Can NSEC5 be practical for DNSSEC deployments?

Dimitrios Papadopoulos, Jan Včelák, Moni Naor, Leonid Reyzin, Sharon Goldberg

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February 26 2017

BOSTON UNIVERSITY
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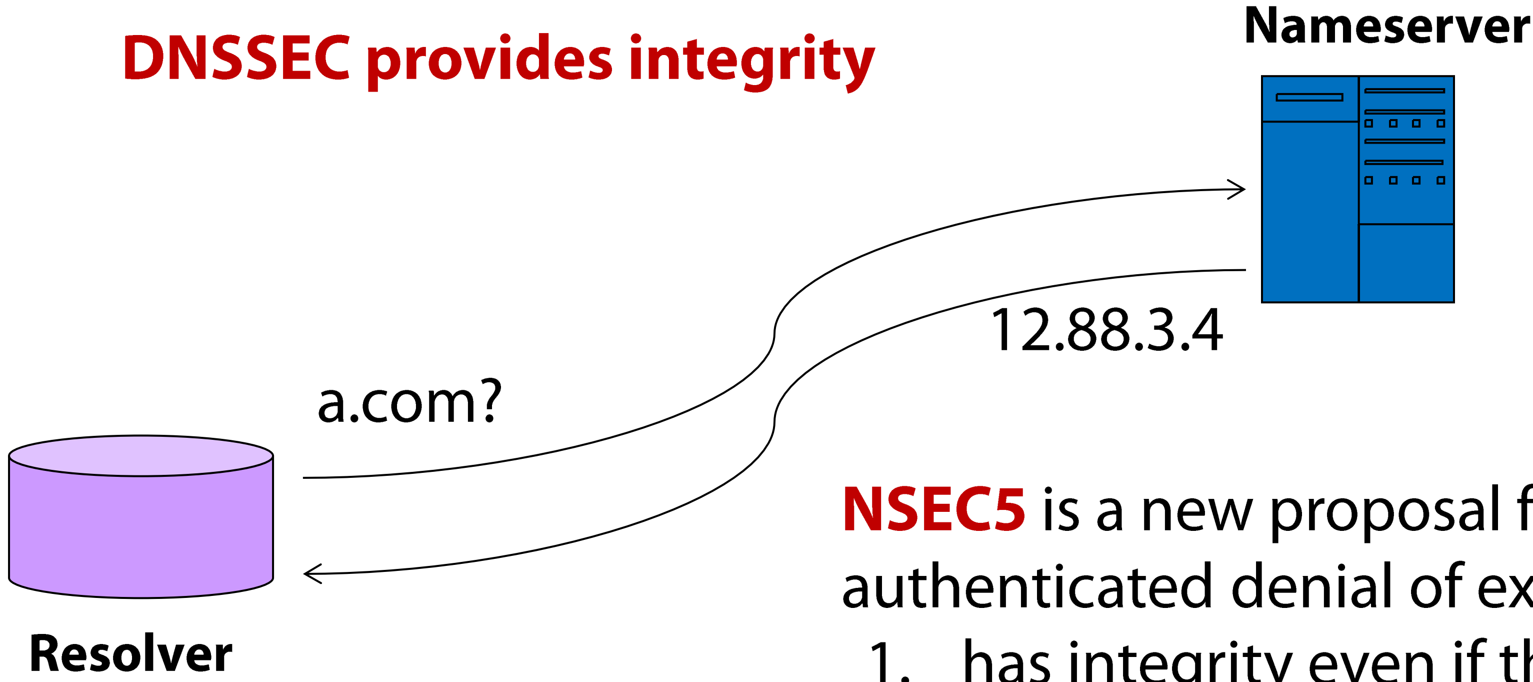
UNIVERSITY OF MARYLAND
cz.nic
NS1.

DNSSEC negative responses and NSEC5

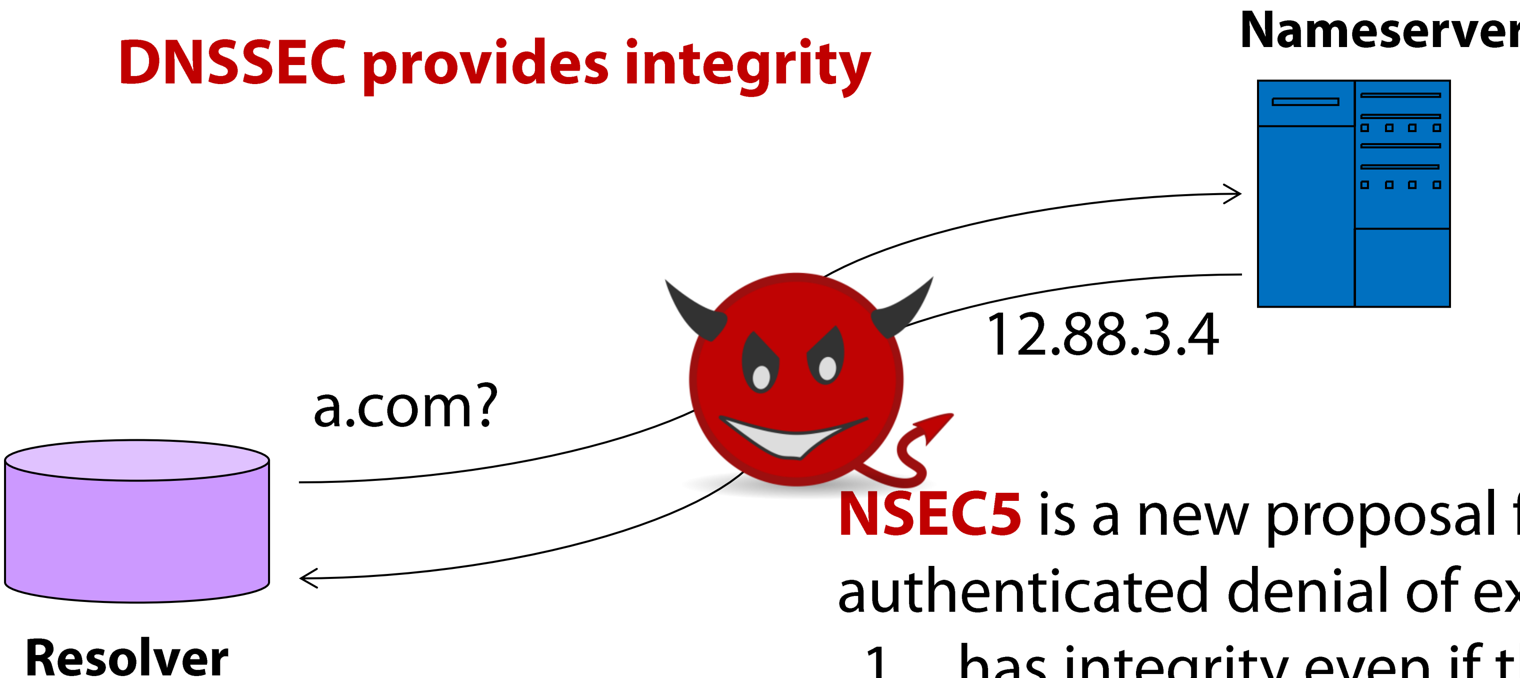


NSEC5 is a new proposal for DNSSEC authenticated denial of existence

1. has integrity even if the nameserver is compromised.
2. prevents offline zone enumeration

DNSSEC negative responses and NSEC5

DNSSEC provides integrity



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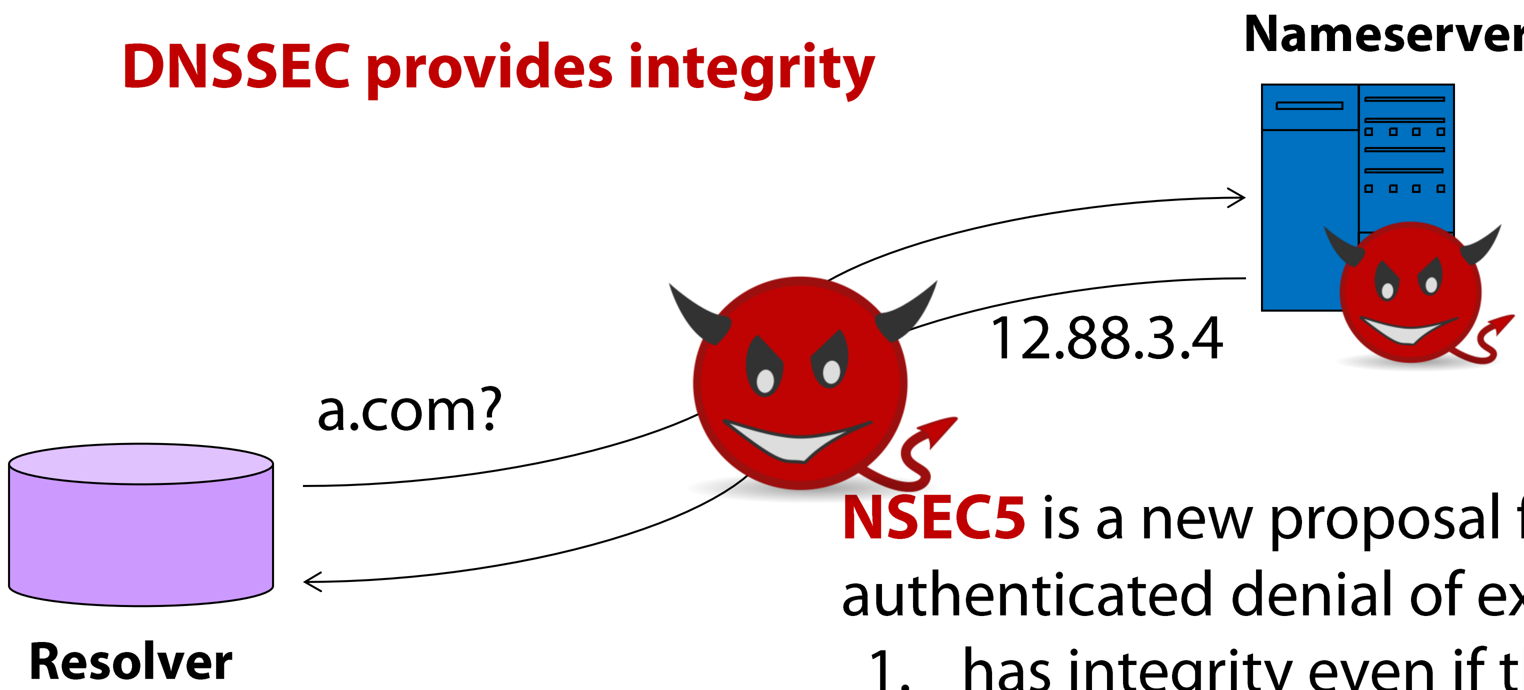

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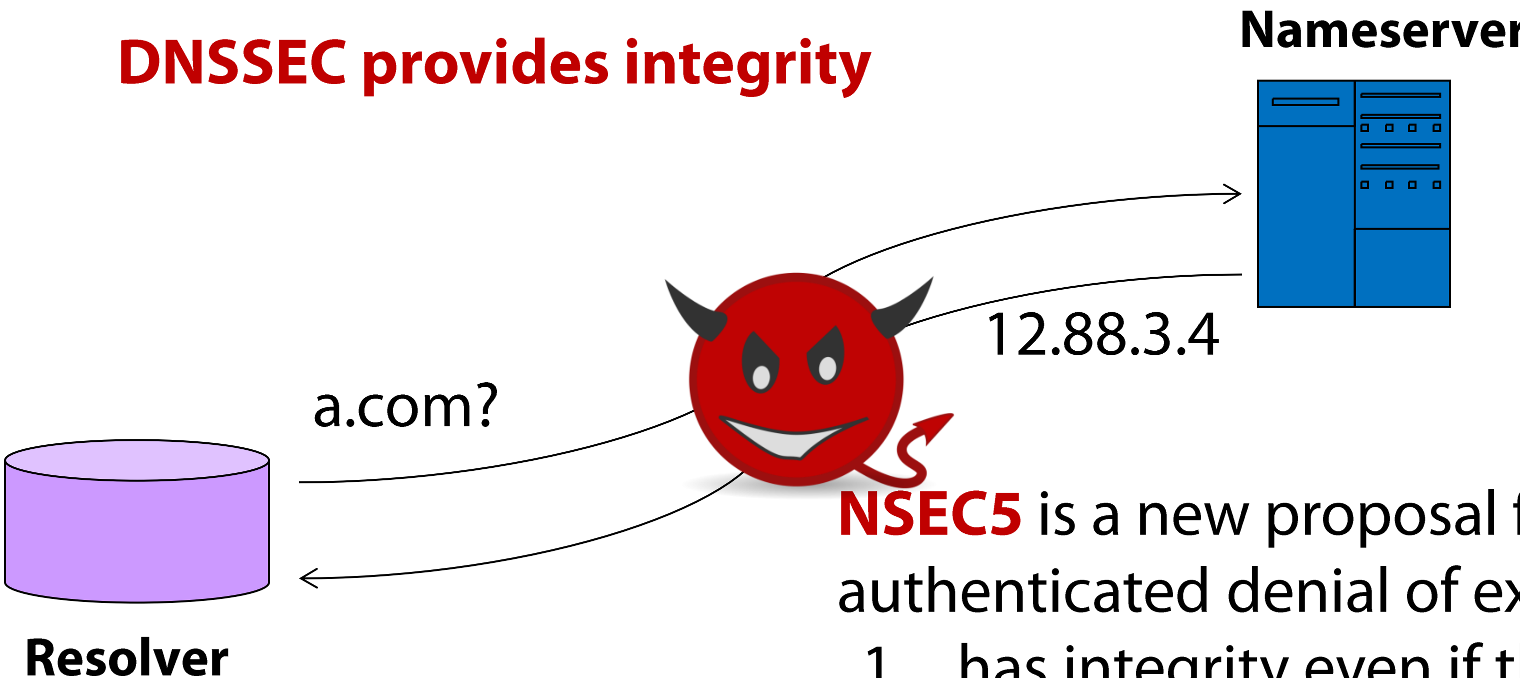

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1. has integrity even if the nameserver is compromised.
2. prevents offline zone enumeration

New contributions:

- Elliptic curve NSEC5
- Full specification
- Full implementation
- Prelim performance results

offline signing with NSEC3 [RFC5155]

a.com

c.com

z.com

offline signing with NSEC3 [RFC5155]

H(a.com) = a1bb5

H(c.com) = 23ced

H(z.com) = dde45

a.com

c.com

z.com

offline signing with NSEC3 [RFC5155]

H(a.com) = a1bb5

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Hash names

a.com

c.com

z.com

sort

23ced

a1bb5

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c.com
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Hash names

H(a.com) = a1bb5
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sort

23ced
a1bb5
dde45

Sign NSEC3 records with secret ZSK

23ced.com
a1bb5.com

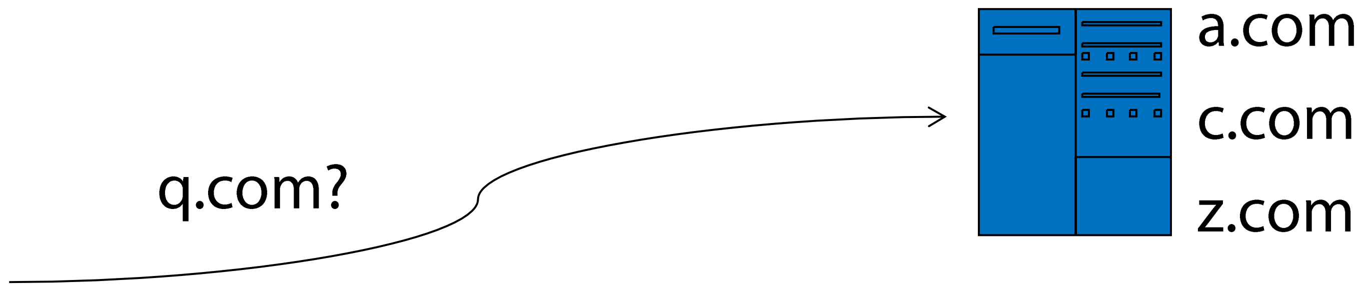
a1bb5.com
dde45.com

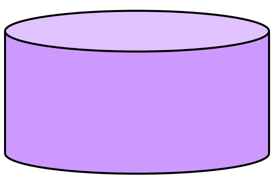
dde45.com
23ced.com

NSEC3 in action [RFC5155]

Public Zone Signing Key (ZSK): 

H(q.com**)** = c987b





<u>To verify</u>

Does NSEC3 cover query hash?

a1bb5 < c987b < dde45

NSEC3 in action [RFC5155]

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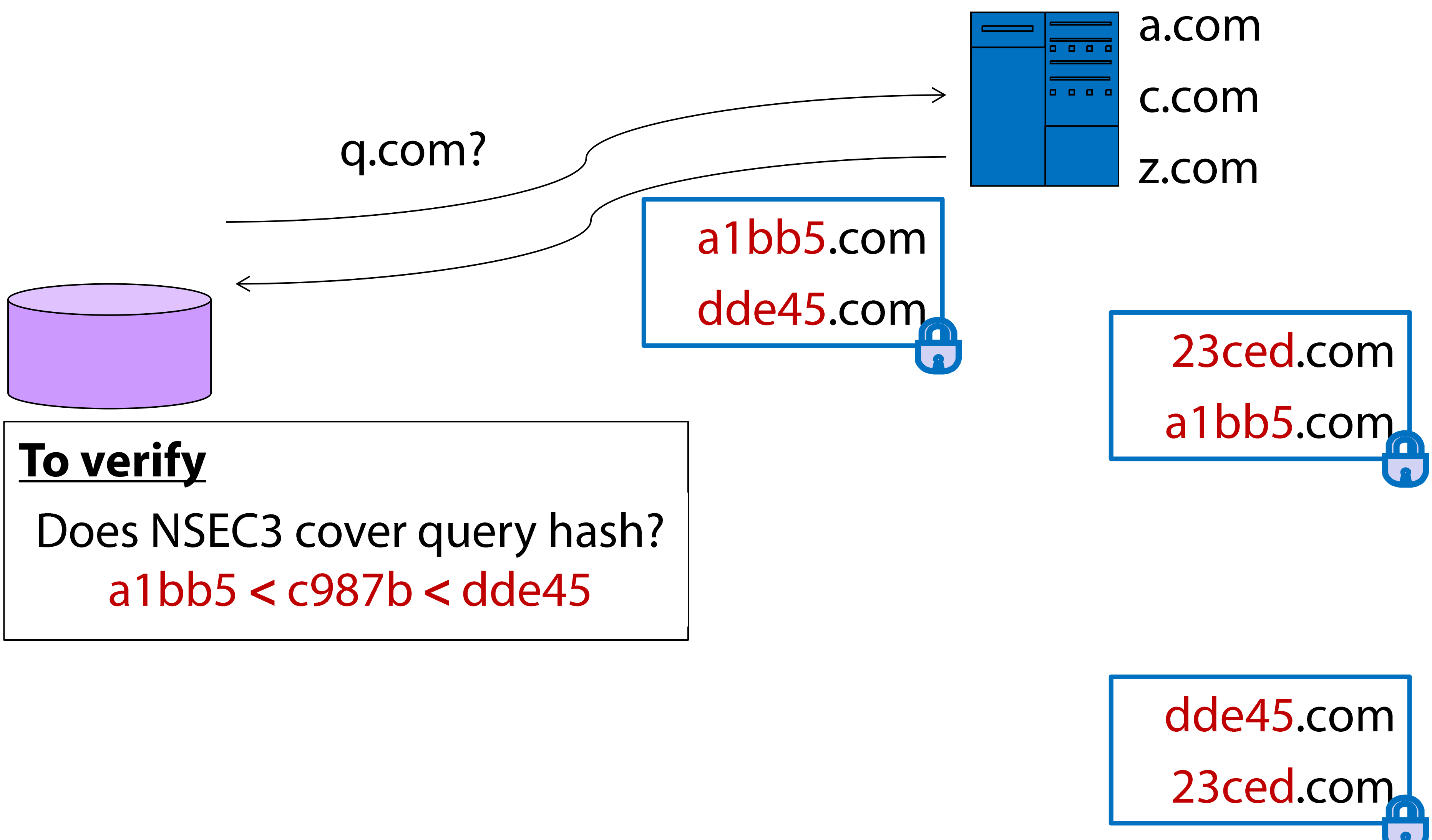

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NSEC3 offline zone enumeration attack

Public Zone Signing Key (ZSK):

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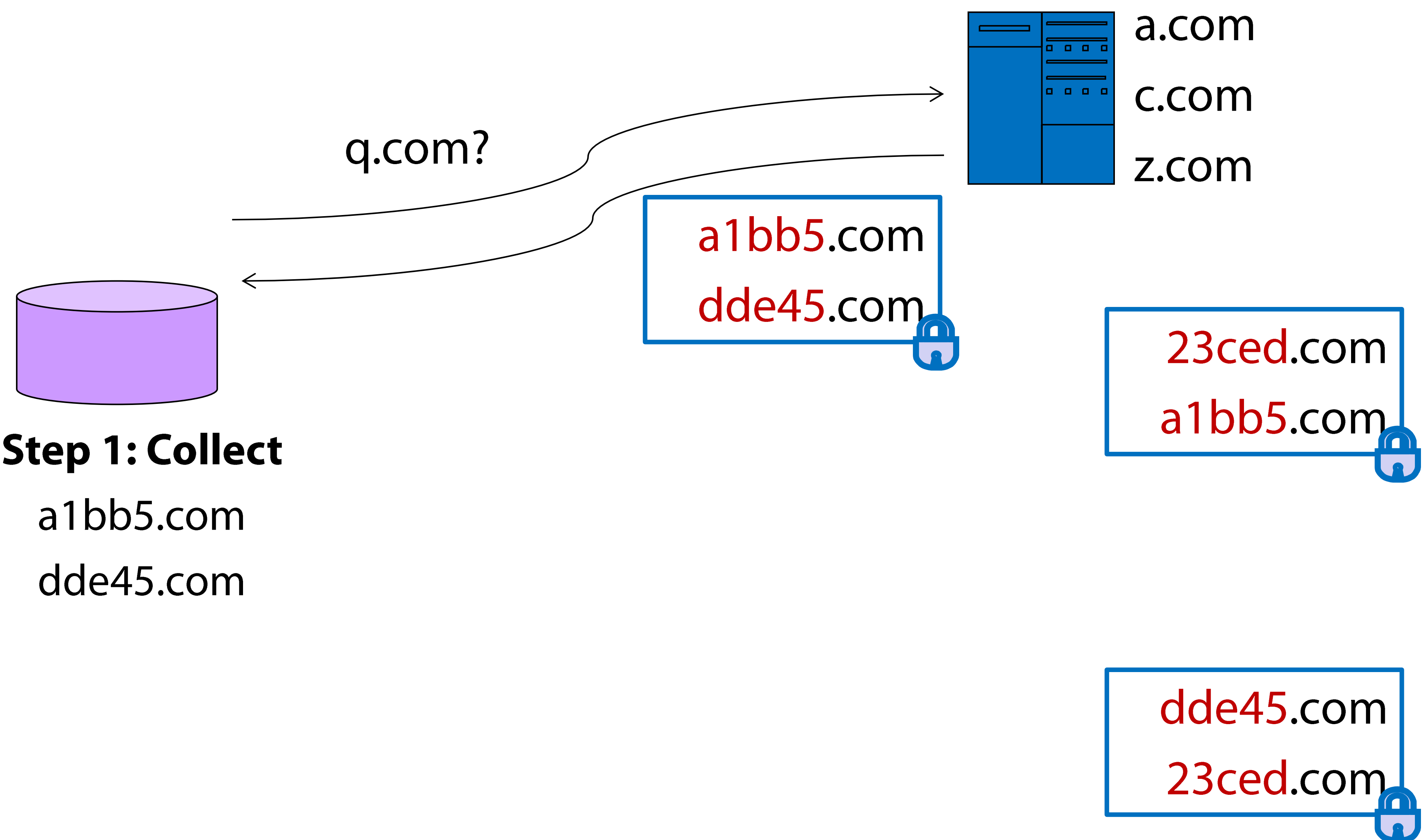
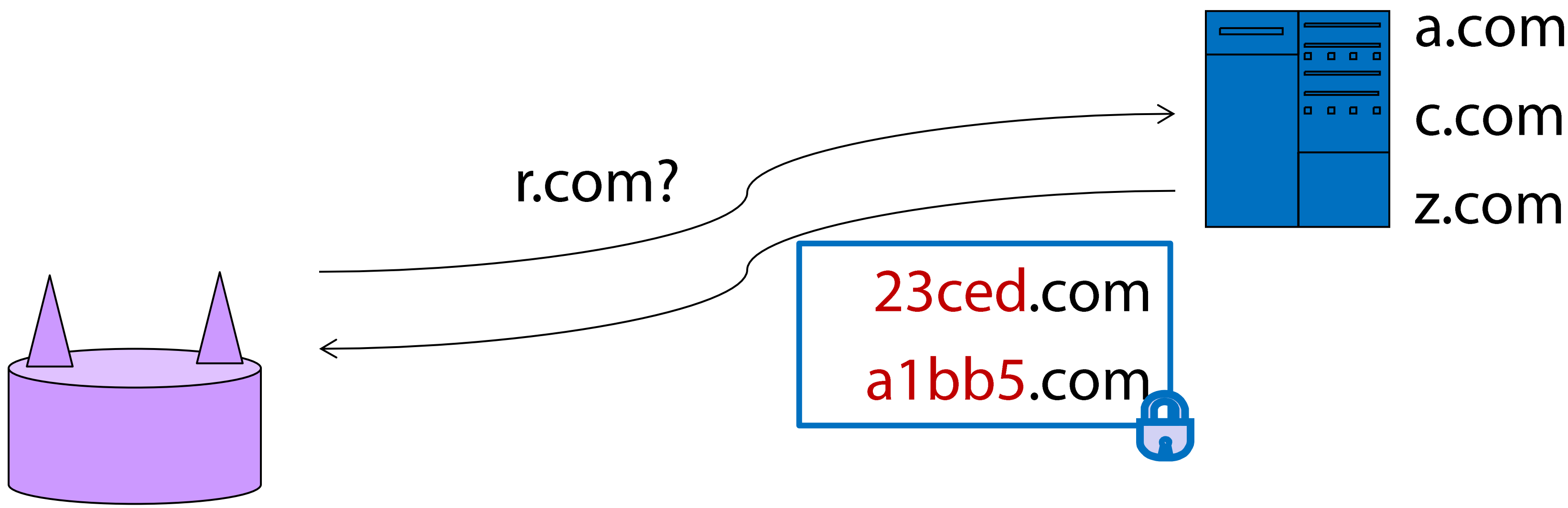


NSEC3 offline zone enumeration attack

Public Zone Signing Key (ZSK): 

H(r.com**)** = 33c46



Step 1: Collect

a1bb5.com

dde45.com

23ced.com

NSEC3 offline zone enumeration attack

Public Zone Signing Key (ZSK): 

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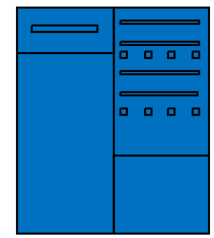
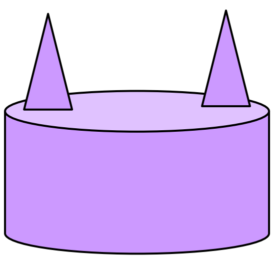


a.com

c.com

z.com



Step 1: Collect

a1bb5.com

dde45.com

23ced.com

Offline dictionary attack

Step 2: Crack

a.com

z.com

c.com

[Wander, Schwittmann, Boelmann, Weis 2014] reversed 64% of NSEC3 hashes in the .com in less than a day with one GPU. See also [nmap] & [jack-the-ripper] plugins.

why is offline zone enumeration possible with NSEC3?

Because resolvers can compute hashes offline.

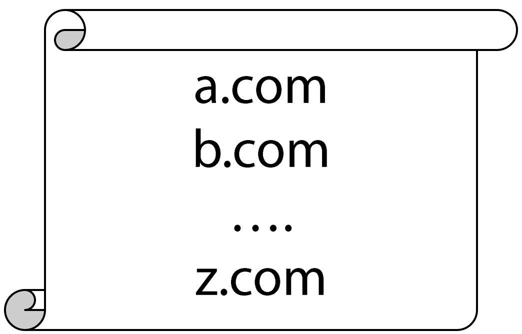
Step 1: Collect

a1bb5.com

dde45.com

23ced.com

A) Make dictionary



B) Hash each name

H(a.com**) = a1bb5**
H(b.com**) = 33333**
....
H(z.com**) = dde45**

NSEC5 replaces the hash **H** with a **Verifiable Random Function (VRF)** that resolvers cannot compute offline.

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Step 1: Collect

a1bb5.com

dde45.com

23ced.com

Step 2: Crack

a.com

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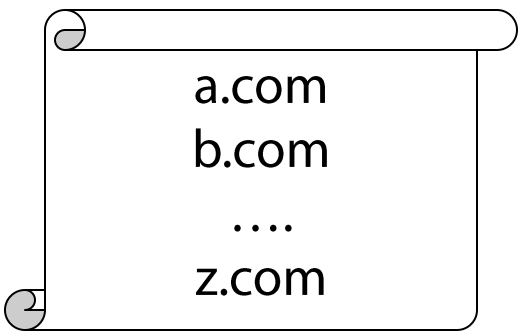

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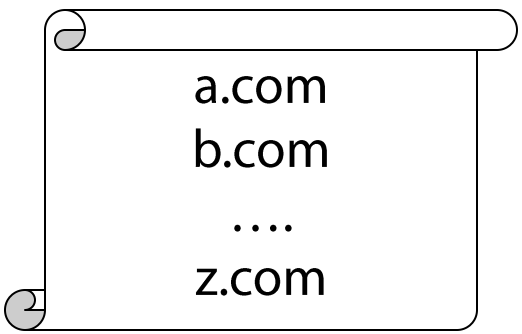

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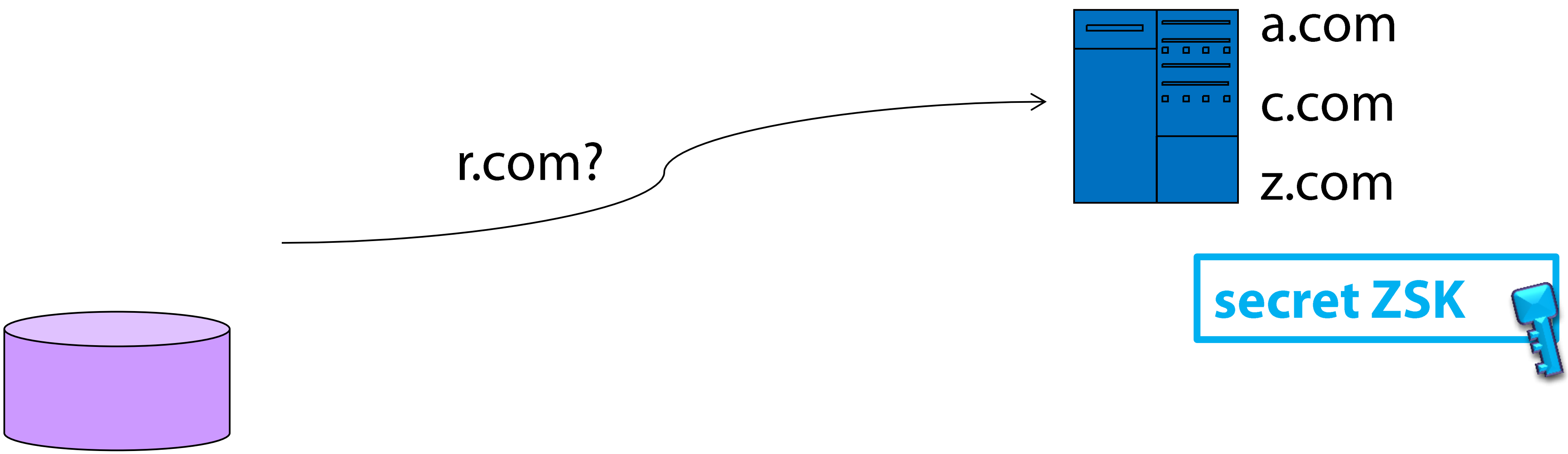
online signing stops offline zone enumeration!

Public Zone Signing Key (ZSK): 



“NSEC3 White Lies”

online signing stops offline zone enumeration!

Public Zone Signing Key (ZSK):

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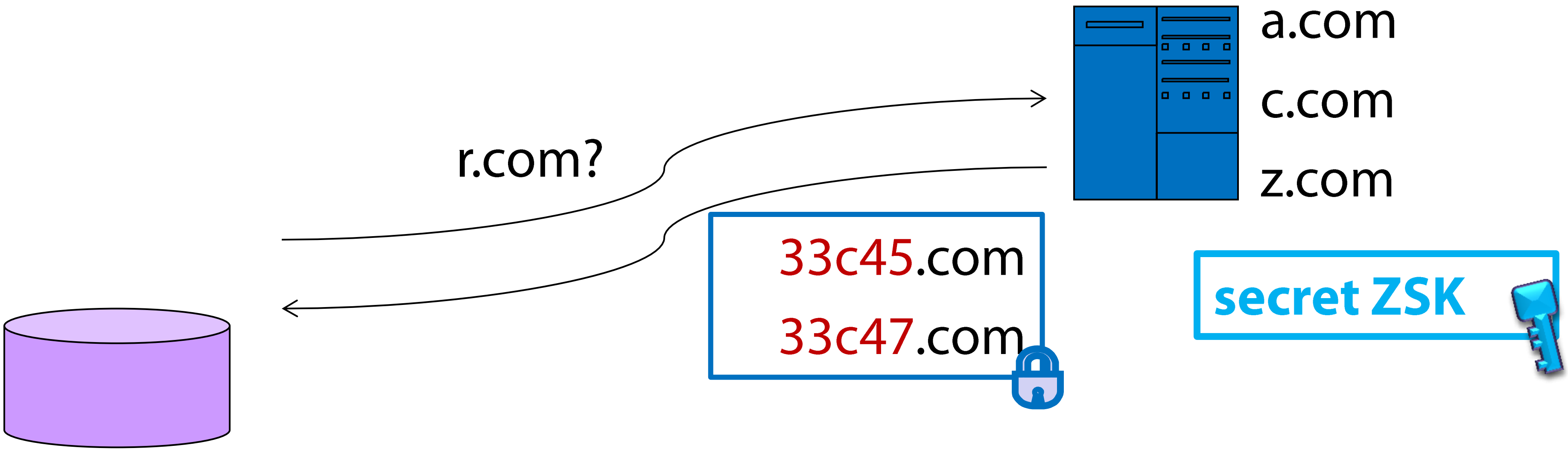

"NSEC3 White Lies"

comparison of different schemes

	No offline zone enumeration	Integrity vs outsiders	Integrity vs compromised nameserver	No online crypto
DNS (legacy)	✔	X	X	✔
NSEC or NSEC3	X	✔	✔	✔
Online Signing ("NSEC3 White Lies")	✔	✔	X	X

Theorem [NDSS'15]: For ANY denial of existence scheme that

1. prevents offline zone enumeration, and
2. provides integrity against outsiders

nameservers must compute a public-key signature for each negative response.

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Online Signing (“NSEC3 White Lies”)	✔	✔	X	X
NSEC5	✔	✔	✔	X

Theorem [NDSS’15]: For ANY denial of existence scheme that

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nameservers must compute a public-key signature for each negative response.

NSEC5: precomputing records

a.com

c.com

z.com

NSEC5: precomputing records

H(Π(a.com)) =9ae3e

H(Π(c.com)) =8cb67

H(Π(z.com)) =3cd91

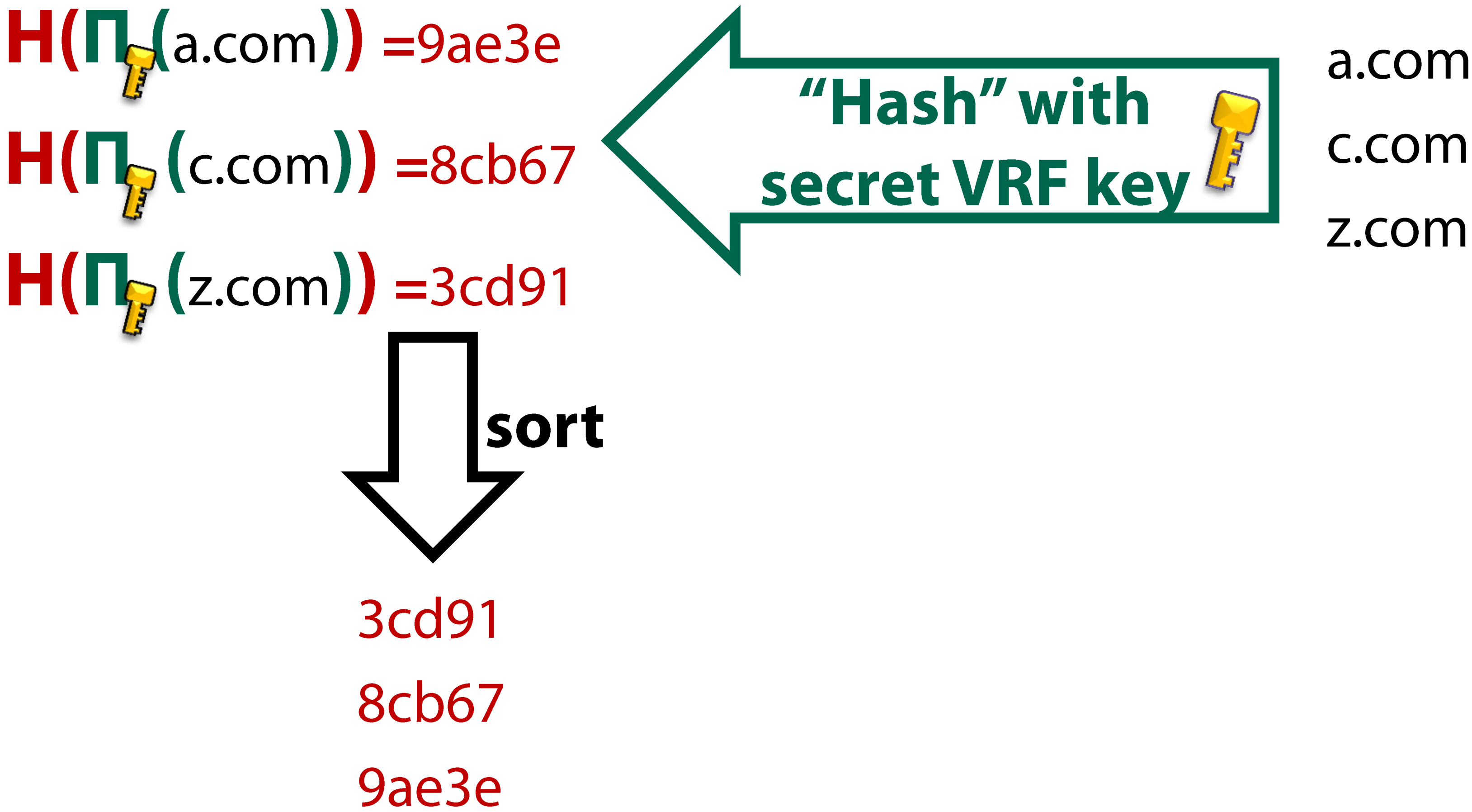
"Hash" with secret VRF key

a.com

c.com

z.com

NSEC5: precomputing records



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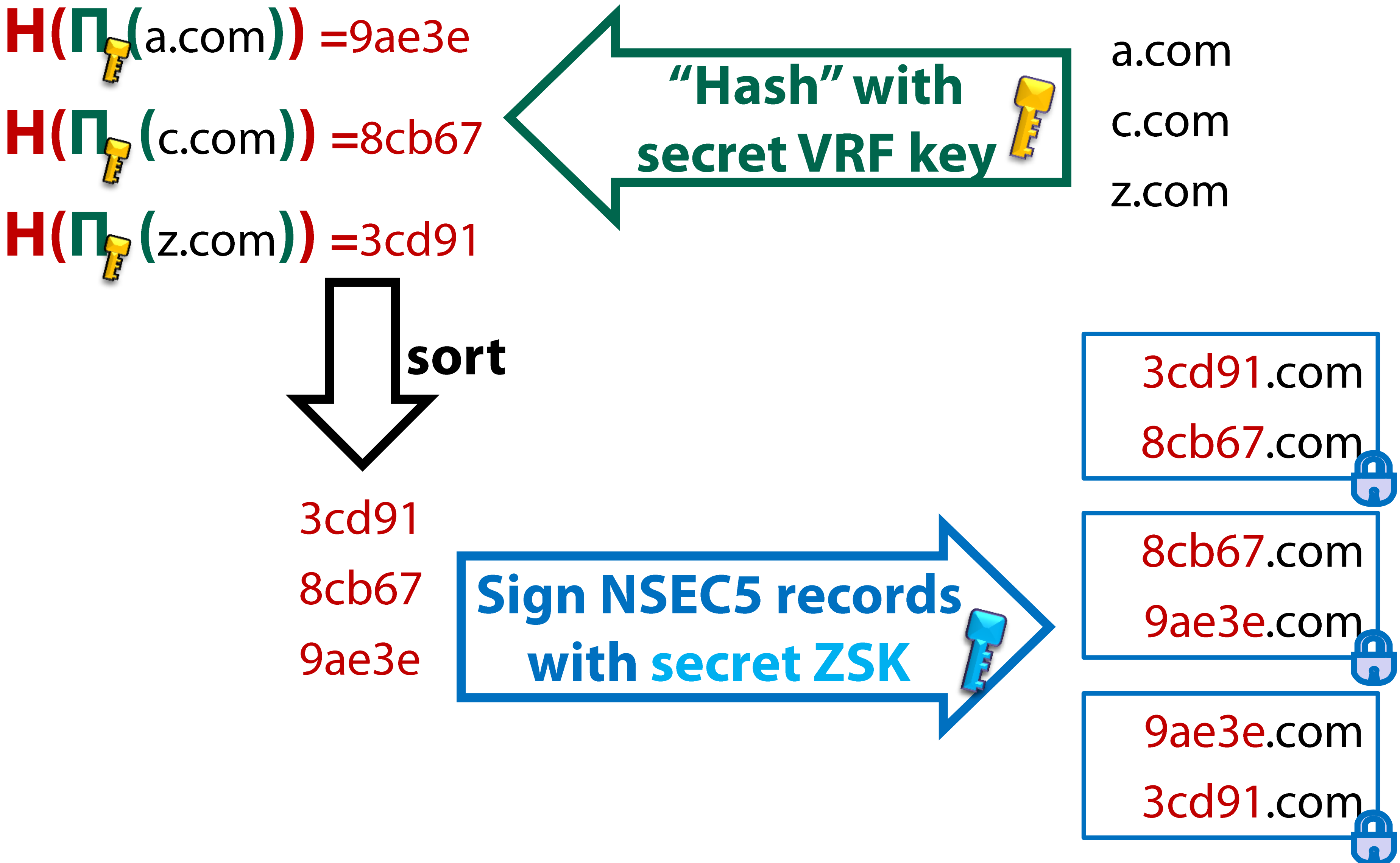

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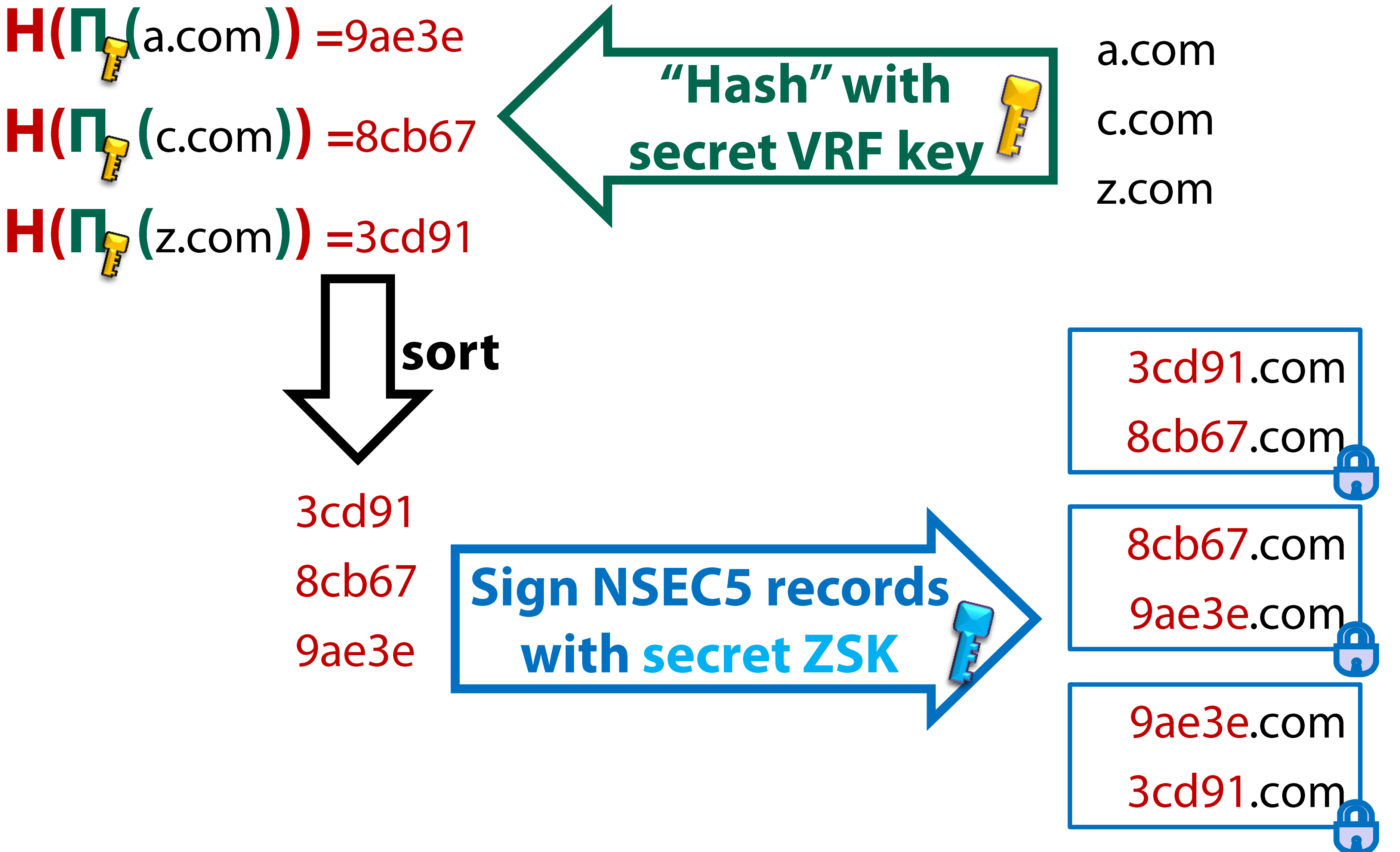


NSEC5: precomputing records

* **NSEC5-RSA:** **Π** is a deterministic RSA signature

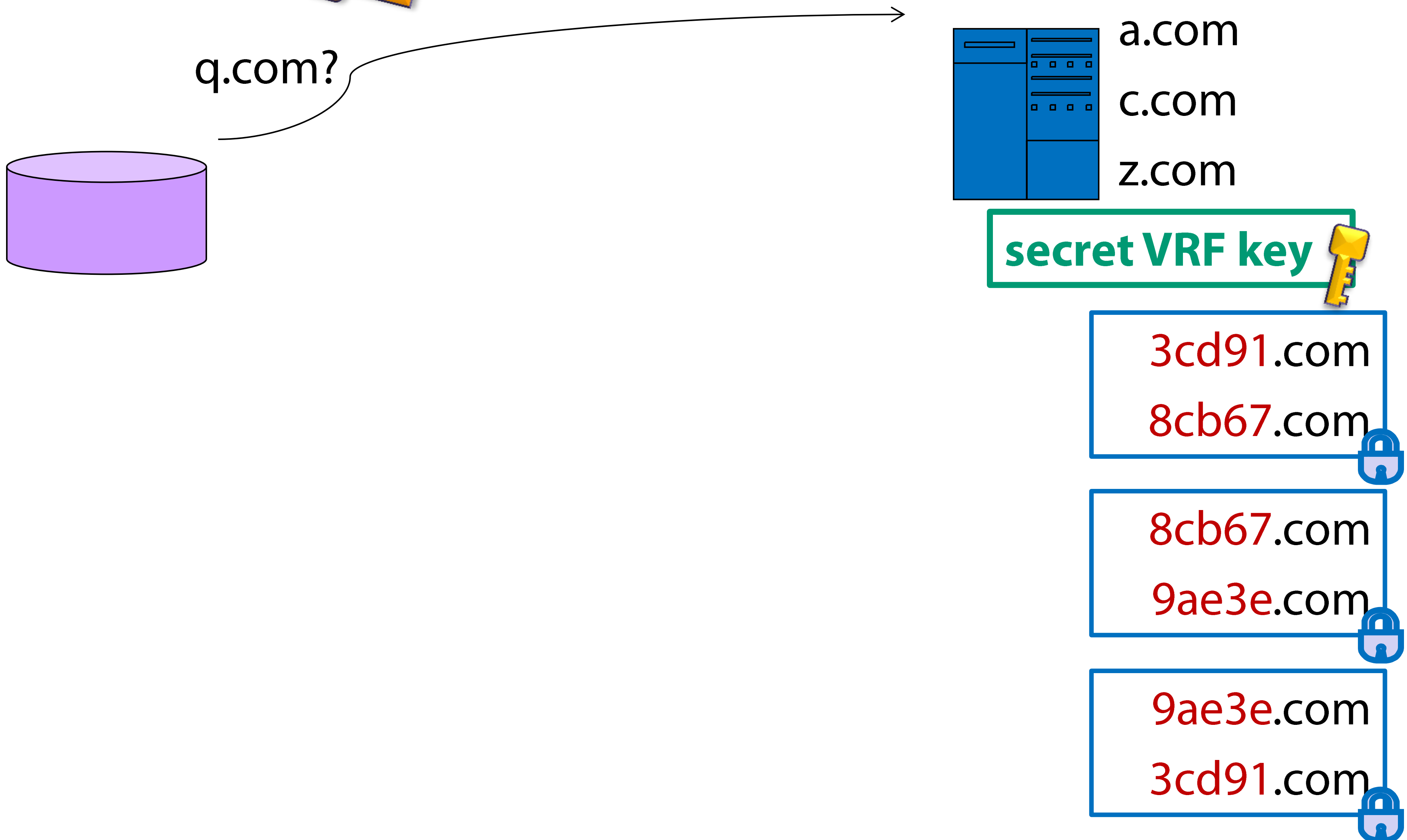
* **NSEC5-ECC:** new construction based on elliptic curves

- **Π** is implicit in **[Goh-Jareki'02][FranklinZhang'13]**
- We prove it's a VRF.
- For 256-bit elliptic curves, **Π** gives 641-bit outputs.

NSEC5 in action

Public Zone Signing Key (ZSK):

Public VRF Key:



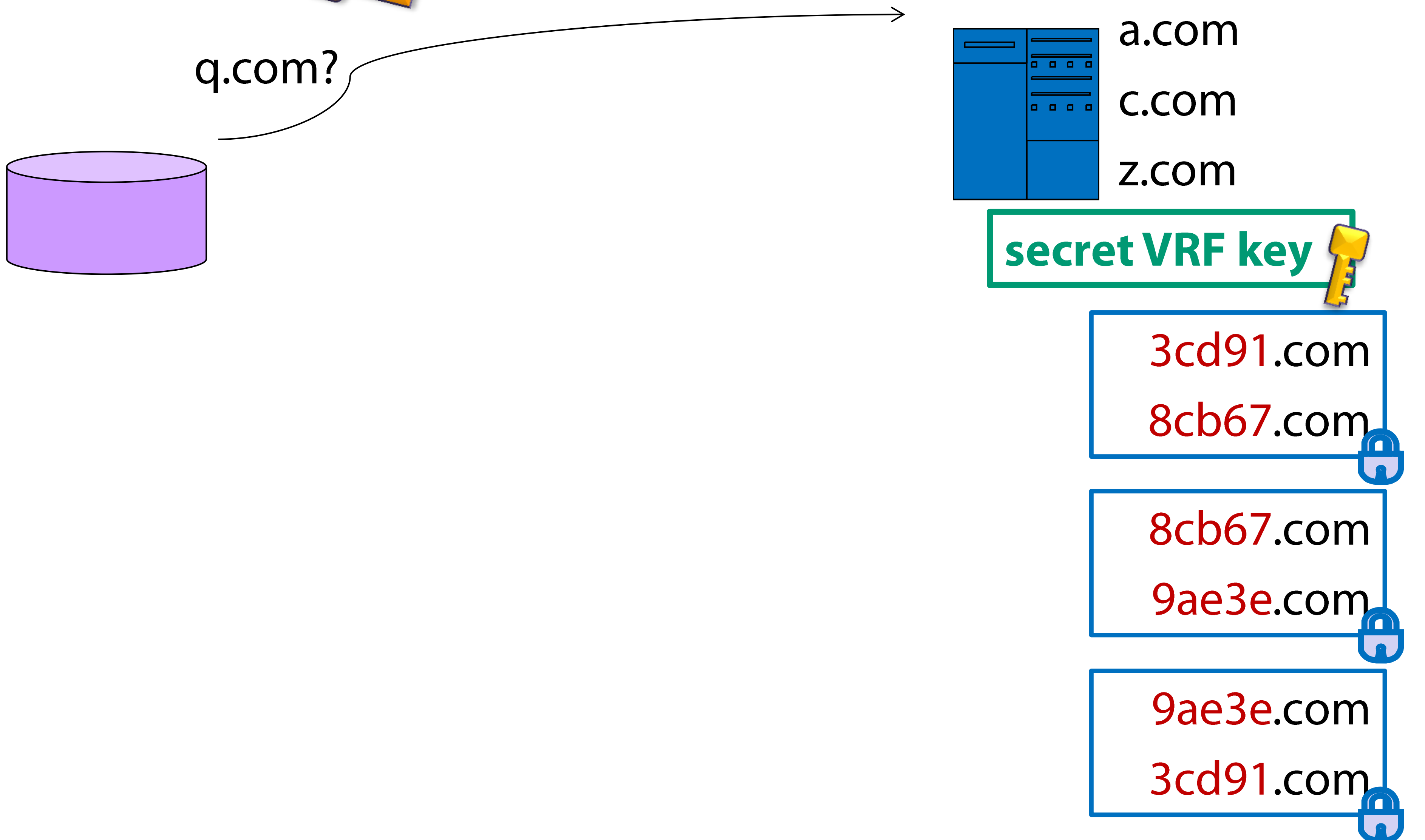
NSEC5 in action

Public Zone Signing Key (ZSK):

Public VRF Key:

$\Pi(\text{q.com}) = \text{aa8678}$

$H(\text{aa867}) = \text{7a89b}$



NSEC5 in action

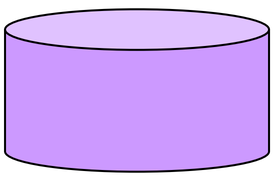
Public Zone Signing Key (ZSK):

Public VRF Key:

Π(q.com)=aa8678

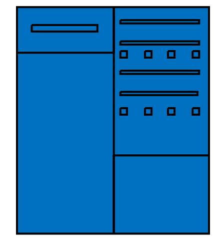
H(aa867)=7a89b

q.com?



3cd91.com

8cb67.com



a.com

c.com

z.com

secret VRF key

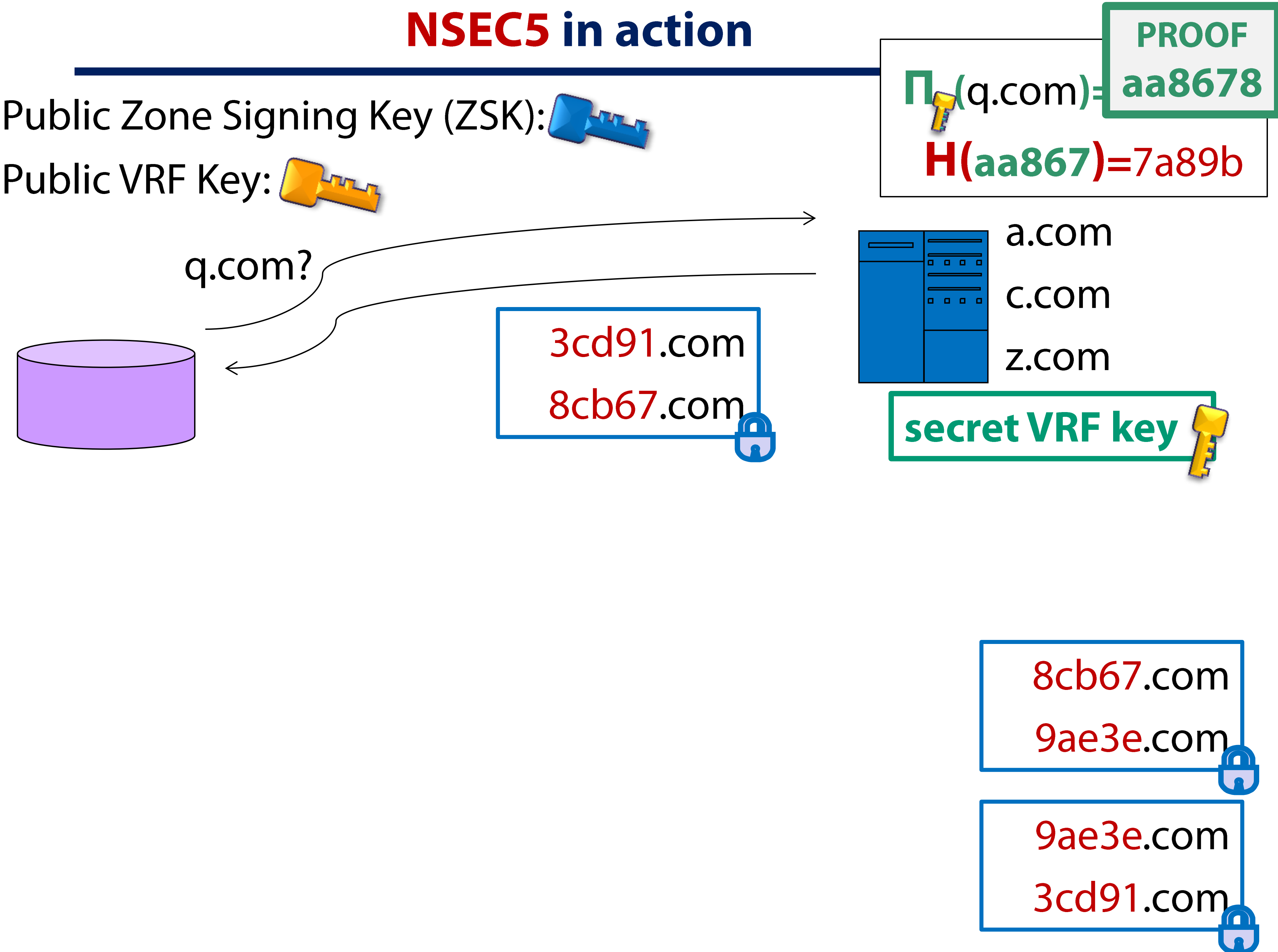
8cb67.com

9ae3e.com

9ae3e.com

3cd91.com

NSEC5 in action



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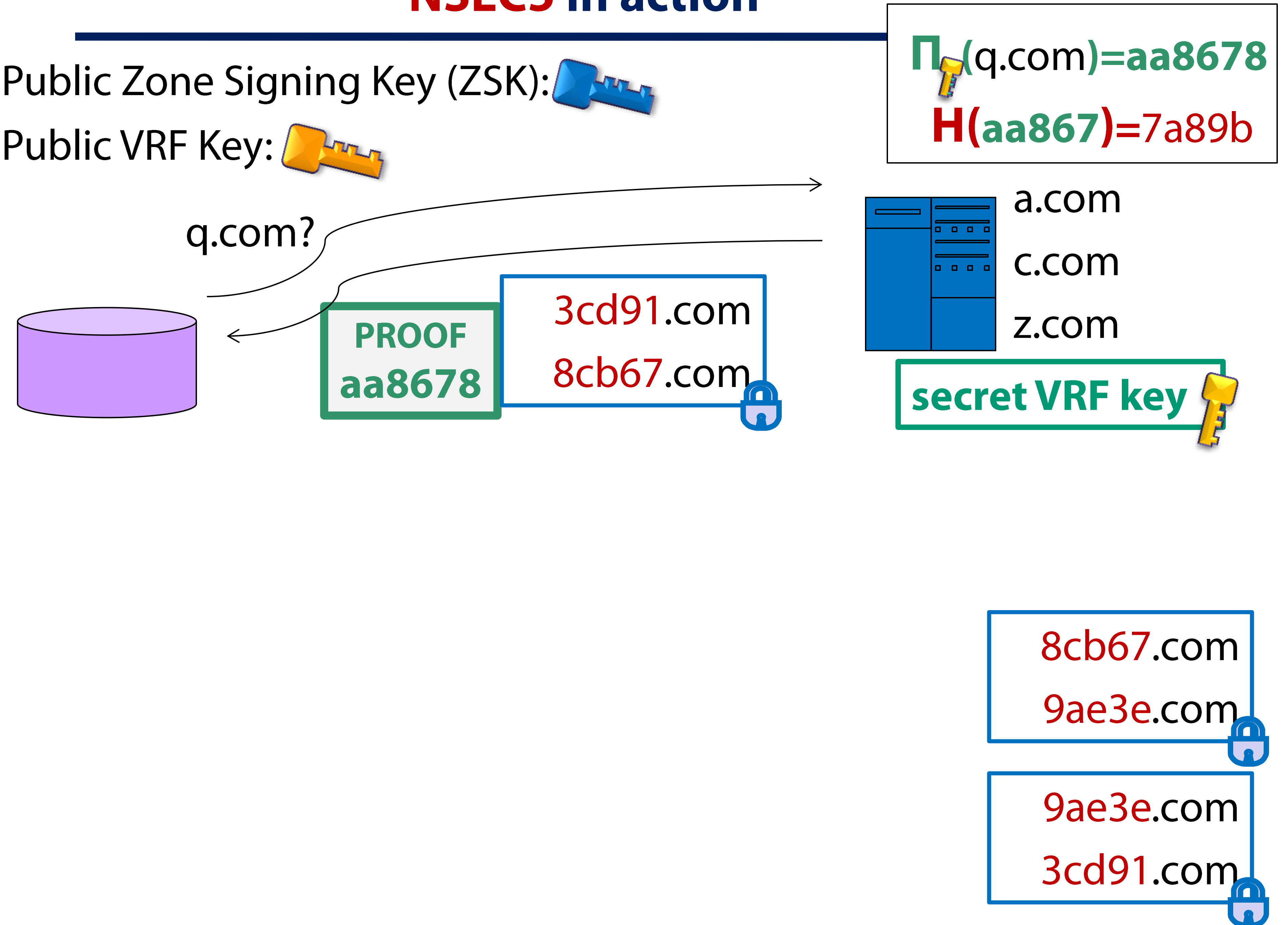

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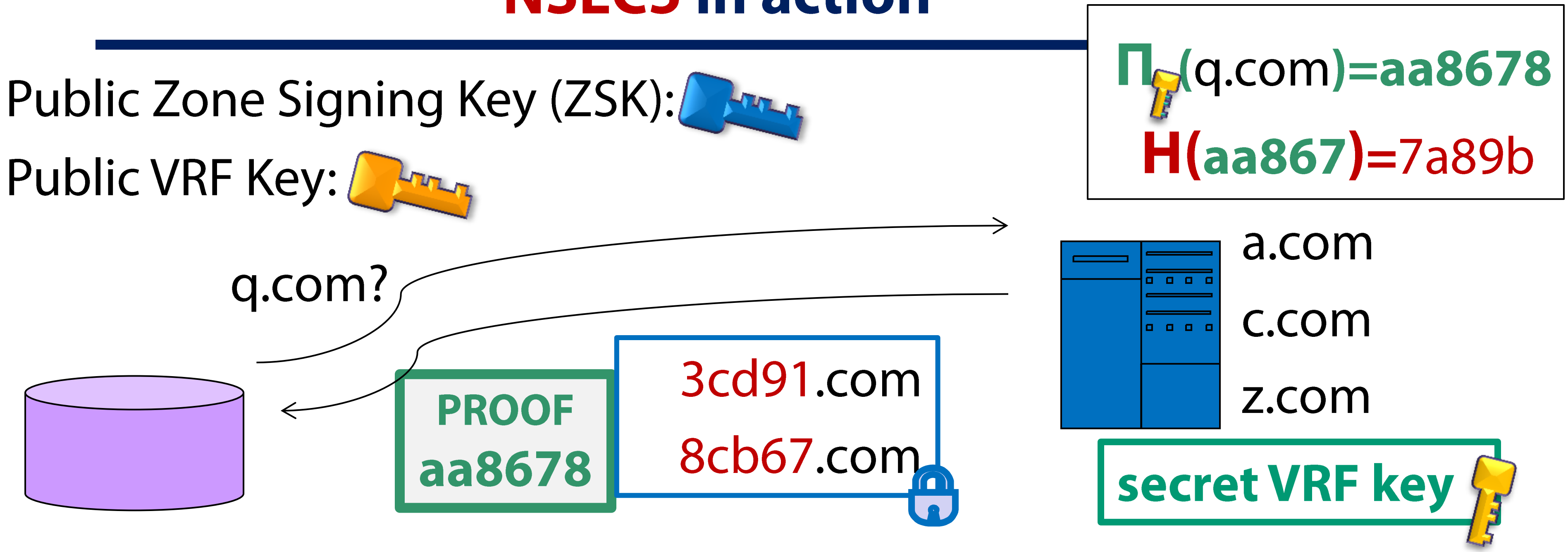


To verify:

Does NSEC5 cover PROOF?

3cd19 < H(aa8678) < 8cb67

Does PROOF match query?

VER(q.com, aa8678)

With **NSEC5-RSA** this is just an RSA verification

comparison of different schemes

	No offline zone enumeration	Integrity vs outsiders	Integrity vs compromised nameserver	No online crypto
DNS (legacy)	✔	X	X	✔
NSEC or NSEC3	X	✔	✔	✔
Online Signing ("NSEC3 White Lies")	✔	✔	X	X
NSEC5	✔	✔	✔	X

Because resolvers cannot compute VRF hashes offline

Necessary to prevent zone enumeration & have integrity

Because the nameserver doesn't know the zone-signing key

Show proof

NSEC5 implementation*

Knot DNS & **Unbound**

authoritative nameserver — recursive resolver

Two versions of NSEC5:

1. NSEC5-RSA from **[NDSS'15]**
   - The VRF proof is a deterministic RSA signature (2048 bits)
2. New NSEC5-ECC:
   - For 256-bit elliptic curves, the VRF proof is 641 bits.

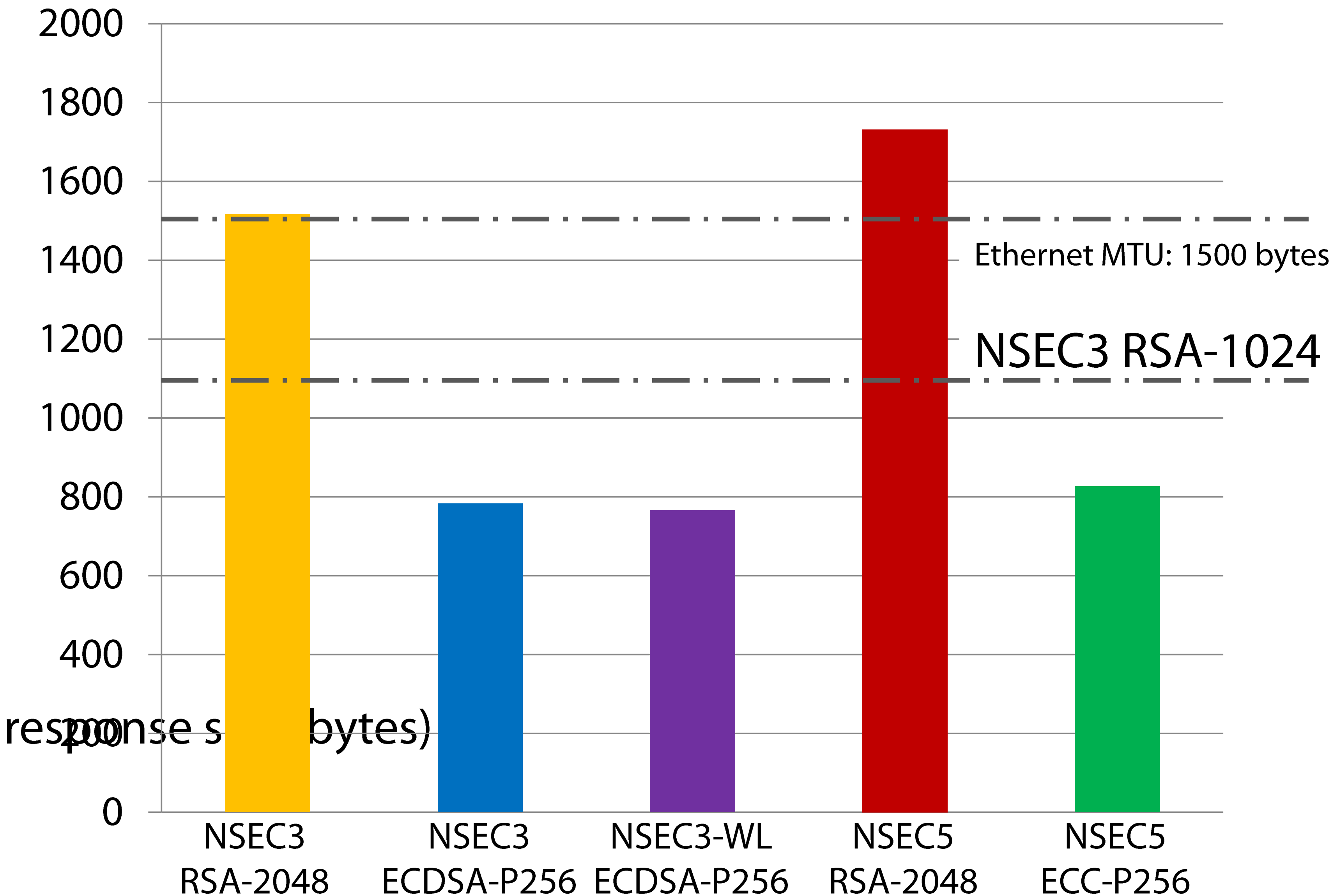
We use unstandardized optimizations developed for NSEC3

1. The wildcard bit **[GiebenMekking'12]**
2. Precomputed closest encloser proofs

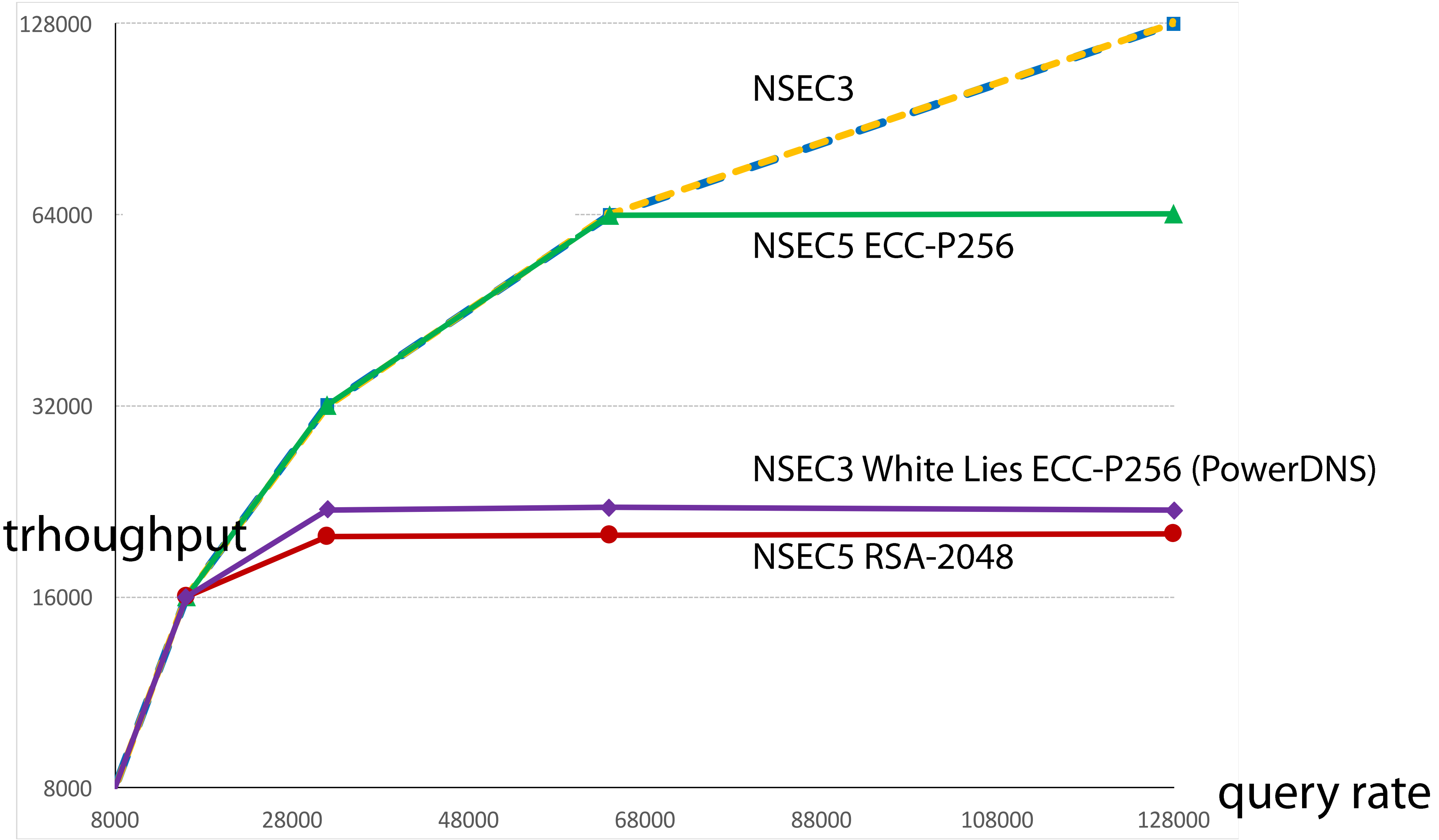
9K Lines of Code, no new libraries (openSSL) or system optimizations

*** Work done while on internship at Verisign Labs**

empirical measurement of NXDOMAIN response sizes



nameserver query throughput (pure NXDOMAIN traffic)



Machine specs: 20X Intel(R) Xeon(R) CPU E5-2660 v3 @ 2.60GHz Dual Mode **(Total 24 threads on 40 virtual CPUs)** 256GB RAM running CentOS Linux 7.1

NSEC5 project resources

Full results in our new tech report (Feb 2017)
https://ia.cr/2017/099

Project page: https://www.cs.bu.edu/~goldbe/papers/nsec5.html
Internet Draft: https://datatracker.ietf.org/doc/draft-vcelak-nsec5/

Implementation coming soon.

Anonymous posts (not from our team!) from
http://dnsreactions.tumblr.com/

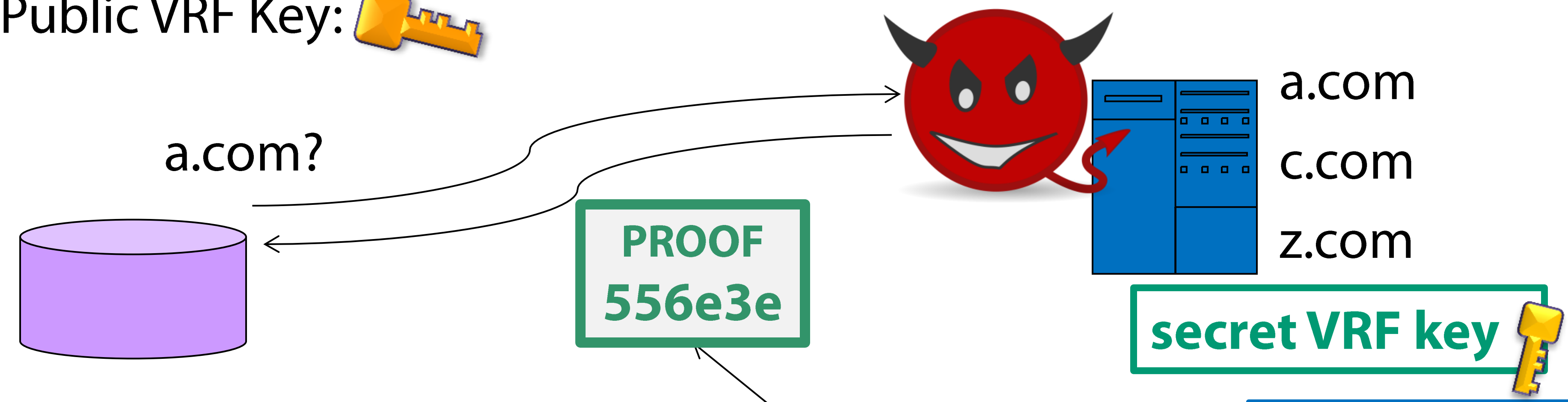
Hearing about NSEC5

When I finally grasp NSEC5

why NSEC5 has integrity even if secret VRF key is lost

Public Zone Signing Key (ZSK):

Public VRF Key:



The proof is unique given the public VRF key. It must be correct b/c resolvers validate it!

! Don't know secret ZSK, so can't forge NSEC5s

! There is no covering NSEC5 to replay, since **H(556e3e)=**9ae3e

back to talk

Public parameters. Let q be a prime number, Z_q be the integers modulo q, $Z_q^* = Z_q - \{0\}$, and let G a cyclic group of prime order q with generator g. We assume that q, g and G are public parameters of our scheme. Let H_1 be a hash function (modeled as a random oracle) mapping arbitrary-length bitstrings onto the cyclic group G. (See Appendix A for a suggested instantiation of H_1.) Let H_3 be a hash function (modeled as a random oracle) mapping arbitrary-length bitstrings to fixed-length bitstrings. We can use any secure cryptographic function for H_3; in fact, we need only the first ℓ bits of its output for ℓ-bit security. Let H_2 be a function that takes the bit representation of an element of G and truncates it to the appropriate length; we need a 256 bit output for 128-bit security.

Keys. The secret VRF key $x \in Z_q$ is chosen uniformly at random. The public VRF key is g^x.

Hashing. Given the secret VRF key x and input α, compute the proof π as:

1. Obtain the group element $h = H_1(\alpha)$ and raise it to the power of the secret key to get $\gamma = h^x$.
2. Choose a nonce $k \in Z_q$.
3. Compute $c = H_3(g, h, g^x, h^x, g^k, h^k)$.
4. Let $s = k - cx \mod q$.

The proof π is the group element γ and the two exponent values c, s. (Note that c may be shorter than a full-length exponent, because its length is determined by the choice of H_3). The VRF output $\beta = F_{SK}(\alpha)$ is computed by truncating γ with H_2. Thus

$$\pi = (\gamma, c, s) \qquad\qquad \beta = H_2(\gamma)$$

Notice that anyone can compute β given π.

Verifying. Given public key g^x , verify that proof π corresponds to the input α and output β as follows:

1. Given public key g^x, and exponent values c and s from the proof π, compute $u = (g^x)^c \cdot g^s$. Note that if everything is correct then $u = g^k$.
2. Given input α, hash it to obtain $h = H_1(\alpha)$. Make sure that $\gamma \in G$. Use h and the values (γ, c, s) from the proof to compute $v = (\gamma)^c \cdot h^s$. Note that if everything is correct then $v = h^k$.
3. Check that hashing all these values together gives us c from the proof. That is, given the values u and v that we just computed, the group element γ from the proof, the input α, the public key g^x and the public generator g, check that:

$$c = H_3(g, H_1(\alpha), g^x, \gamma, u, v)$$

Finally, given γ from the proof π, check that $\beta = H_2(\gamma)$.

Figure 2: An EC-based VRF for NSEC5. We use a multiplicative group notation. This VRF adapts the Chaum-Pederson protocol [28] for proving that two cyclic group elements g^x and h^x have the same discrete logarithm x base g and h, respectively.