UNIVERSITÄT DUISBURG ESSEN

# Measurement Survey of Server-Side DNSSEC Adoption

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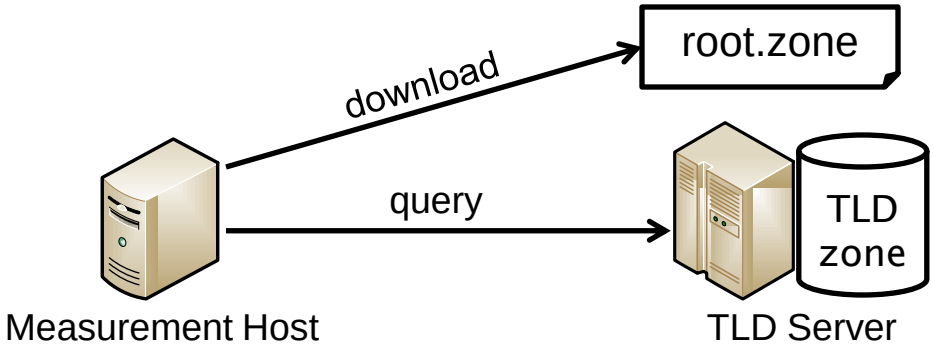
# Outline

1. DNSSEC signing at top-level domains
2. Quantification of **all** signed second-level domains (5.1 million)
3. Analysis of 3.4 million signed second-level domains

- Datasets acquired in **February/March 2015**
  - Partial update on signing algorithms from **June 2016**

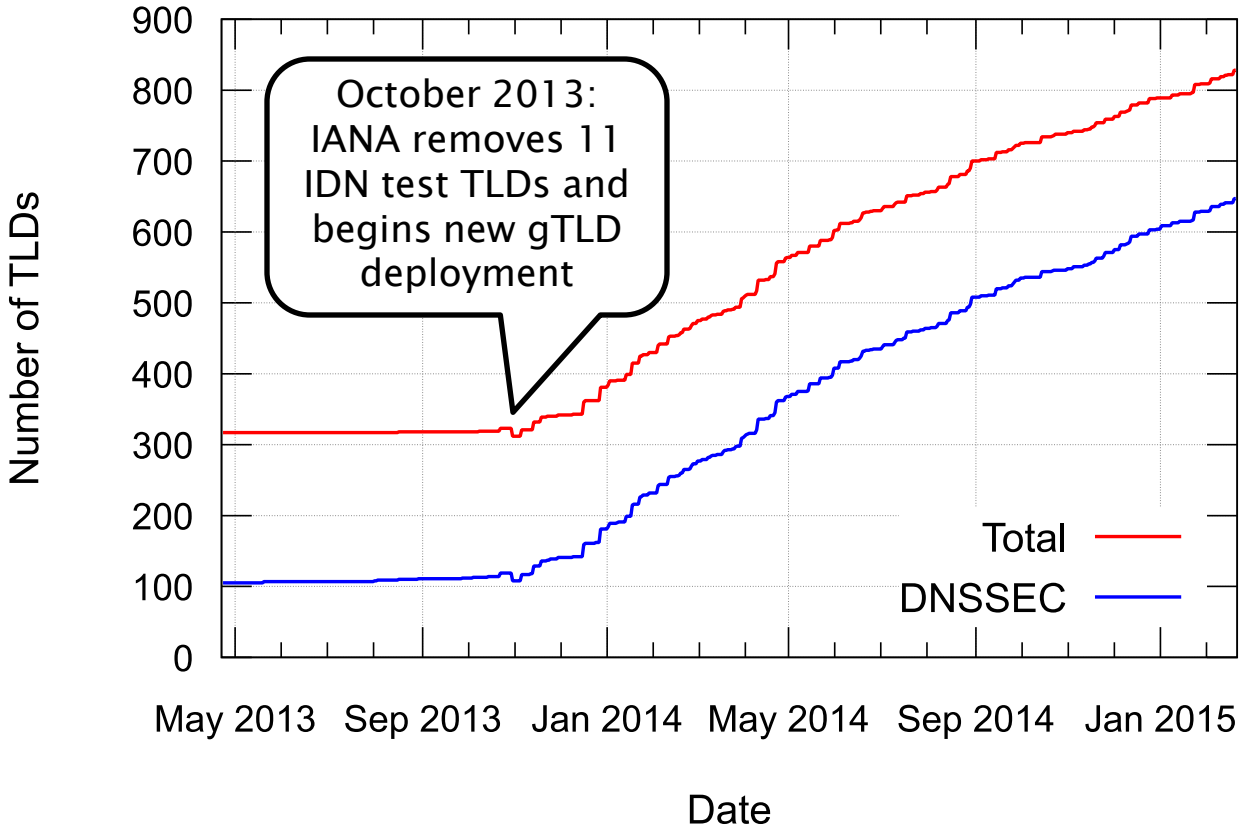
# TOP-LEVEL DOMAINS

# Signed Top-Level Domains




- Method:
  - Download and parse IANA root zone file daily
  - Probe TLD servers daily for various records
  - 22-month observation from Apr 2013 to Feb 2015

# Timeline


900
800
700
600
500
400
300
200
100
0
Number of TLDs
October 2013:
IANA removes 11
IDN test TLDs and
begins new gTLD
deployment
Total
DNSSEC
May 2013
Sep 2013
Jan 2014
May 2014
Sep 2014
Jan 2015
Date

# Public Keys

- **647** TLDs (**100%**) use RSA as signing algorithm
  - All with separate KSK/ZSK

KSK

| Key Length | Count |
|---|---|
| 1024 | 1 |
| 1280 | 4 |
| 2048 | 772 |
| 2056 | 1 |
| 4096 | 5 |

*Feb 2015*

Most frequent: 2048-bit KSK

ZSK

| Key Length | Count |
|---|---|
| 1024 | 594 |
| 1032 | 1 |
| 1048 | 2 |
| 1152 | 3 |
| 1280 | 225 |
| 2048 | 32 |

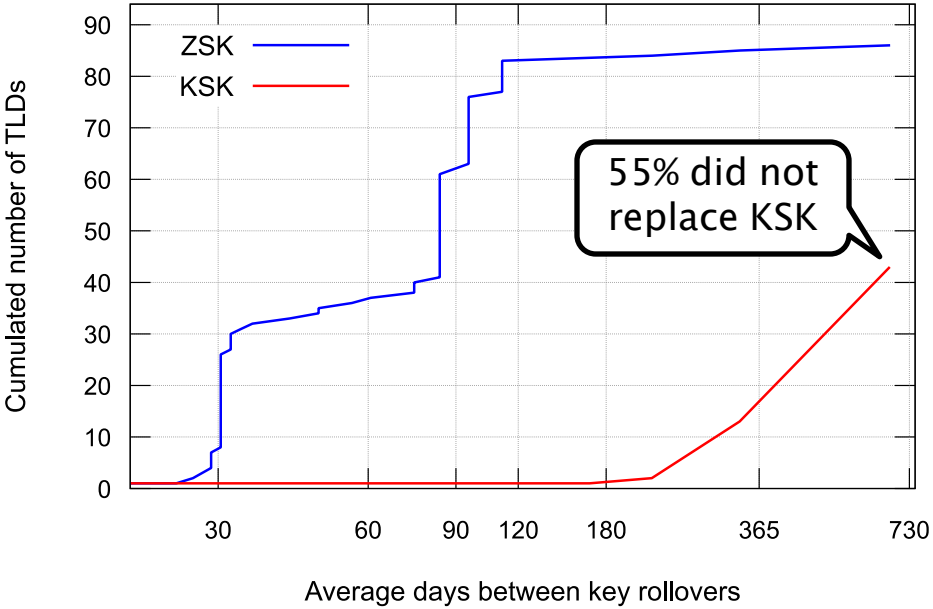
*Feb 2015*

Most frequent: 1024-bit ZSK

ARI Registry Services uses 1280-bit ZSK for new gTLDs

# Key Rollover Intervals

94 TLDs signed for the whole period



# Key Rollover Intervals

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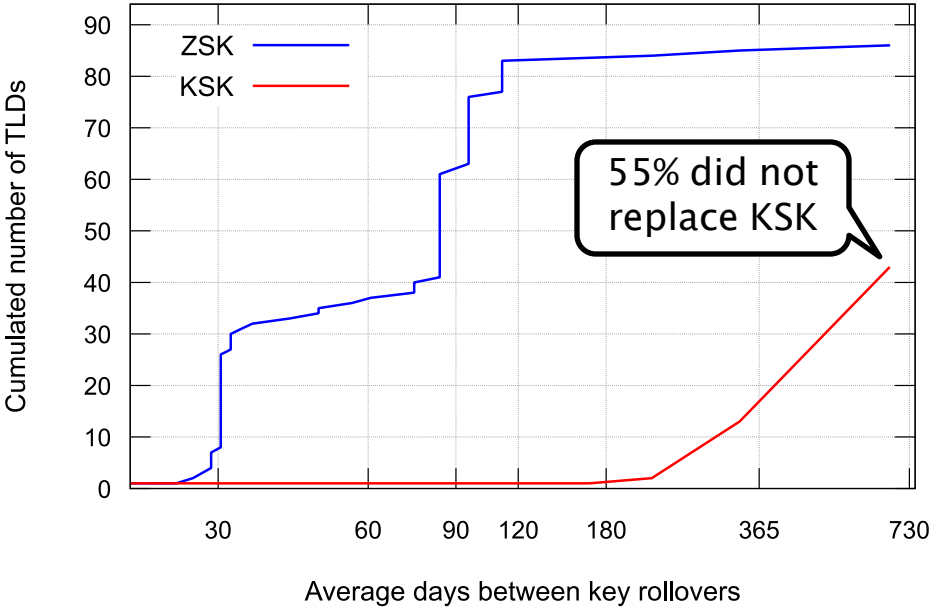
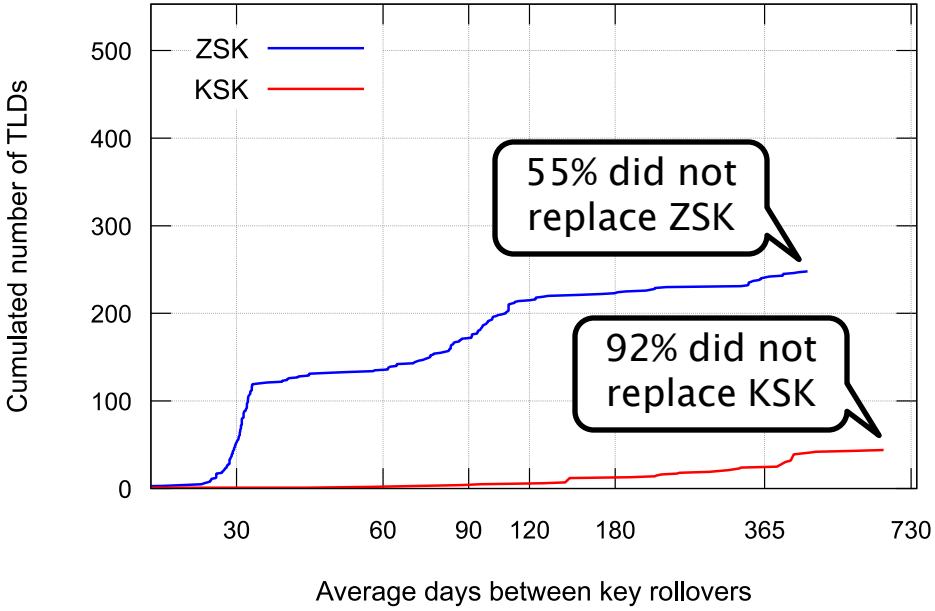



553 newly signed TLDs



# RSA Public Exponent

- Choice of *e* determines verification performance
  - Guideline: small value, low hamming weight

KSK

| Exponent | Count |
|---|---|
| 3 | 15 |
| $2^{16} + 1$ | 762 |
| $2^{32} + 1$ | 6 |

*Feb 2015*

e.g. by Verisign

ZSK

| Exponent | Count |
|---|---|
| 3 | 15 |
| $2^{16} + 1$ | 834 |
| $2^{32} + 1$ | 8 |

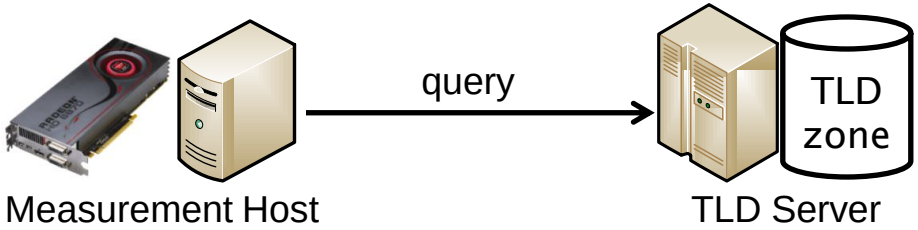
*Feb 2015*

Most frequent: *e*=65,537

- Above choices are fine (safe and fast)

# QUANTIFICATION OF SIGNED SECOND-LEVEL DOMAINS

# DNSSEC at Second-Level Domains




- Method:
  - Perform NSEC & NSEC3 zone enumeration on all TLDs
  - Includes 26 SLDs like `com.br`, `co.kr`, `com.tw`, `co.uk`
  - NSEC: `ldns-walk` [http://www.nlnetlabs.nl/projects/ldns/]
  - NSEC3: `nsec3breaker` [http://dnssec.vs.uni-due.de/nsec3]

# Zone Enumeration Results

- Duration: about 3–4 days in March 2015
- 107 TLDs with NSEC: 7.99 million names
- 540 TLDs with NSEC3: 7.49 million hash values
  - Most TLDs use opt-out, thus fewer NSEC3 records
  - CPU fast enough to retrieve most NSEC3 hash values
  - Switched to GPU to close the last few gaps (~100) for large zones ⇨ yields complete NSEC3 chain

# TLDs with most Secure Delegations

| | TLD | NSEC(3) | DS | Address | Empty | Other |
|---|---|---|---|---|---|---|
| 1. | nl | NSEC3, opt-out, i=5 | 2,279,702 | 5 | 1 | 1 |
| 2. | br | subject to subdomain | 566,694 | 0 | 0 | 34,625 |
| 3. | cz | NSEC3, i=10 | 448,984 | 0 | 0 | 717,267 |
| 4. | com | NSEC3, opt-out, i=0 | 426,182 | 0 | 0 | 1 |
| 5. | se | NSEC | 349,514 | 9 | 0 | 940,946 |
| 6. | eu | NSEC3, opt-out, i=1 | 320,311 | 7 | 1 | 1 |
| 7. | fr | NSEC3, opt-out, i=1 | 205,662 | 0 | 6 | 3 |
| 8. | no | NSEC3, opt-out, i=5 | 119,759 | 4 | 2 | 2 |
| 9. | be | NSEC3, opt-out, i=5 | 92,385 | 0 | 1 | 2 |
| 10. | net | NSEC3, opt-out, i=0 | 81,391 | 0 | 0 | 1 |
| | *[637 others omitted]* | | | | | |
| | | **Total:** | **5,146,705** | **926,279** | **131,610** | **9,272,944** |

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| 7. | fr | NSEC3, o | | | 0 | |
| 8. | no | NSEC3, o | | | 4 | 2 |
| 9. | be | NSEC3, opt-out, i=5 | 92,3 | | | |
| 1 | | | 81,391 | | | |
| | | | *37 others omitted]* | | | |
| | | **Total:** | **5,146,705** | **926,279** | **131,610** | **9,272,944** |

A or AAAA records (plus a few CNAME or MX records)

Insecure delegations or other records

Empty non-terminals

Total number of securely delegated registered domains

# Address Records

| | TLD | NSEC(3) | DS | Address | Empty | Other |
|---|---|---|---|---|---|---|
| 11. | org | NSEC3, opt-out, i=1 | 46,382 | 10,737 | 4,976 | 448 |
| 12. | ovh | NSEC3, opt-out, i=1 | 29,372 | 0 | 0 | 1 |
| 13. | nu | NSEC3, i=5 | 21,126 | 0 | 0 | 235,308 |
| 14. | de | NSEC3, opt-out, i=15 | 20,004 | 185,107 | 89,689 | 2 |
| 15. | pl | NSEC3, opt-out, i=12 | 18,110 | 7 | 0 | 1 |

- Some TLDs allow to put addresses directly into the TLD zone instead of delegations
  - Causes empty non-terminals when e.g. record for `www.example.de` exists but `example.de` is empty

# Dangling Glue Records

| | TLD | NSEC(3) | DS | Address | Empty | Other |
|---|---|---|---|---|---|---|
| 11. | org | NSEC3, opt-out, i=1 | 46,382 | 10,737 | 4,976 | 448 |
| 12. | ovh | NSEC3, opt-out, i=1 | 29,372 | 0 | 0 | 1 |
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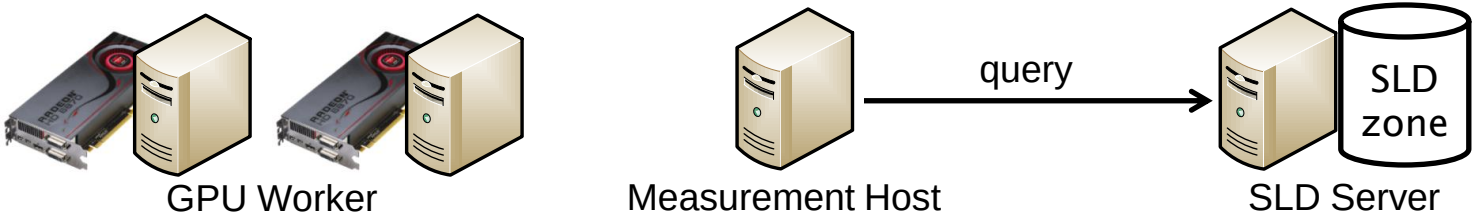
| 15. | pl | NSEC3, opt-out, i=12 | 18,110 | 7 | 0 | 1 |

- Some TLDs do not enforce removal of glue records after a delegation has been removed
  - Former glue record like `ns1.example.org` becomes authoritative and causes empty non-terminal

# ANALYSIS OF SIGNED SECOND-LEVEL DOMAINS

# Algorithms and Keys at Second-Level Domains




- Method:
  - Break NSEC3 hash values with `nsec3breaker`
  - Query for DS and DNSKEY records for known second-level domains

# NSEC3 Hash Breaking

- NSEC3: 7.49 million hash values from 540 TLDs
  - 4.65 million (62%) broken after 3 weeks of computing
  - 4 graphic cards (AMD HD 7970, AMD HD 6970, 2x NVIDIA GTX 690)
  - 22 CPU cores (contribute 2% of total computing power)

| Method | Names tested | Names found |
|---|---|---|
| Brute-force | $5.2 \times 10^{14}$ | 1,353,657 |
| Dictionary | $3.2 \times 10^{14}$ | 3,198,966 |
| Markov | $1.1 \times 10^{13}$ | 96,817 |
| **Total** | **$8.4 \times 10^{14}$** | **4,649,424** |

NSEC3 attack details: [https://www.vs.uni-due.de/paper/2014_Wander_NSEC3.pdf]

# Signing Algorithms and Public Keys

- 3.4 million domains with DS (67% out of 5.1M)
  - 89% of them appear to use a KSK/ZSK scheme

Zero RSA/MD5

Few DSA keys

| Algorithm | Key SEP=1 | Key SEP=0 |
|---|---|---|
| RSA/MD5 | 0 | 0 |
| DSA/SHA-1 | 2,176 | 2,279 |
| RSA/SHA-1 | 1,550,859 | 1,848,283 |
| RSA/SHA-256 | 1,875,294 | 2,785,784 |
| RSA/SHA-512 | 1,220 | 1,158 |
| GOST R 34.10-2001 | 30 | 30 |
| ECDSA P-256/SHA-256 | 27 | 25 |
| ECDSA P-384/SHA-384 | 21 | 17 |
| **Total** | **3,429,630** | **4,637,576** |

*March 2015*

Most frequent: RSA (>99%)

ECDSA rarely (in **2015**)

# Signing Algorithms and Public Keys (2016)

- 2.6 out of the 3.4 million domains still there
  - Some domains have ceased to exist in the meantime

| Algorithm | Key SEP=1 | Key SEP=0 | Key SEP=1 | Key SEP=0 |
|---|---|---|---|---|
| RSA/MD5 | 0 | 0 | 0 | 0 |
| DSA/SHA-1 | 2,176 | 2,279 | 1,256 | 1,289 |
| RSA/SHA-1 | 1,550,859 | 1,848,283 | 1,057,868 | 1,365,548 |
| RSA/SHA-256 | 1,875,294 | 2,785,784 | 1,442,347 | 2,131,923 |
| RSA/SHA-512 | 1,220 | 1,158 | 26,285 | 51,409 |
| GOST R 34.10-2001 | 30 | 30 | 34 | 34 |
| ECDSA P-256/SHA-256 | 27 | 25 | 707 | 551 |
| ECDSA P-384/SHA-384 | 21 | 17 | 44 | 36 |
| **Total** | **3,429,630** | **4,637,576** | **2,528,542** | **3,550,790** |
| | *March 2015* | | *June 2016* | |

DSA declining

Most frequent: RSA (>99%)

ECDSA growing

# RSA Key Lengths

- 0.4% of domains have an insufficient key length

| Key Length | Key SEP=1 | Key SEP=0 |
|---|---|---|
| 512 | 8,704 | 14,416 |
| 1024 | 724,324 | 4,333,715 |
| 1280 | 878 | 214,944 |
| 1536 | 154,748 | 123 |
| 2048 | 2,454,645 | 64,947 |
| 4096 | 83,602 | 5,142 |
| Other | 472 | 925 |
| **Total** | **3,427,373** | **4,635,221** |

*March 2015*

Insecure

Most frequent: 1024-bit ZSK

Most frequent: 2048-bit KSK

2016 shifts slightly to longer keys but no major change yet

# RSA Public Exponent

| Exponent | Key SEP=1 | Key SEP=0 |
|---|---|---|
| 3 | 202 | 252 |
| 65,337 | 26 | 60 |
| 65,535 | 124 | 288 |
| $2^{16} + 1$ | 3,421,138 | 4,629,425 |
| $2^{30} + 3$ | 38 | 51 |
| $2^{32} + 1$ | 5,845 | 5,145 |
| **Total** | **3,427,373** | **4,635,221** |

*March 2015*

Most frequent: $e$=65,537

Not $2^{16} + 1$ ☺

- Some strange values for $e$ occur: probably typos
  - Not a problem if basic RSA properties are met: $e$ must be coprime with $\theta(n)$

# DSA Key Lengths

- DSA keys in DNSSEC are specified for group sizes up to 1024 bit
  - Note: a 1024-bit DSA key is about 3x larger in wire format than a 1024-bit RSA key

| Key Length | Key SEP=1 | Key SEP=0 |
|---|---|---|
| 512 | 3 | 5 |
| 768 | 2 | 3 |
| 1024 | 2,173 | 2,271 |
| **Total** | **2,178** | **2,279** |

*March 2015*

Most frequent: 1024-bit KSK

Most frequent: 1024-bit ZSK

# Validation Result

- All 3.4 million domains ought to be signed
  - 0.6% (2015) respectively 1.3% (2016) fail validation

Most frequent error: DNSKEY response contains no key

| Validation Result | Domains | | Domains |
|---|---|---|---|
| No DNSKEY (dangling DS) | 17,751 | | 31,642 |
| No trusted DNSKEY (dangling DS) | 1,066 | | 1,278 |
| No RRSIG for trusted DNSKEY | 238 | | 153 |
| Signature expired | 2,138 | | 668 |
| Signature verify failure | 5 | | 5 |
| **Validation failure** | **21,198** | | **33,746** |
| **Validation success** | **3,416,700** | | **2,520,610** |
| | *March 2015* | | *June 2016* |

# Recommendations

- Deprecate DSA
  - Large DNSKEY records, insufficient key length
- If using RSA, use keys with ≥2048 bits
  - If stuck with 1024 bit, replace them every few weeks
- Consider using ECDSA with 256-bit keys
- Consider using a combined signing key unless KSK/ZSK are stored at separate places

# Conclusions

- More than 5 million domains use DNSSEC
  - Around 1% of signed domains show validation errors
- RSA is the dominant signing algorithm
  - A few domains switched to ECDSA
- Future work: how many **newly signed** domains use elliptic curve cryptosystems?