and new algorithm identifiers are described.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on 3 September 2022.

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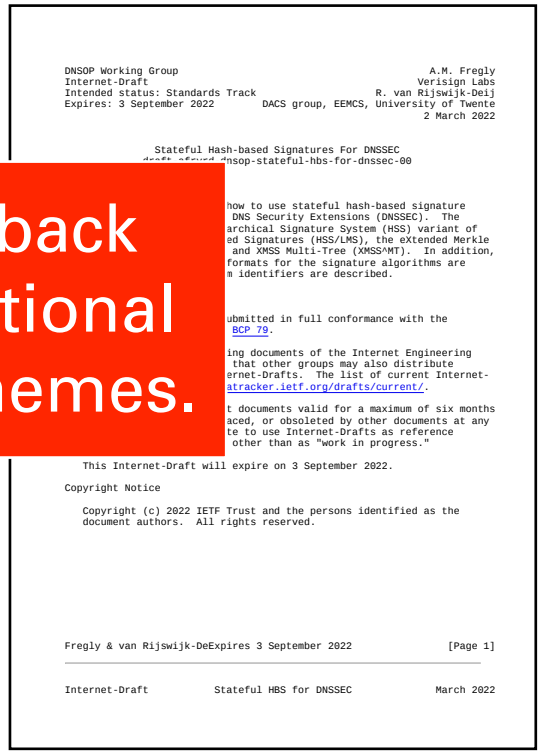
Fregly & van Rijswijk-DeExpires 3 September 2022 [Page 1]

Internet-Draft Stateful HBS for DNSSEC March 2022

DO WE NEED A “FALLBACK OPTION”?

- Introduction of new algorithms in DNSSEC takes a long time (a decade is not exceptional)
- A powerful quantum computer may appear in any
- Giv
  alg
  option”
- We believe so*

*But we expected - and got - significant pushback from the IETF DNSOP working group on operational challenges of stateful hash-based signature schemes.



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Stateful Hash-based Signatures For DNSSEC

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that other groups may also distribute
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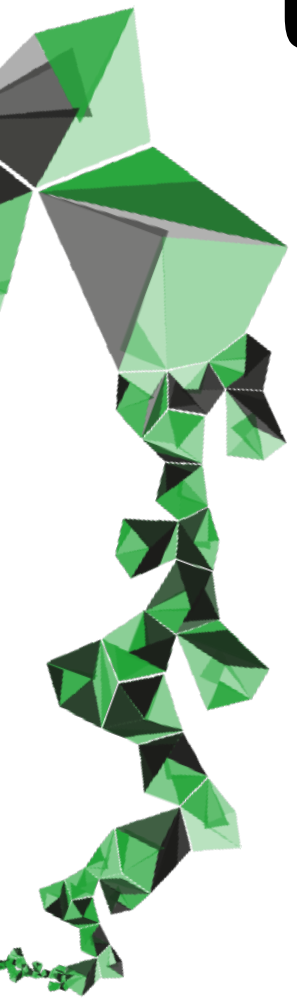
Internet-Draft Stateful HBS for DNSSEC March 2022

UNIVERSITY OF TWENTE.

ONGOING WORK



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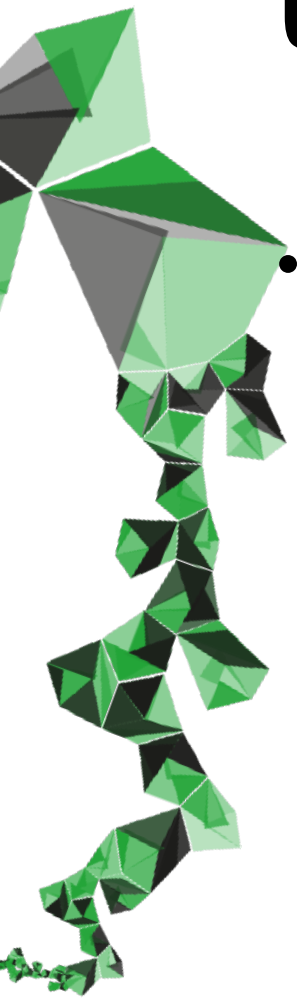
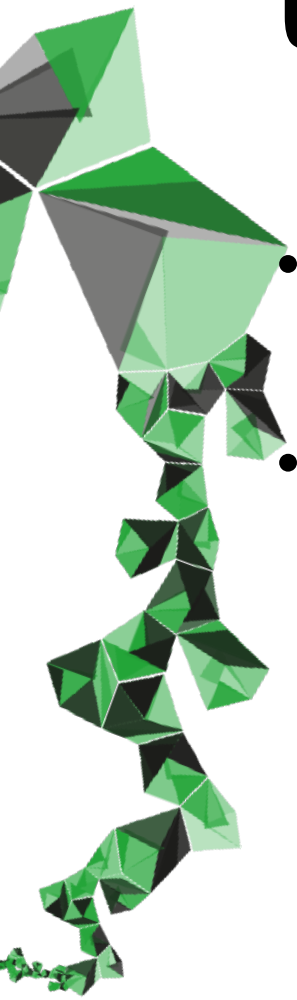


- **Prototyping NIST candidates in DNSSEC** and assessing the operational impact (several universities are working on this)

ONGOING WORK



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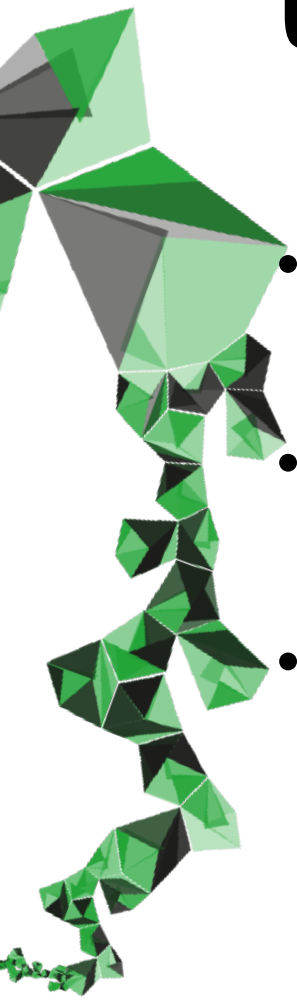

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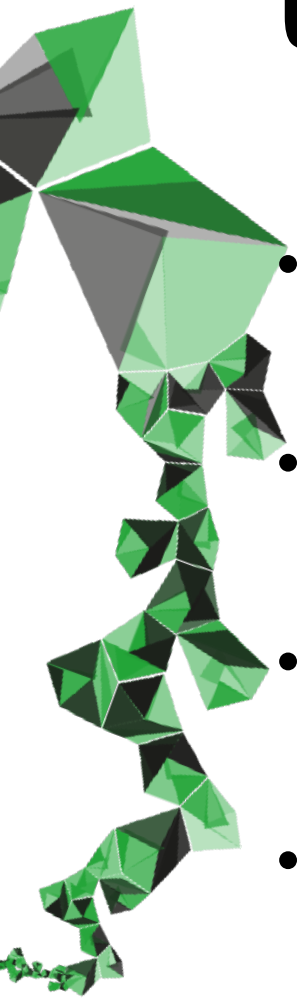

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- **Drafting an RFC on alternative transports** for DNSSEC in a post-quantum world (collaborative effort)

QUESTIONS/DISCUSSION

UNIVERSITY OF TWENTE.
DIGITAL SOCIETY INSTITUTE
FACULTY OF ELECTRICAL ENGINEERING, MATHEMATICS AND COMPUTER SCIENCE
DESIGN AND ANALYSIS OF COMMUNICATION SYSTEMS

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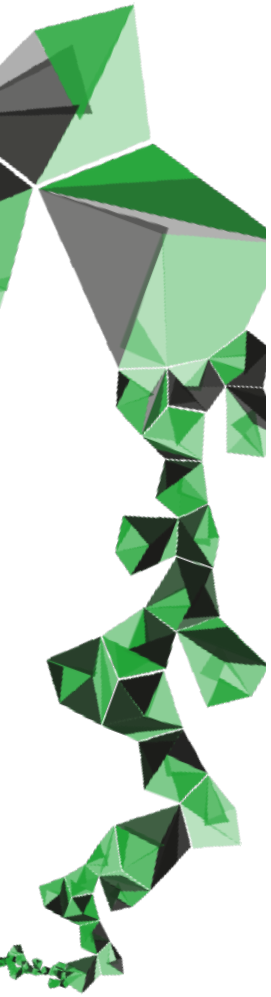

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