DNSSEC

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Security of IT infrastructure (2017/18)

Content

DNS (Domain Name System)

- hierarchical, distributed, decentralized system
- maps domain names to IP addresses and vice versa
- tree structure (zones, delegation of responsibilities)
- 13 root “servers” (a, b, . . . , m) – clusters
    - Anycast routing
- examples (III/2018, www.root-servers.org):
    - “c” (operated by Cogent Communications) has 10 sites, 1 in Bratislava
    - “l” (operated by ICANN) has 157 sites, 1 in Bratislava
    - “j” (operated by Verisign) has 160 sites, 1 in Bratislava
    - “i” (operated by Netnod) has 60 sites, 1 in Bratislava

DNS (2)

- client – server architecture
- resource record types (RR – resource record):

SOA	start of authority	
A	address	
AAAA	IPv6 address	
NS	name server	
MX	mail exchange	
CNAME	canonical name (alias)	…

DNS (3)

- DNS servers:
  - authoritative – for own zone and for nameservers of delegated subzones
  - recursive – query other DNS servers to answer client requests
    ...+ caching functionality – remembering resolved records (efficiency)
- DNS resolvers (clients)
  - part of an operating system or application
  - usually include caching functionality
- Protocol (usually):
  - UDP, port 53
  - stateless (query – response)
  - no confidentiality, integrity or authenticity features

  - TCP for zone transfers, large response data
  - fallback mechanism, when UDP cannot be used to transer data
  - RFC 7766 (2016) DNS Transport over TCP – Implementation Requirements

Some security applications employing DNS

- Let's Encrypt
  - DNS challenge (TXT record) as an option for the proof of domain ownership
- DANE (DNS-based Authentication of Named Entities)
  - binding X.509 (TLS) certificates to names in DNS
  - TLSA resource record
  - signed by DNSSEC
  - low adoption
- Office 365
  - DNS (TXT record) as a proof of domain name ownership

DNS – some security problems (1)

- DNS spoofing / cache poisoning (client, mail server etc. redirected to fake IP address)
  - attacker answers to client before his (recursive) DNS server
  - attacker answers to DNS server before the authoritative DNS server
  - attacker changes the response of the DNS server
  - attacker inserts additional information (e.g. NS records) about other zone into his zone's response, …
  - long TTL for fake IP addresses
- some ideas how to make spoofing harder:
  - RFC 5452 Measures for Making DNS More Resilient against Forged Answers
- weaknesses in protocol design, issues in DNS server implementations (e.g. vulnerabilities in bind (NVD): 2013/5, 2014/5, 2015/7, 2016/11, 2017/3)

DNS – some security problems (2)

- DNS amplification attack
  - DNS server's responses can be much longer than the queries
  - source IP address spoofing
  - publicly open DNS servers … DDoS attack
  - counting open resolvers (dnsscan.shadowserver.org):
    $\sim$ 4.5 mil. (IV/2016), 4.3 mil. (IV/2017), 3.5 mil. (III/2018)
- possible mitigations of amplification attack:
  - Disabling Recursion on Authoritative Name Servers
  - Limiting Recursion to Authorized Clients
  - Response Rate Limiting

DNS – some security problems (3)

- DNS rebinding
  - target the same-origin policy in a web browser
  - the first response of attacker's DNS server with short TTL
  - web browser loads malicious code
  - following question is answered by sending internal IP address
  - …attacking internal web
- mitigation of DNS rebinding:
  - DNS pinning – locking IP address to value from the first DNS response
  - filter out the private IP addresses from DNS responses, etc.
- Threat Analysis of the Domain Name System (DNS), RFC 3833

DNS – few (cryptographic) solutions to security problems

- TSIG
  - Transaction Signatures (RFC 2845)
  - HMAC-MD5 and shared secrets for authentication
  - primary use for dynamic updates of DNS records, zone transfers etc.
  - no means how to manage/distribute shared secrets
- SIG(0)
  - DNS Request and Transaction Signatures (SIG(0)s), RFC 2931
  - digital signatures for dynamic DNS updates
  - public key part of the zone
- DNSSEC
  - *today's theme …*

DNSSEC – introduction

- Domain Name System SECurity extensions

RFC 4033	DNS Security Introduction and Requirements
RFC 4034	Resource Records for the DNS Security Extensions
RFC 4035	Protocol Modifications for the DNS Security Extensions
RFC 5011	Automated Updates of DNSSEC Trust Anchors
RFC 5155	DNSSEC Hashed Authenticated Denial of Existence
...	

- Main idea: digitally signed DNS records (by DNS server)

  ... DNSSEC itself is concerned with object security of DNS data, not channel security of DNS transactions.

- Goals:
  - data authenticity and integrity
  - authenticity of non-existent data

DNSSEC does not provide

- data confidentiality (no encryption)
  - no solution to privacy issues
- DoS attacks protection
  - against DNS server
  - against clients (DNS amplification)
  - DNSSEC can worsen the situation – signature verification, longer responses

Current state (1)

http://stats.research.icann.org/dns/tld_report/

- July 2010: DNS root zone signed
- April 2012: (overall 313 TLDs in root zone / 91 signed)
- April 2013: (317 TLDs in root zone / 111 signed)
- May 2014: (571 TLDs in root zone / 386 signed)
- May 2015: (923 TLDs in root zone / 752 signed)
- April 2016: (1292 TLDs in root zone / 1131 signed)
- April 2017: (1531 TLDs in root zone / 1386 signed)
- March 2018: (1544 TLDs in root zone / 1407 signed)

Current state (2)

- SK and neighbors:

signed zone with DS in root zone	cz., pl., at., ua., hu.
nothing	sk.

- com. zone signed in March 2011
  - current state – negligible(?) DNSSEC deployment in 2nd level domains
  - approx. 0.6% of domains in com. signed (www.statdns.com)
  - nothing: google.com, facebook.com, microsoft.com, apple.com …
- Google Public DNS servers (8.8.8.8, 8.8.4.4) support DNSSEC validation by default since 2013

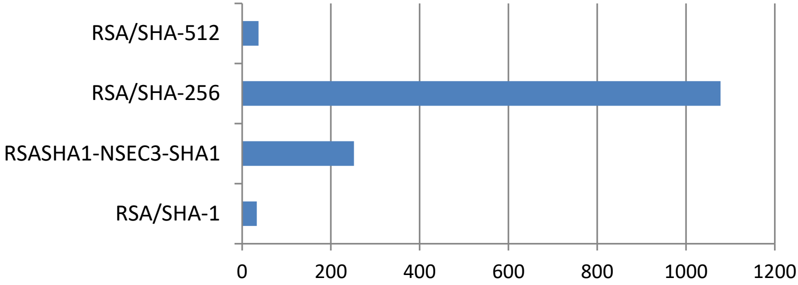
Keys a algorithms

- Key Signing Keys (KSK)
  - signing other keys in DNSKEY records
  - DS record needs to be published in parent zone (public key fingerprint)
- Zone Signing Keys (ZSK)
  - signing other records in the zone
  - simple management of ZSK (completely managed by the zone)

- the most frequent algorithms: RSA (usually 2048 bits) with SHA-256
  - digital signature scheme: RSASSA-PKCS1-v1.5 (PKCS #1)
  - RSA key length max. 4096 bits
    (min. 1024 for RSA/SHA-512, 512 for RSA/SHA-256)

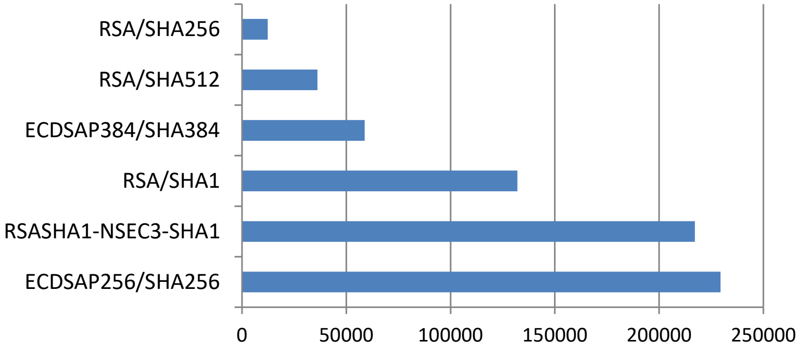
Algorithms – basic statistics (1)

- DS records in the root zone (March 2018):



Algorithms – basic statistics (2)

- algorithms in the CZ. zone (data published by cz.nic, March 2018):



New DNS record types – DNSKEY and DS

examples from the root zone

`http://www.internic.net/zones/root.zone`

- DNSKEY – public key

  ```
  . 172800 IN DNSKEY 256 3 8 AwEAAZLsvv...pp/
  . 172800 IN DNSKEY 257 3 8 AwEAAagAIK...z0=
  ```

  - . 172800 IN – owner, TTL, class
  - 256, 257 – flags (256: ZSK; 257: KSK, the last bit denotes SEP (Secure Entry Point))
  - 3 – protocol (fixed)
  - 8 – algorithm (RSA/SHA-256)
- DS (Delegation signer) – KSK identification (for delegated zone)

  ```
  GR. 86400 IN DS 35136 7 2 F7BF4C362...5C3
  ```

  - 35136 – key tag (for fast selection of DNSKEY record)
  - 7 – algorithm corresponding to referenced DNSKEY record (RSA/SHA1/NSEC3)
  - 2 – hash function (SHA-256) used for digest calculation

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Root zone

- Management of KSK and ZSK for the root zone:
  - DNSSEC Practice Statement for the Root Zone KSK Operator
  - DNSSEC Practice Statement for the Root Zone ZSK Operator
- Publishing KSK:
  - DNSSEC Trust Anchor and Keys Publication for the Root Zone
  - XML (digest), p7s (S/MIME signature), pem (certificates for validating the signature)
  - available via HTTPS: `https://www.iana.org/dnssec/files`
  - 2017: new KSK generated
  - the root zone contains KSK-2010 and KSK-2017
  - KSK rollover postponed → October 2018 (1 year later than planned)

New DNS record types – RRSIG

- RRSIG – signature for a record set
  `. 518400 IN RRSIG NS 8 0 518400 20170505170000 20170422160000 14796 . D/aCx ...Uw==`
  - `. 518400 IN RRSIG` – owner, TTL, class, type
  - NS – type that the signature covers
  - 8 – signing algorithm (RSA/SHA-256)
  - 0 – the number of labels (used to validate $*$)
  - 518400 – original TTL value
  - 20170505170000 20170422160000 – signature validity (until 05.05.2017 17:00 UTC, starting 22.04.2017 16:00 UTC) ~ 13 days
  - 14796 – key tag of the key in DNSKEY record for signature verification
  - . – singer's name (the owner in the DNSKEY record)
  - and finally, the signature

RRSIG

- a record set is signed (RRset)
  - RRset is determined by shared attributes: owner, class, type
- some records are unsigned:
  - NS records of delegated zones
  - A, AAAA records of delegated zones
  - these are data of delegated zones (not their parent zone)

Authenticated denial of existence – NSEC

- How to answer that a record does not exist?
- we don't want to sign on-line (access to private key required, slow)
- sorted records (canonical order)
- NSEC – "next secure" record

  `cz. 86400 IN NSEC dabur. NS DS RRSIG NSEC`

  `cz. 86400 IN RRSIG NSEC . . .`

  - for particular domain name (`cz.`)
  - `dabur.` – next owner (domain name) in zone file
  - NS DS RRSIG NSEC – types of existing records for current owner/name (`cz.`)
- the last NSEC refers to the beginning (next owner)
- there is one RRSIG record for each NSEC record

Nonexistent record – response types

- NXDOMAIN (nonexistent domain name, e.g. `da.`)

```
$dig da. @8.8.8.8
...
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NXDOMAIN, id: 4649
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 0, AUTHORITY: 1, ...
```

- NOERROR & ANSWER: 0 (the name exists but not the name with given type)

```
$dig nic.de. A @8.8.8.8 +short
81.91.170.12
$dig nic.de. AAAA @8.8.8.8 +short
$
```

Nonexistence responses using NSEC

- NXDOMAIN: in response (in authority section) – NSEC record with RRSIG, proving the missing domain name:
  `cz. 10574 IN NSEC dabur. NS DS RRSIG NSEC`
  - no name between `cz.` and `dabur.`
- NOERROR & ANSWER: 0: in response (in authority section) – NSEC record with RRSIG, proving the missing type for the domain name:

```
$dig @149.20.64.20 sk. DS +dnssec
...
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 7087
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 0, AUTHORITY: 4, ...
...
sk.       3178    IN       NSEC      ski. NS RRSIG NSEC
...
```

NSEC vs. NSEC3

- zone walking (domain names enumeration)
- nonexistent name (NXDOMAIN) leaks neighbors “above” and “below”
- possibility to enumerate the zone (∼ zone transfer via NSEC)
  - number of queries approx. linear with respect to the number of records
- problem for DNSSEC deployment …solution: NSEC3

NSEC3

- replacement of NSEC records; domain names replaced with fingerprints

```
dig @149.20.64.20 x.bund.de A +dnssec
...
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 38332
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 0, AUTHORITY: 8, ...
...
QNAS...QFBM.bund.de. 10660 IN NSEC3 1 0 10 B32599
                     QQQ9...L54O A RRSIG
```

- record-chain ordered according fingerprint values
- resolver computes name's fingerprint and finds the value between fingerprints in NSEC3 record (in practice other NSEC3 and corresponding RRSIG)

NSEC3 (2)

- NSEC3 parameters

```
QNAS...QFBM.bund.de. 10660 IN NSEC3 1 0 10 B32599
                      QQQ9...L54O A RRSIG
```

  - 1 – hash function (SHA-1)
  - 0 – flags
  - 10 – iteration count for fingerprint calculation
  - `B32599` – salt
  - next name's fingerprint, record types for current owner
- off-line attack on fingerprints (the space of domain names is limited)

Differences DNSEC vs. PKI

- no certificates
- no validity interval for keys (but signatures have validity interval)
- keys managed by corresponding zone
- trusting a public key:
  - trusting KSK of the root zone (static import) → ZSK (.) → DS (in . for de.) → KSK (de.) → ZSK (de.) → DS (in de. for .bund.de.) → KSK (bund.de.) → ZSK (bund.de)

    …and then we can verify RRSIG of A record for www.bund.de
  - of course: … + caching