TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

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Resilient Networking

Module 5: Name Resolution / DNS

Disclaimer: This module prepared in cooperation with Mathias Fischer, Michael Roßberg, and Günter Schäfer

Dresden, SS 19

Module Outline

Overview of DNS

Known attacks on DNS
- Denial-of-Service
- Cache Poisoning

Securing DNS
- Split-horizon DNS
- DNS Cookies (RFC 7873)
- DNSSEC
- DNSCurve
- PNRP
- GNS

DNS – The Domain Name System

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What is DNS?

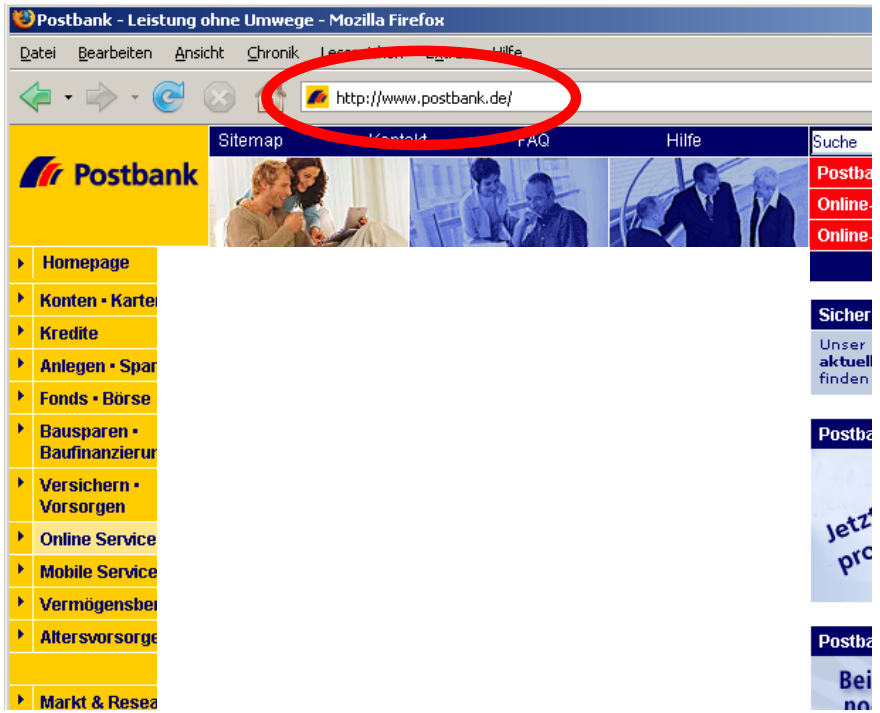
Naming Service for (almost all) Internet traffic

Lookup of (resolve)

- Host-Addresses
- Mail-Servers
- Alias Names
- Alternative Name Servers
- ...

Distributed Database consisting

of multitude of servers



DNS – Names

People: many identifiers:

- SSN, name, passport #

Internet hosts, routers:

- IP address (32 bit) - used for addressing datagrams
- "Name", e.g., www.yahoo.com - used by humans

Q: Map between IP addresses and name ?

Domain Name System:

Distributed database implemented in hierarchy of many *name servers*

Application-layer protocol: hosts, routers, name servers communicate to *resolve* names (address/name translation)

- Note: core Internet function, implemented as application-layer protocol
- Complexity at network's "edge"

DNS – what does it do?

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DNS services

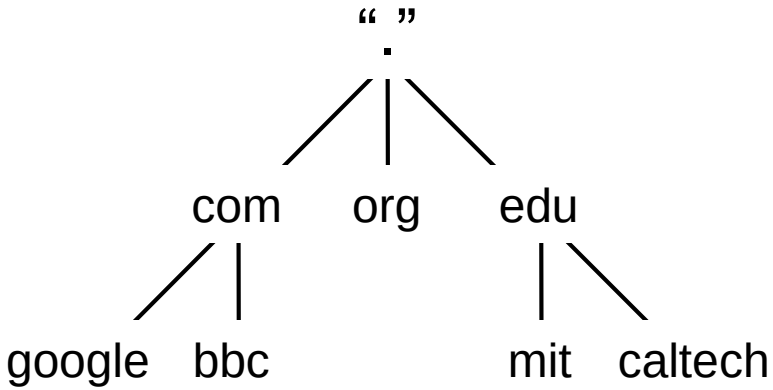
- Hostname to IP address translation
- Host aliasing
  - Canonical and alias names
- Mail server aliasing
- Load distribution
  - Replicated Web servers: set of IP addresses for one canonical name

Why not centralize DNS?

- Single point of failure
- Traffic volume
- Distant centralized database
- Maintenance
- *does not scale!*

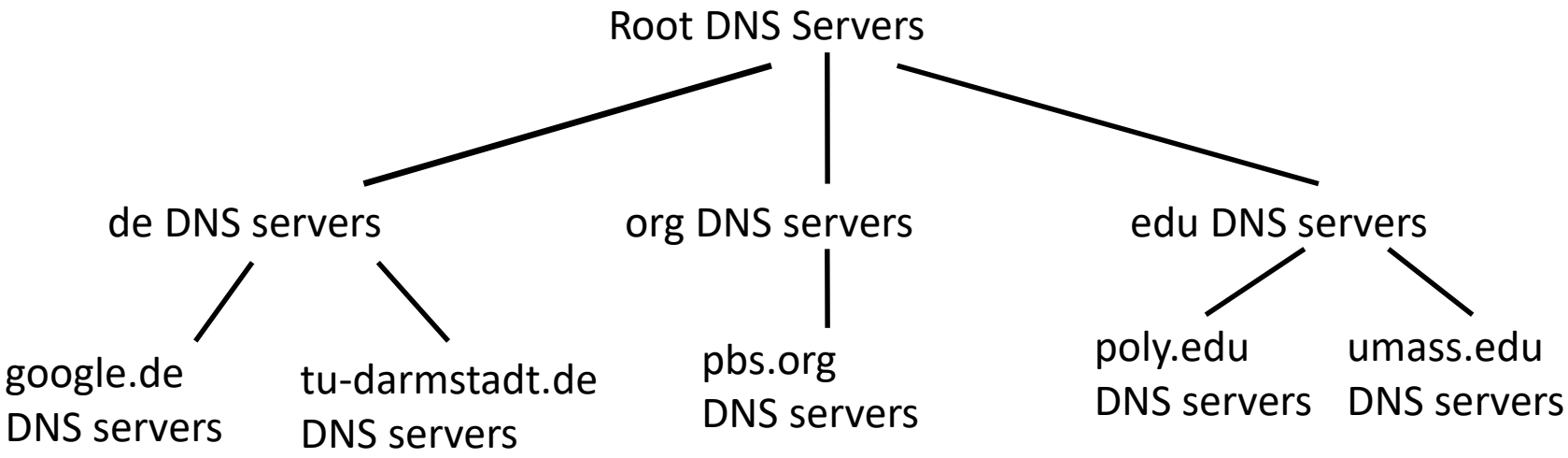
What does this „it scales“ mean anyways!?

DNS – Data Organization: Domains / Zones

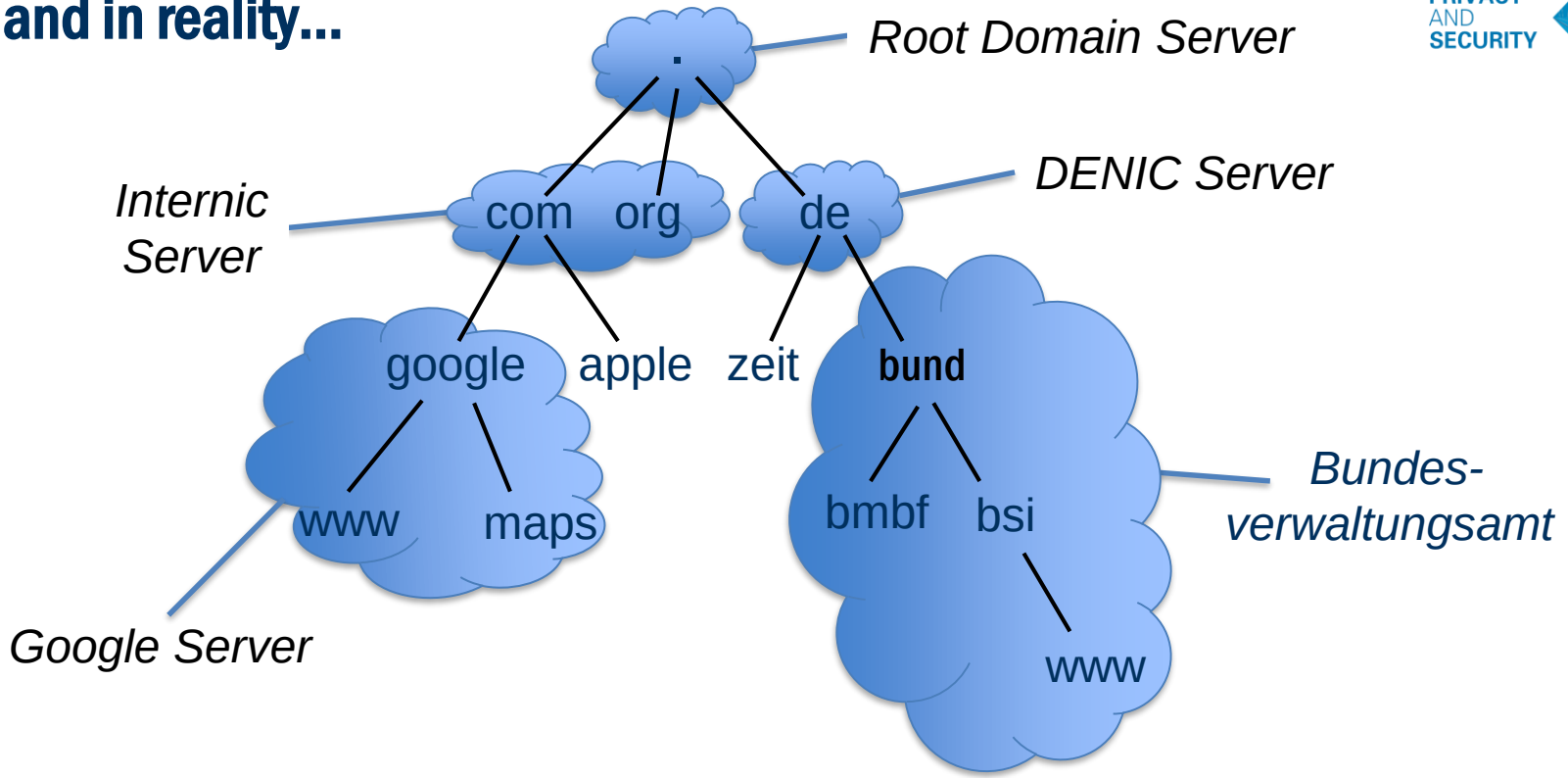


- Structured Namespace
- Hierarchical organization in sub domains/zones
- Sourced at “root zone” (“.”)
- Parent zones maintain pointers to child zones (*“zone cuts”*)
- Zone data is stored as “Resource Records” (RR)

Distributed, Hierarchical Database



...and in reality...



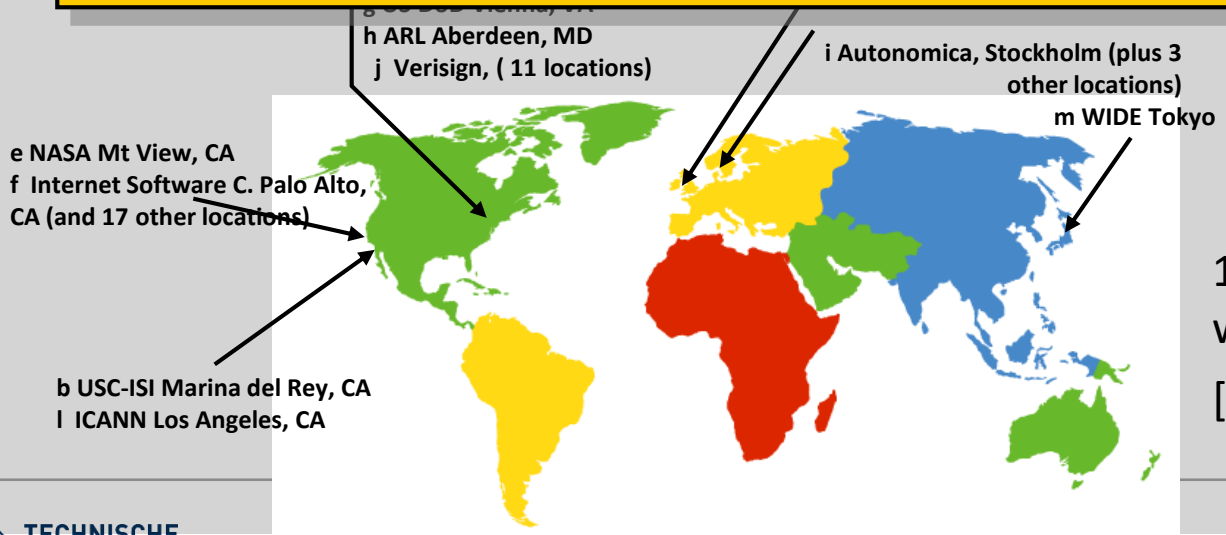
Client wants IP for www.dud.inf.tu-dresden.de; 1st approx:

- Client queries a root server to find **de** DNS server
- Client queries de DNS server to get **tu-dresden.de** DNS server
- Client queries tu-dresden.de DNS server to get IP address for www.dud.inf.tu-dresden.de

DNS: Root Name Servers

- Contacted by local name server that can not resolve name
- Root name server:
  - Contacts authoritative name server if name mapping not known
  - Gets mapping
  - Returns mapping to local name server

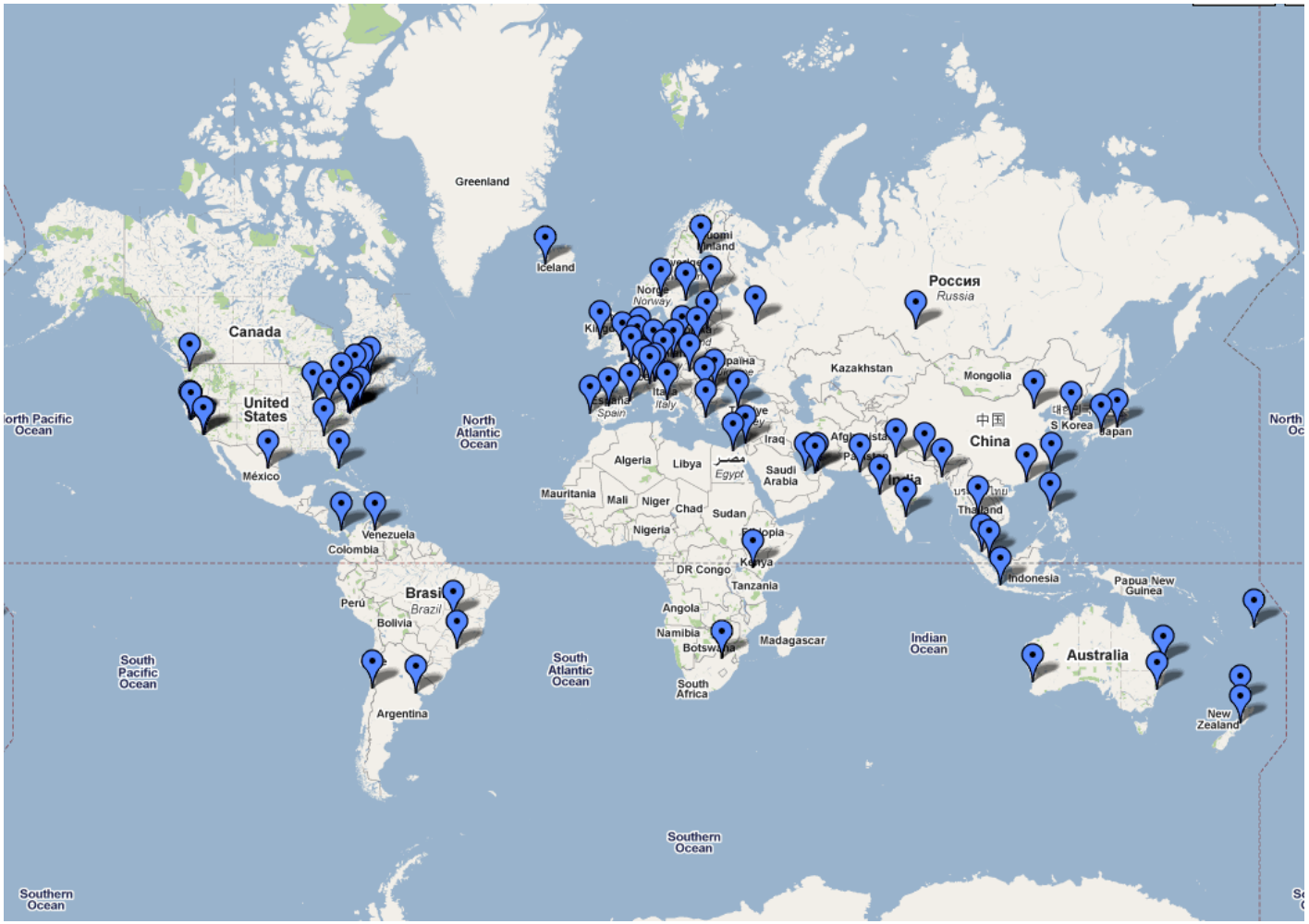
So, how many root nameservers are there actually? (physically)



13 root name servers worldwide

[A..M].ROOT-SERVERS.NET

DNS: Root Name Servers



http://www.root-servers.org/

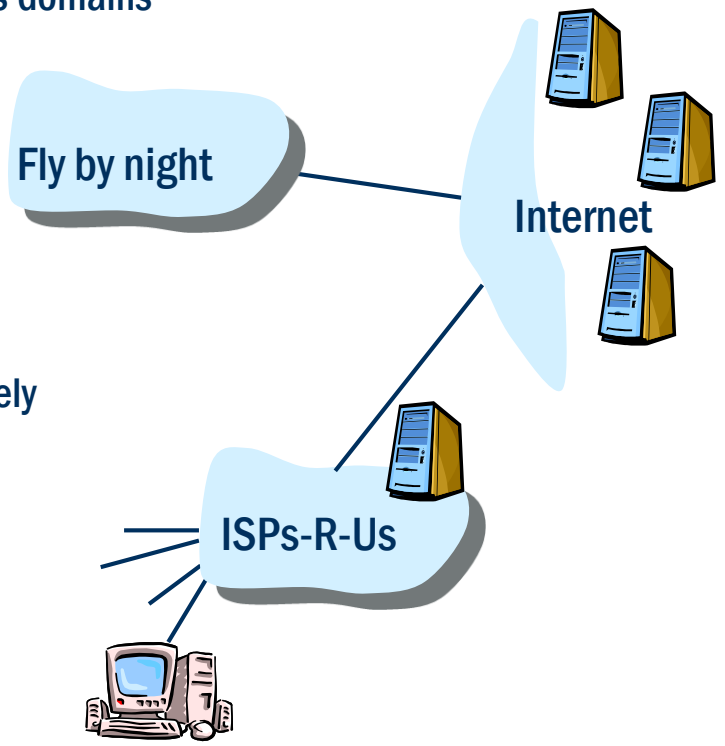
DNS – Components

Authoritative Server
- Server maintaining authoritative content of a complete DNS zone
- Top-Level-Domain (TLD) servers & auth servers of organization's domains
- Pointed to in parent zone as authoritative
- Possible load balancing: master/slaves

Recursive (Caching) Server
- Local proxy for DNS requests
- Caches content for specified period of time (soft-state with TTL)
- If data not available in the cache, request is processed recursively

Resolver
- Software on client's machines (part of the OS)
- Windows-* and *nix: Stub resolvers

- Delegate request to local server
- Recursive requests only, no support for iterative requests



DNS – Resource Record Type

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Atomic entries in DNS are called "Resource Records" (RR)

Format: <name> [<ttl>] [<class>] <type> <rdata>

- `name` (domain name of resource)
- `ttl` (Time-to-live)
- `class` (used protocol): IN (Internet), CH (Chaosnet)…
- `type` (record type): A (Host-Address), NS (Name Server),

  MX (Mail Exchange), CNAME (Canonical Name),

  AAAA (IPv6-Host-Address), DNAME (CNAME, IPv6)

- `rdata` (resource data): ***Content!*** *(What did we want to look up?)*

Specific DNS Records

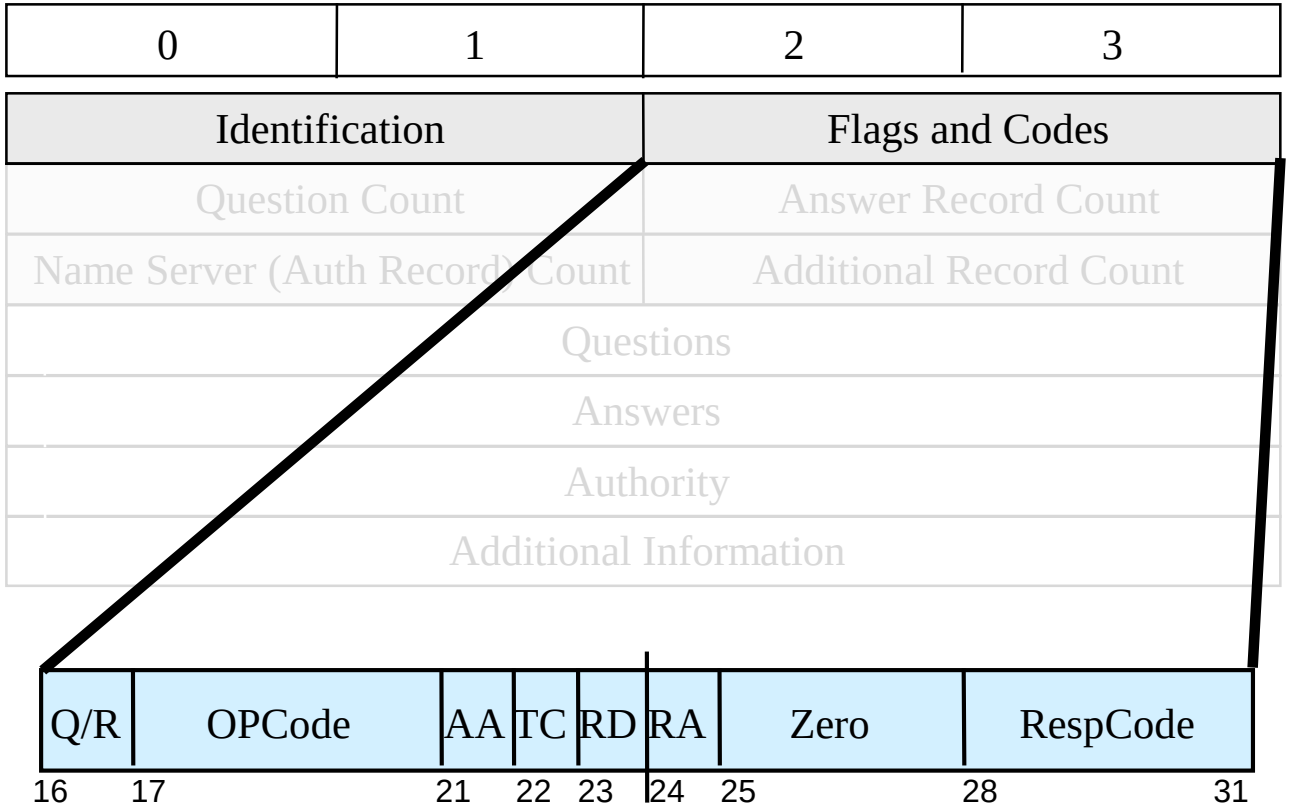
RR Format: **(name, ttl, class, type, value)**

- Type=A
  - **`name`** is hostname
  - **`value`** is IP address
- Type=NS
  - **`name`** is domain (e.g. foo.com)
  - **`value`** is IP address of authoritative name server for this domain
- Type=MX
  - **`value`** is name of mailserver associated with **`name`**
- Type=CNAME
  - **`name`** is alias name for some "canonical" (the real) name

    `www.ibm.com` is really

    `servereast.backup2.ibm.com`
  - **`value`** is canonical name

DNS – Message Format



- Q/R *Query/Response Flag*
- *Operation Code*
- AA *Auth. Answer Flag*
- TC *Truncation Flag*
- RD *Recursion Desired Flag*
- RA *Recursion Available Flag*
- Zero (three resv. bits)
- *Response Code*

DNS – Header Fields

Identifier: a 16-bit identification field generated by the device that creates the DNS query. It is copied by the server into the response, so it can be used by that device to match that query to the corresponding reply

Query/Response Flag: differentiates between queries and responses (0 ~ Query, 1 ~ Response)

Operation Code: specifies the type of message (Query, Status, Notify, Update)

Authoritative Answer Flag (AA): set to1 if the answer is authoritative

Truncation Flag: When set to 1, indicates that the message was truncated due to its length (might happen with UDP, requestor can then decide to ask again with TCP as transport service)

Recursion Desired: set to 1 if requester desired recursive processing

Recursion Available: set to 1 if server supports recursive queries

DNS: Caching and Updating Records

Once (any) name server learns mapping, it caches mapping

- Stored as “soft state”: Cache entries timeout (disappear) after some time
- TLD servers typically cached in local name servers
- Thus, root name servers not often visited

Updating records, independent of TTL

- RFC 2136 defines dynamic updates
- BIND (>8) implements `nsupdate` (upon TSIG, see below)

Inserting Records Into DNS

- Example: just created startup “Fireblog”
- Register name `fireblog.de` at a registrar (e.g., denic)
  - Need to provide registrar with names and IP addresses of your authoritative name server (***primary*** and ***secondary***)
  - Registrar inserts two RRs into the de TLD server:

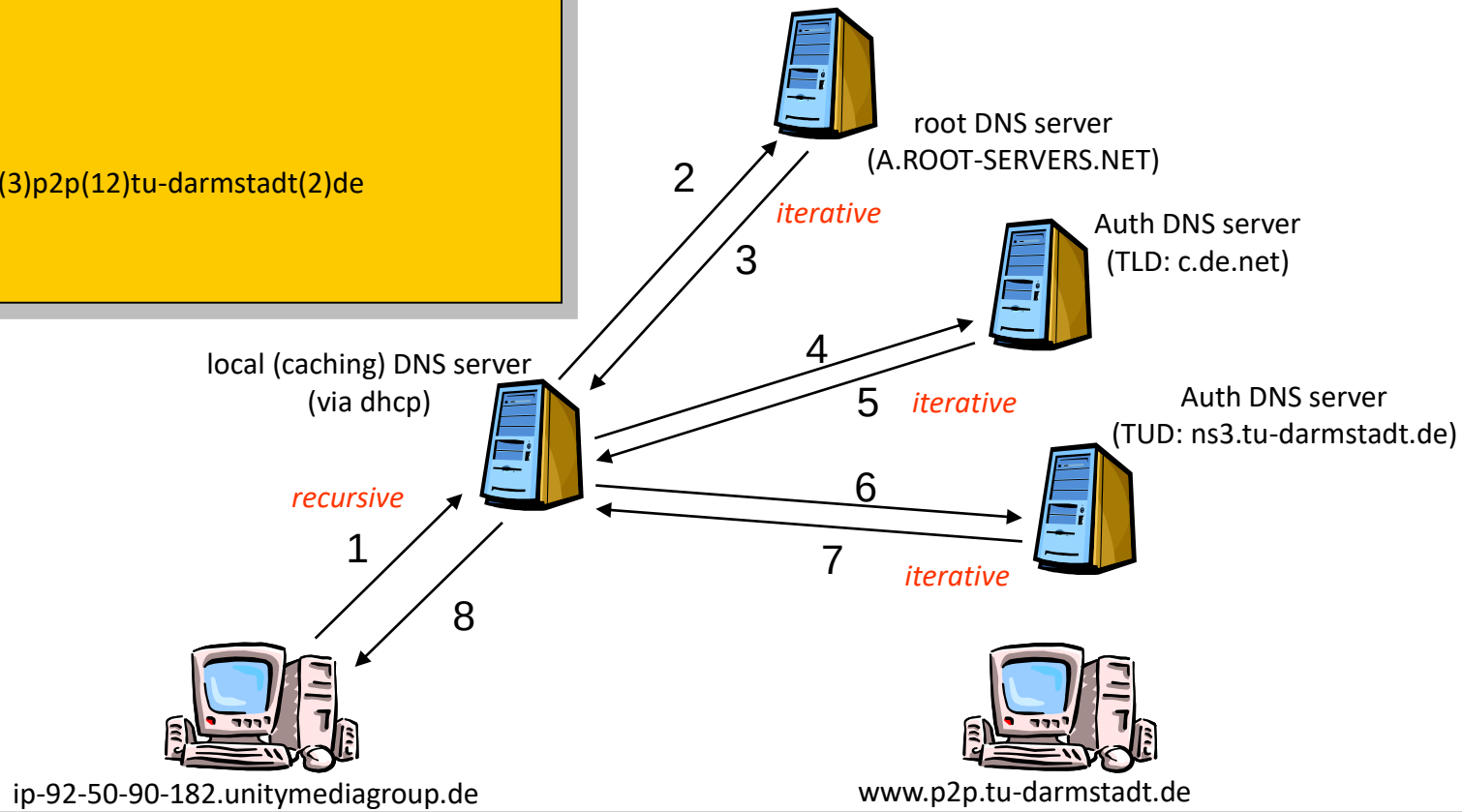
```
(fireblog.de, dns1.fireblog.de, NS)
(dns1.fireblog.de, 212.212.212.1, A)
```

- Add authoritative server Type A record for `www.fireblog.de` and Type MX record for `fireblog.de`

DNS – Recursive and Iterative Queries

DNS HEADER (send)
- Identifier: 0x3116
- Flags: 0x00 (Q)
- Opcode: 0 (Standard query)
- Return code: 0 (No error)
- Number questions: 1
- Number answer RR: 0
- Number authority RR: 0
- Number additional RR: 0

QUESTIONS (send)
- Queryname: (3)www(3)p2p(12)tu-darmstadt(2)de
- Type: 1 (A)
- Class: 1 (Internet)



A Quick Example…

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```
strufe@eris:~$ dnstracer -v www.p2p.tu-darmstadt.de
Tracing to informatik.tu-darmstadt.de[a] via 130.83.163.141, maximum of 3 retries
130.83.163.141 (130.83.163.141) IP HEADER
-Destination address:  130.83.163.141
-DNS HEADER (send)
-- Identifier:         0x3116
-- Flags:              0x00 (Q )
-- Opcode:             0 (Standard query)
-- Return code:        0 (No error)
-- Number questions:   1
-- Number answer RR:   0
-- Number authority RR:  0
-- Number additional RR: 0
-QUESTIONS (send)
-- Queryname:          (3)www(3)p2p(12)tu-darmstad
-- Type:               1 (A)
-- Class:              1 (Internet)
-DNS HEADER (recv)
-- Identifier:         0x3116
-- Flags:              0x8080 (R RA )
-- Opcode:             0 (Standard query)
-- Return code:        0 (No error)
-- Number questions:   1
-- Number answer RR:   2
-- Number authority RR:  0
-- Number additional RR: 0
-.......
```

```
QUESTIONS (recv)
- Queryname:          (3)www(3)p2p(12)tu-darmstadt(2)de
- Type:               1 (A)
- Class:              1 (Internet)
ANSWER RR
- Domainname:         (6)charon(7)dekanat(10)informatik(12)tu-darmstadt(2)de
- Type:               1 (A)
- Class:              1 (Internet)
- TTL:                1592 (26m32s)
- Resource length:    4
- Resource data:      130.83.162.6
ANSWER RR
- Domainname:         (3)www(3)p2p(12)tu-darmstadt(2)de
- Type:               5 (CNAME)
- Class:              1 (Internet)
- TTL:                49817 (13h50m17s)
- Resource length:    28
- Resource data:      (6)charon(7)dekanat(10)informatik(12)tu-darmstadt(2)de
Got answer [received type is cname]
```


DRESDEN concept

So where is the Info?

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```
strufe@eris:~$ dnstracer -v -qns tu-darmstadt.de
Tracing to tu-darmstadt.de[ns] via 130.83.163.130
130.83.163.130 (130.83.163.130) IP HEADER
- Destination address:  130.83.163.130
DNS HEADER (send)
- Identifier:          0x4C45
- Flags:               0x00 (Q )
- Opcode:              0 (Standard query)
- Return code:         0 (No error)
- Number questions:    1
- Number answer RR:    0
- Number authority RR:  0
- Number additional RR: 0
QUESTIONS (send)
- Queryname:           (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
DNS HEADER (recv)
- Identifier:          0x4C45
- Flags:               0x8080 (R RA )
- Opcode:              0 (Standard query)
- Return code:         0 (No error)
- Number questions:    1
- Number answer RR:    5
- Number authority RR:  0
- Number additional RR: 9

.....
```

```
QUESTIONS (recv)
- Queryname:           (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
ANSWER RR
- Domainname:          (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
- TTL:                 70523 (19h35m23s)
- Resource length:     6
- Resource data:       (3)ns1(3)hrz(12)tu-darmstadt(2)de
ANSWER RR
- Domainname:          (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
- TTL:                 70523 (19h35m23s)
- Resource length:     5
- Resource data:       (2)ns(6)man-da(2)de
ANSWER RR
- Domainname:          (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
- TTL:                 70523 (19h35m23s)
- Resource length:     6
- Resource data:       (3)ns2(3)hrz(12)tu-darmstadt(2)de

.....
```

Answer ctd…

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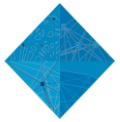


…….
ADDITIONAL RR
- Domainname: (3)ns1(3)hrz(12)tu-darmstadt(2)de
- Type: 1 (A)
- Class: 1 (Internet)
- TTL: 17335 (4h48m55s)
- Resource length: 4
- Resource data: 130.83.22.63

ADDITIONAL RR
- Domainname: (2)ns(6)man-da(2)de
- Type: 28 (unknown)
- Class: 1 (Internet)
- TTL: 38386 (10h39m46s)
- Resource length: 16
- Resource data: 2001:41b8:0000:0001:0000:0000:0000:0053

ADDITIONAL RR
- Domainname: (2)ns(6)man-da(2)de
- Type: 1 (A)
- Class: 1 (Internet)
- TTL: 38386 (10h39m46s)
- Resource length: 4
- Resource data: 82.195.66.249

ADDITIONAL RR
- Domainname: (3)ns2(3)hrz(12)tu-darmstadt(2)de
- Type: 28 (unknown)
- Class: 1 (Internet)
- TTL: 17335 (4h48m55s)
- Resource length: 16
- Resource data: 2001:41b8:083f:0022:0000:0000:0000:0063

…….

…….
ADDITIONAL RR
- Domainname: (3)ns2(3)hrz(12)tu-darmstadt(2)de
- Type: 1 (A)
- Class: 1 (Internet)
- TTL: 17335 (4h48m55s)
- Resource length: 4
- Resource data: 130.83.22.60

ADDITIONAL RR
- Domainname: (3)ns2(6)man-da(2)de
- Type: 1 (A)
- Class: 1 (Internet)
- TTL: 38386 (10h39m46s)
- Resource length: 4
- Resource data: 217.198.242.225

ADDITIONAL RR
- Domainname: (3)ns3(3)hrz(12)tu-darmstadt(2)de
- Type: 28 (unknown)
- Class: 1 (Internet)
- TTL: 17335 (4h48m55s)
- Resource length: 16
- Resource data: 2001:41b8:083f:0056:0000:0000:0000:0060

ADDITIONAL RR
- Domainname: (3)ns3(3)hrz(12)tu-darmstadt(2)de
- Type: 1 (A)
- Class: 1 (Internet)
- TTL: 17335 (4h48m55s)
- Resource length: 4
- Resource data: 130.83.56.60

Got answer

DNS – Lessons Learned

1. Structure name space (divide et impera)
2. Simple „routing“ b/c of structured (hierarchical) namespace
3. Store information at multiple locations
4. Maintain multiple connections
5. Be redundant! (Replicate…)
   - primary and secondary server, multiple TLD servers
6. Delegation using iterative or recursive forwarding

   (Btw: what are the pros and cons of each?)

Security of the Domain Name System

Vital service for the Internet

- "Do you know the IP-Address of your mail server?"
- "You know you shouldn't follow the link

```
http://malicio.us/phishing/yourbank.html
```

but what about

```
http://www.yourbank.de ??"
```

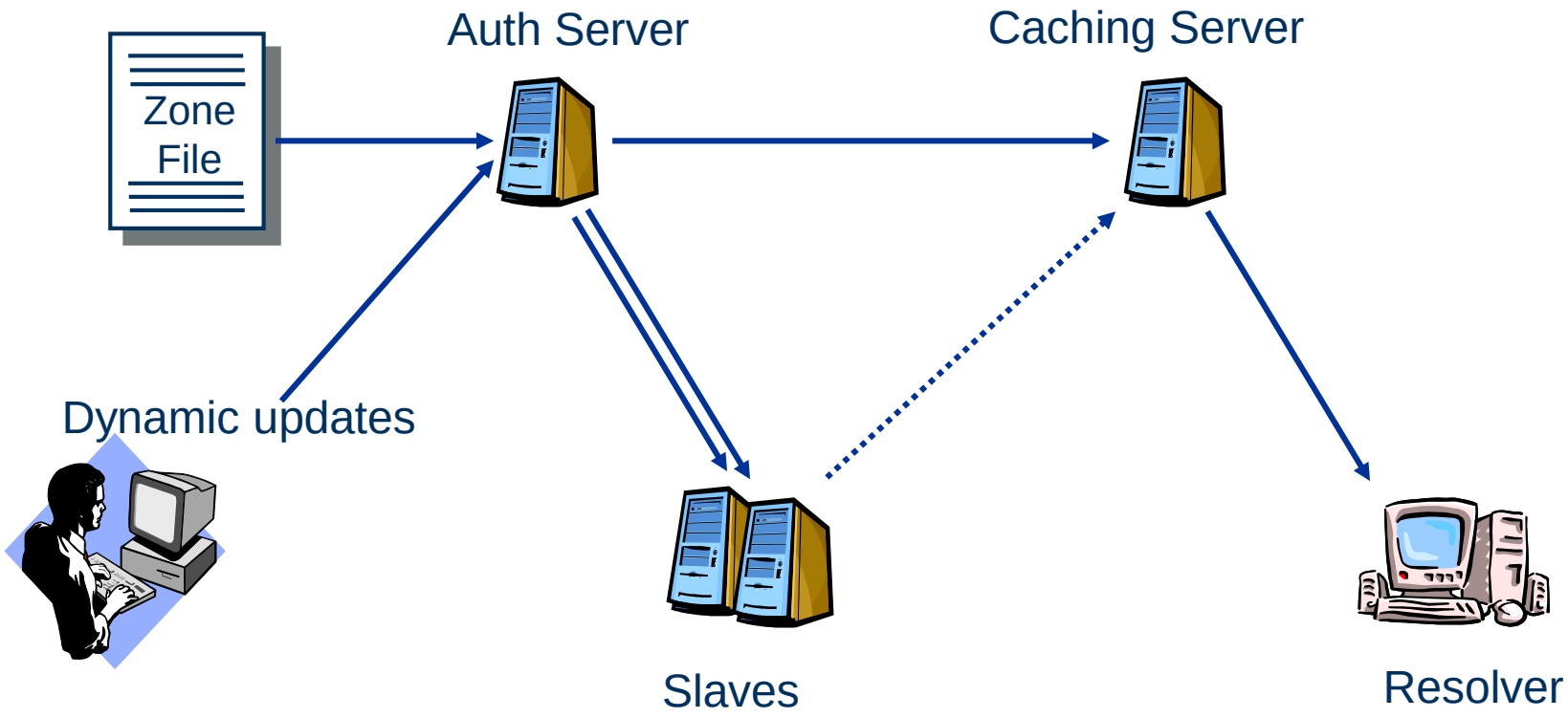
But: DNS does not support

- Data integrity
- Data origin authentication

Threats:

- Denial of Service
- Data Authenticity/Integrity

DNS – Data Flow



[http://www.ripe.net/training/dnssec/]

DNS Security Issues Outline

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Robustness towards DDoS
- General issues
- Redundancy

Robustness towards data corruption
- Cache Poisoning and simple countermeasures
- More complex countermeasures:

- Split-Split DNS / Split-horizon DNS
- Cryptographic countermeasures

- DNS Cookies
- DNSSEC
- DNSCurve

Threats to DNS: Denial of Service

DNS as vital service a “worthy” target

- Without DNS most Internet services will not work
  (usage of names rather than IP-Addresses for numerous reasons!)

DDoS Attacks on root servers: via notorious “typos” in TLDs

DNS Amplification Attack (15.02.2006)

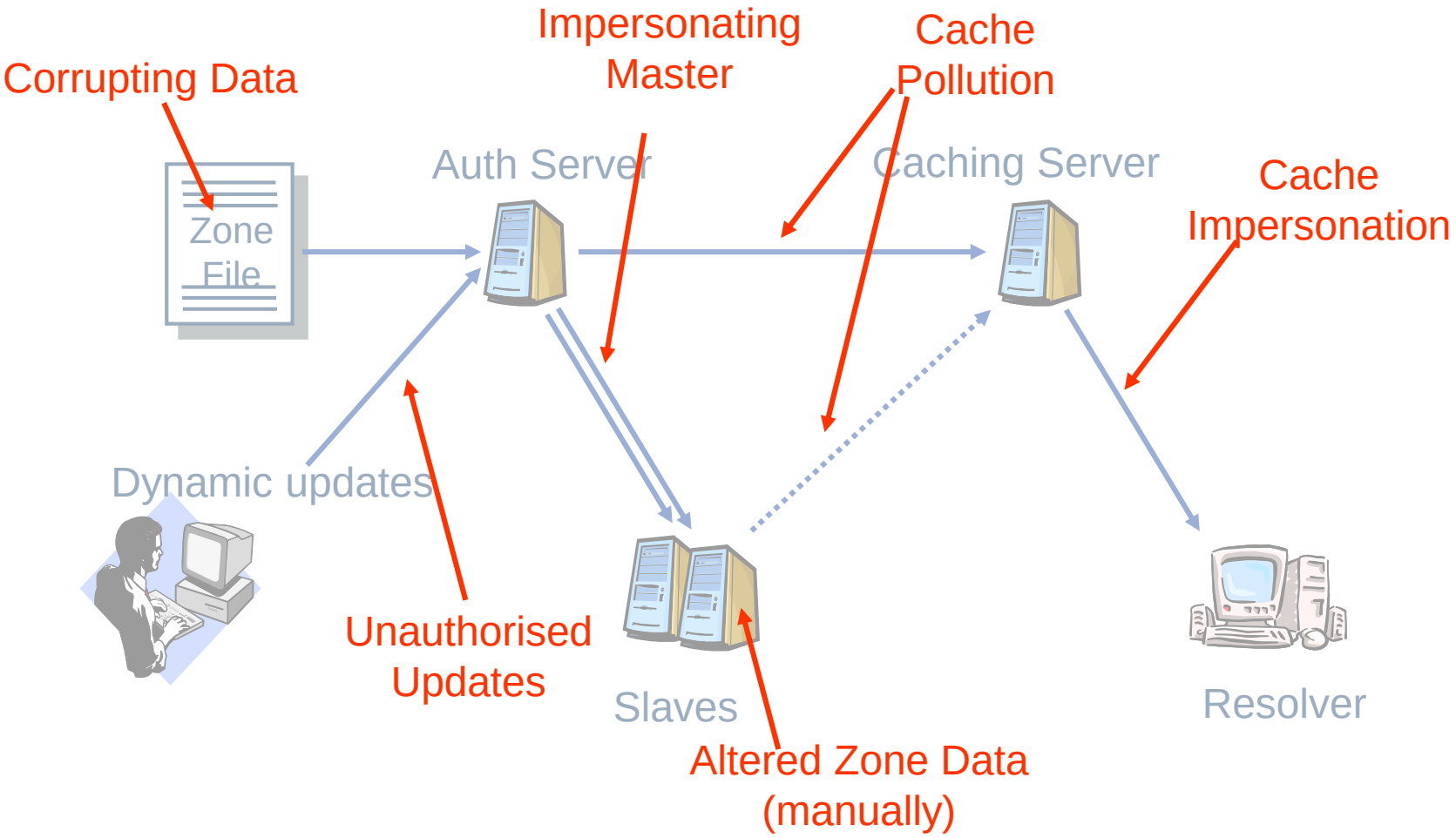
- Spoofed queries (60 Bytes) may generate potentially large responses (4KBytes)
- Exploit open recursive servers to generate load on other DNS servers
- Exploit open servers as reflectors when flooding a victim with traffic
  (via source IP Address spoofing in request)

Robustness towards DDoS

General issues

- Secure DNS server
  - OS selection and updates
  - Firewalls
  - Server software selection and updates
- Redundancy and over provisioning
  - Root ".": 13 name server "names" ({a..m}.root-servers.net)
  - "com", "net", "de": several name servers each
- Anycast
  - Announcement of an IP prefix from multiple locations
  - Requests from different parts of the internet are routed to different machines with the same IP address
  - Done with several DNS servers

DNS – Threats to Data Integrity

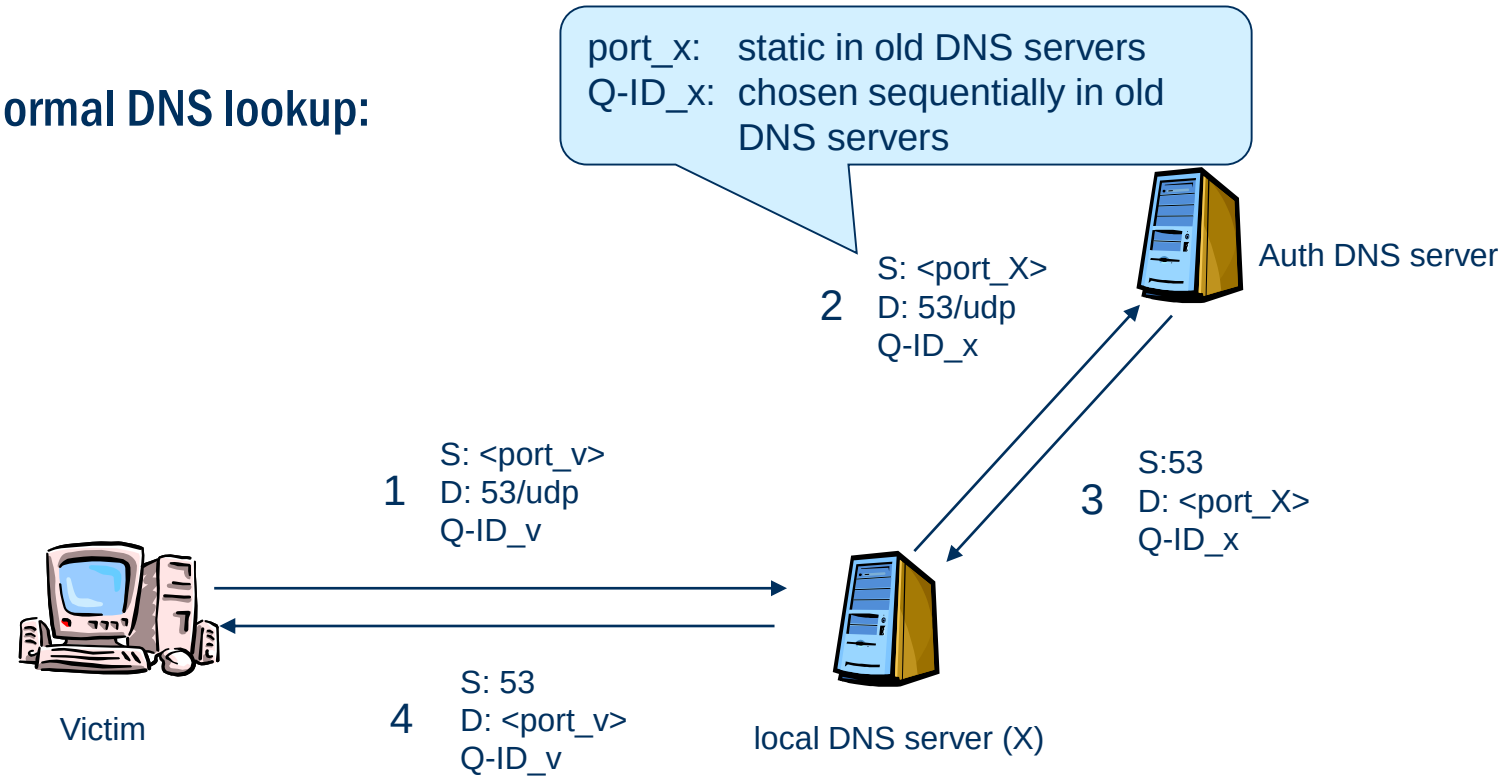


Threats to DNS: Data Corruption / Cache Poisoning

All resolved RRs are cached at local DNS servers

DNS slave servers replicate zone data from master

Normal DNS lookup:



DNS Threats – Cache Poisoning: Simple Poisoning (1)

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Attack: plant fake data in slaves / caching servers

(*and nobody will realize the redirection from* `www.yourbank.de` *to* `malicio.us/phishing/yourbank.html` *…)*

DNS via UDP/IP, no handshakes for connection establishment

Transactions in DNS only identified by tuple of

```
<auth server(ip-address), auth server(port), transaction id>
```

With knowledge about transactions: distribute malicious data

IP Address of authoritative name servers are well known

In many implementations same **port** for all transactions

Q-ID unknown, *but*: BIND used to choose them sequentially…

DNS Threats – Cache Poisoning: Simple Poisoning (2)

4. Attacker sends request for target domain
5. DNS server performs lookup
6. Attacker sends fake information to known port_x, with last Q-ID +1 and source address of correct Auth DNS server
7. Second reply (by correct Auth DNS server) is ignored

D: 53
S: <port_X>
Q-ID_x + 1

Auth DNS server

1. Attacker requests DNS-Info on own Domain
2. Victim‘s server requests Info recursively
3. Port and last Q-ID known to Attacker

D: 53
S: <port_X>
Q-ID_x

Victim

local
DNS server

Auth DNS server
of Attacker’s Domain

[<port_X>, Q-ID_x]

8. Victim requests IP for host in target domain
9. Local DNS server answers with poisoned info

D: <port_X>
S: 53
Q-ID_x + 1

Attacker

Mitigation of Cache Poisoning

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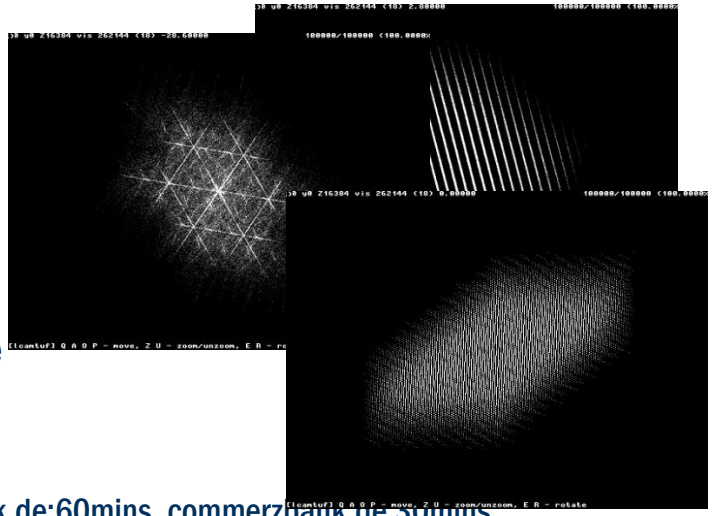
Random ports for each transaction (BIND8)
- Since Version 8 BIND uses PRNG for port number and query id selection
- However PRNG == **Pseudo** Random Number Generator, with knowledge about previous port numbers future port numbers can be guessed if PRNG not cryptographically secure

More random ports for each transaction (BIND9)
- New and better PRNG since BIND9, random numbers are harder to guess



Cache Poisoning only after aging of entry in local DNS server
- Only if attacker attacks at the right moment, he can poison the cache
- Typical TTL:

- 172800 (2d) for most name servers
- Seconds to hours for A-Entries of organizations (tu-ilmenau.de 24h, deutschebank.de:60mins, commerzbank.de 30mins, postbank.de 30s, microsoft.com:60mins (*where do you get your sec-updates today*?))

Nevertheless: cache poisoning is still not solved...

Cache Poisoning with “Brute Force”

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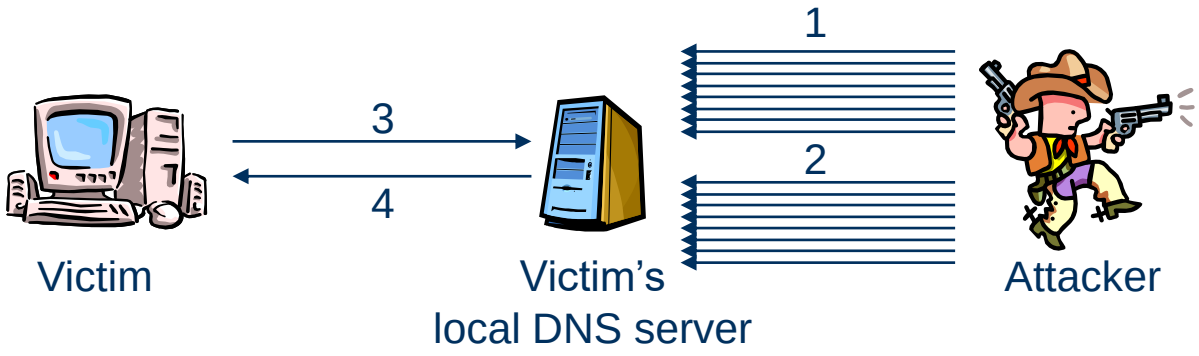
1. Attacker sends ***multitude of requests*** for targeted domain to local DNS server of victim and
2. Attacker sends ***multitude of fake replies*** with IP and port from auth server of targeted domain ~ guessing transaction id for one of the recursive requests from local caching server to auth server (2^{16} x $2^{16} = 2^{32}$ 4 Billion possible combinations)
3. Victim requests data about targeted domain
4. Local caching server responds with fake data



More Sophisticated Cache Poisoning

Usually not a high number of chances ***when TTL high***, e.g., 1 day

Imagine the attacker M:

- M → Cache: Give me `kslkskdf.bank.com` (w/ random "kslkskdf")

- The cache server must now ask the Authoritative Server at bank.com

- M → Cache: Not responsible for `kslkskdf.bank.com`, but `www.bank.com` is. You may reach `www.bank.com` at `A.B.C.D` (`A.B.C.D` being the address of the attacking host)

- The cache will then ask A.B.C.D for kslkskdf.bank.com and will also remember the "name server" www.bank.com

More Sophisticated Cache Poisoning - Defense

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How can we increase the entropy of DNS queries?

Idea: DNS does not distinguish between upper and lower case, encode more bits in the name

Now the same attack:

– M → Cache: Give me `kslkskdf.bank.com`

- The Cache Server must now ask the Authoritative Server at bank.com
  Cache → Auth Server: Give me `kSLkSkdF.bAnK.COM`

– M → Cache: Not responsible for `kslkskdf.bank.com`, but `www.bank.com` is. You may reach `www.bank.com` at 141.24.212.114. (Ignored as kslkskdf.bank.com does not match the case of the query)

– Auth Server → Cache: `kSLkSkdF.bAnK.COM` is unknown

Entropy is increased to 2^{32+n} for n being the letters in a domain name

Helps for `www.tu-dresden.de` but not much for `tud.de`

Most Sophisticated Cache Poisoning

DNS is usually transported over UDP, which may fragment

What happens when a DNS reply gets fragmented?

- Random port numbers, Query ID and perhaps the original question (e.g. `kSLkSkdF.bAnK.COM`) are in the first fragment
- Depending on the query and the MTU the actual answer may be in the second fragment
- Fragments are matched by a 16 bit identification field…

Attackers thus can try to

- Find queries leading to large answers
- Spoof PMTU related ICMP messages to set the fragmentation boundary
- Send a “second” fragment with different identifications to the cache
- Send the query to the cache
- Wait for the cache to reassemble the reply and the crafted second fragment…

DNS server should avoid large answers and PMTU discovery…

Prevent Data Corruption: Split-Split DNS

Goal: Avoid cache poisoning from external machines

Idea: Split the name service functions

- Name resolution (look up of DNS info)
- Domain information (Auth service of local DNS info)

Internal server

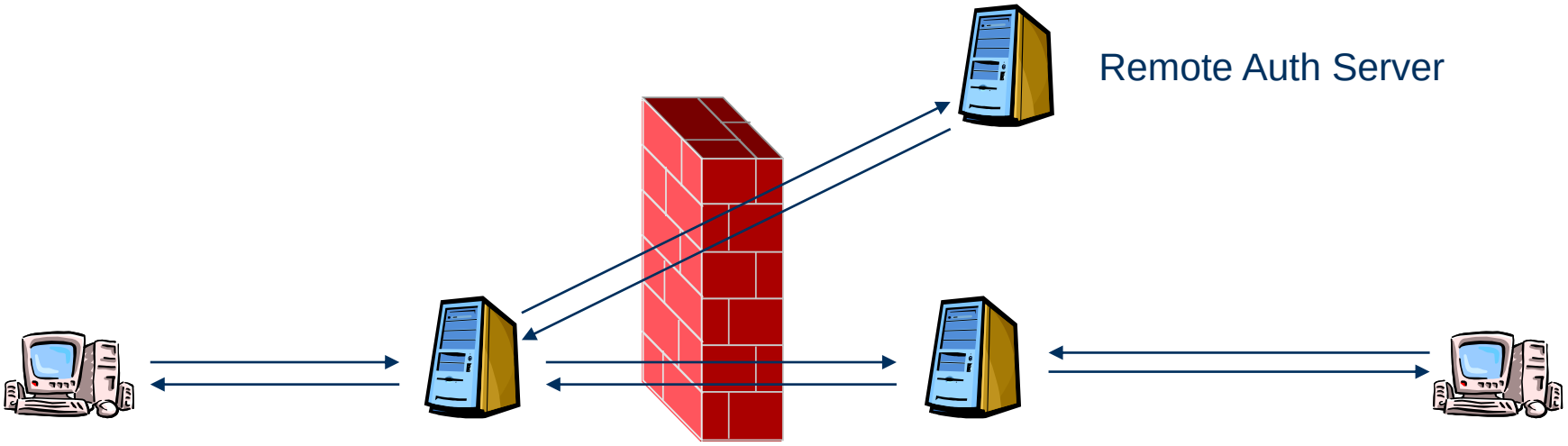
- Implements name resolution
- Performs recursive look-ups at remote DNS servers
- Located behind firewall and only accepts requests from local LAN

External server

- Authoritative server of domain
- Accepts remote requests but **never accepts** remote updates

Zone transfer from external to internal server allowed

Split-Split DNS/ Split-Horizon DNS



Securing DNS Cryptographically

Securing DNS has different goals:

- DNS transaction security
  - Peer/message authentication
- DNS data security
  - Data origin authentication
  - Authenticated denial of existence

Transaction Authentication (TSIG)

PRIVACY AND SECURITY

Idea:

Use signatures to secure data at zone transfer **master → slave**

Pre shared symmetric key at each entity

MD5 Hash used as signature

TSIG Resource Record:

`(Name, Type ("TSIG"), Class ("ANY"), TTL("0"), Length, Data(<signature>))`

Possibility to authenticate, but very complex to administrate in large domains (manual pre-sharing of keys)

- amount of keys required: $\frac{n\,(n-1)}{2}$

Main application areas:

- Secure communication between stub resolvers and security aware caching servers *(?)*
- Zone transfers (master → slave)
- Combined with nsupdate in data centers, to update stale information in caches

[Vixie et. al: „RFC 2845: Secret Key Transaction Authentication for DNS“]

DNS Security (DNSSEC) – Objectives

DNS security ***objectives***:

- End-to-end zone data *origin authentication* and integrity
- *Detection* of data corruption and spoofing

DNSSEC ***does not*** (want to) provide:

- DoS-Protection *(in fact, it facilitates DoS Attacks on DNS servers)*
- Data delivery guarantees (availability)
- Guarantee for correctness of data (only that it has been signed by some authoritative entity)

[Eastlake: „RFC 2535: Domain Name System Security Extensions“ (obsolete)]
[Arends et. al: „RFC 4033: DNS Security Introduction and Requirements“]
[RFCs:4033,4034,4035,4310,4641]

DNSSEC

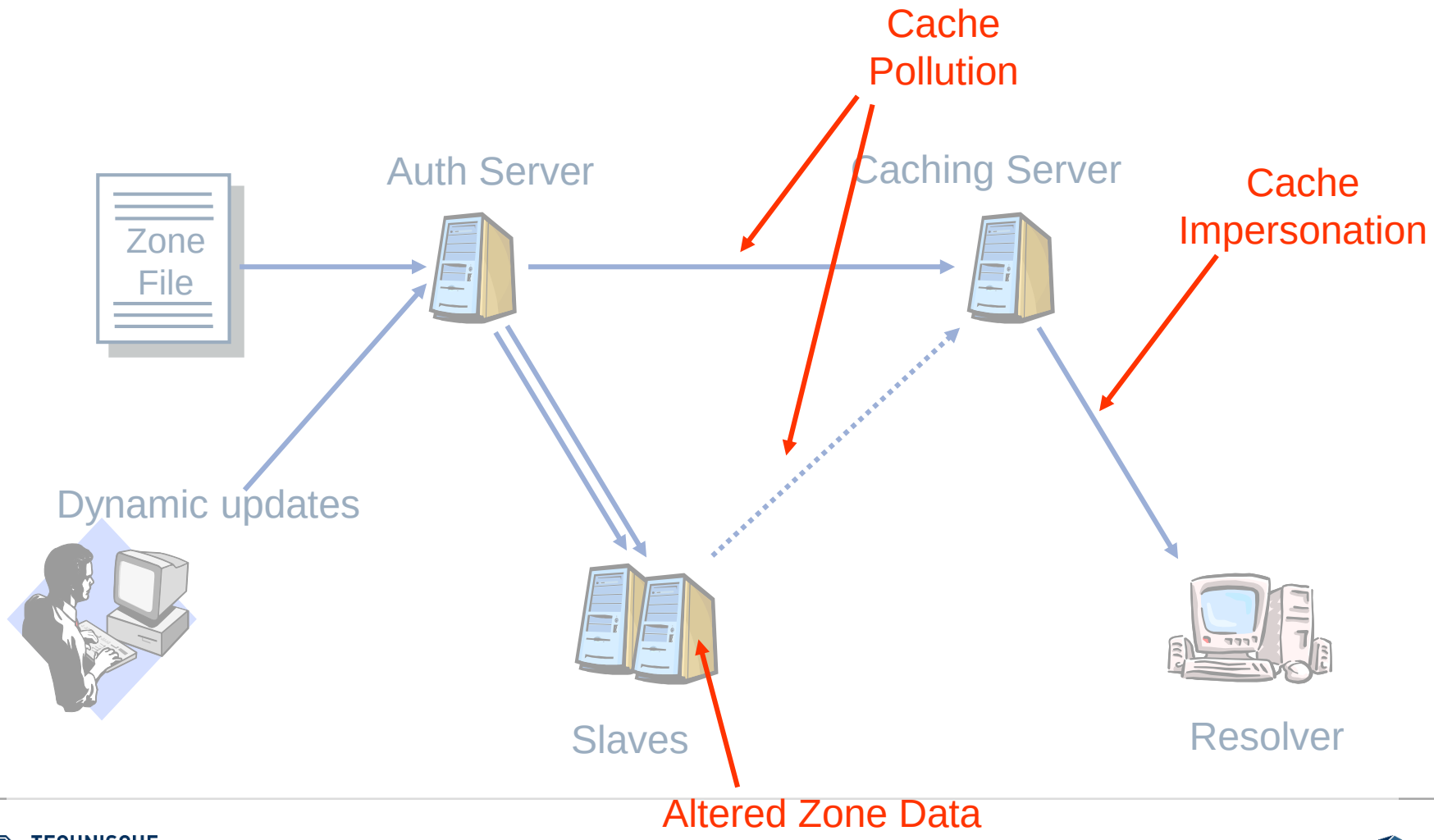
Usage of *public key cryptography* to allow for ***data origin authentication*** on a world wide scale

- **RRSets** (groups of RRs) signed with private key of authoritative entities
- **Public keys** (DNSKEYs) published using DNS

- Distinguish *zone signing key* (**ZSK**) and *key signing key* (**KSK**)
- Child zone keys are authenticated by parents (according to the zone hierarchy) and hence anchored trust chains established
- Only root zone key signing key (KSK) needed (manual distribution) to create complete trust hierarchy (in theory)

- Until then: islands of trust with manually shared anchor keys
- No key revocation → DNSSEC keys should have short expiration date (quick rollover)

DNSSEC – Targeted Threats



DNSSEC – Means of Securing RRSets

Goal: authenticity and integrity of Resource Record Sets

Means:

- Public Key Cryptography (with Trust Chains)
- Security integrated in DNS (new RRs)

New Resource Record Types:

- `RRSig`: RR for signatures to transmitted RRs
- `DNSKEY`: RR for transmission of public keys
- `DS`: RR for trust chaining (trust anchor signs key of child zone)
- `NSEC`: RR for next secure zone in canonical order (authenticated denial for requested zone)

DNSSEC – New Resource Records: RRSIG

Resource Record for transmission of ***signatures***

`RRSIG:`

(Name, Type, Algorithm, Labels, TTL, Sig Expiration, Sig Inception, Key Tag, Signer's Name, Signature)

- `Name` – name of the signed RR
- `Type` – RRSIG (46)
- `Algorithm` – MD5(1), Diffie-Hellman(2), DSA (3)
- `Labels` – number of labels in original RR (wildcard indication)
- `TTL` – TTL at time of signature inception
- `Signature Expiration` – End of validity period of signature
- `Signature Inception` – Beginning of validity period of signature
- `Key Tag` – ID of used key if signer owns multiple keys
- `Signer's Name` – Name of the signer
- `Signature` – Actual Signature

DNSSEC – New Resource Records: DNSKEY

Resource Record containing ***public keys*** for distribution

`DNSKEY:` (Label, Class, Type, Flags, Protocol, Algorithm, Key)

- `Label` – Name of key owner
- `Class` – Always: IN (3)
- `Type` – DNSKEY
- `Flags` – key types: Key Signing Key (257) or Zone Signing Key (256)
- `Protocol` – Always DNSSEC (3)
- `Algorithm` – RSA/MD5(1), Diffie-Hellman(2), DSA/SHA-1(3), elliptic curves(4), RSA/SHA-1(5)
- `Key` – Actual key

DNSSEC – New RRs: Delegation Signer (DS)

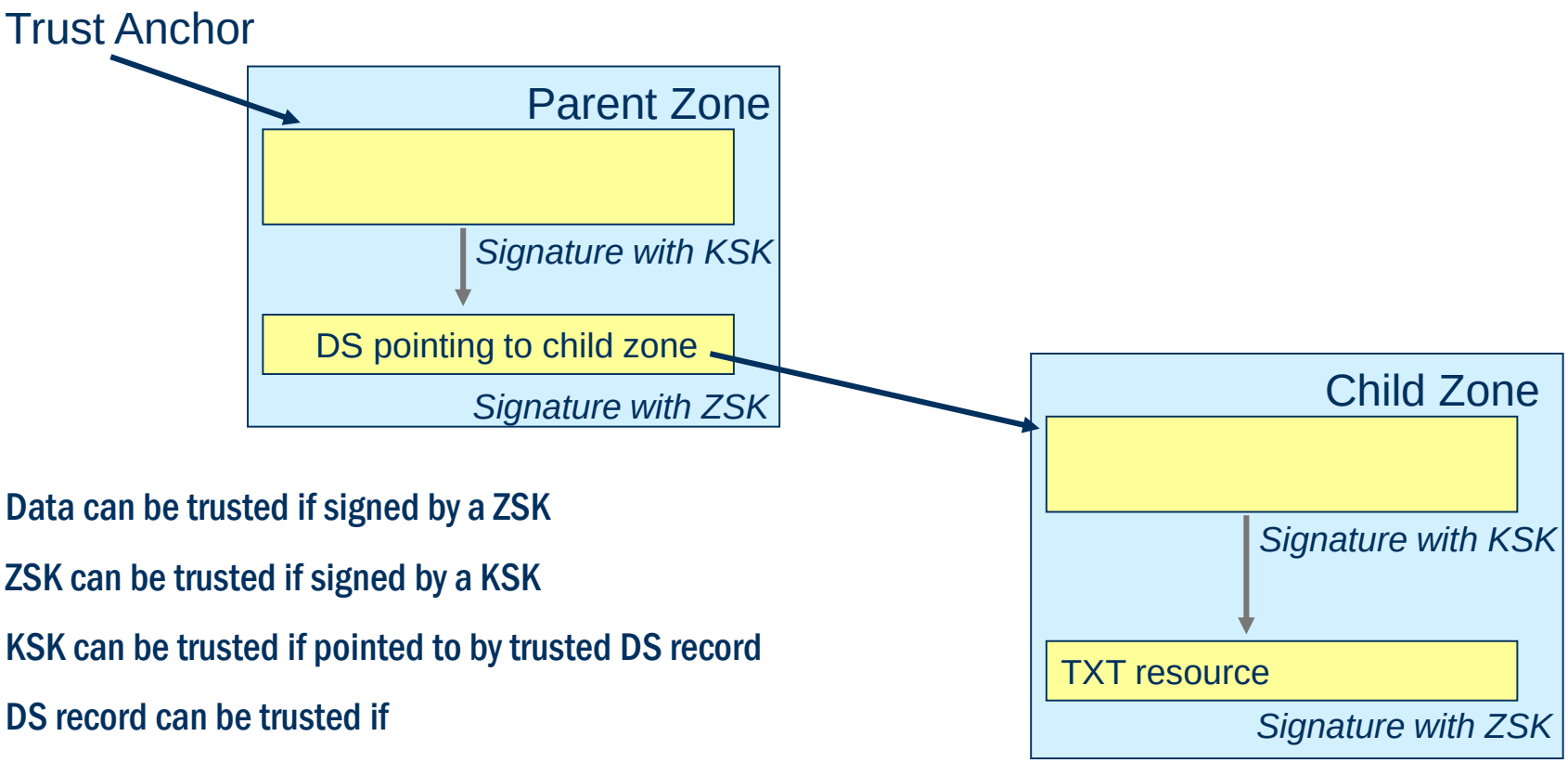
DS contains ***hash-value of DNSKEY*** of the name server of a sub zone

Together with NS Resource Record, DS is used for trust chaining

`DS` : (Name, Type, Key Tag, Algorithm, Digest Type, Digest)

- `Name` – Name of the chained sub zone
- `Type` – DS
- `Key Tag` – Identification of the hashed key
- `Algorithm` – RSA/MD5(1), Diffie-Hellman(2), DSA(3) (of referred DNSKEY)
- `Digest Type` – SHA-1(1), SHA-256(2)
- `Digest` – Actual value of hashed DNSKEY

DNS – Authority Delegation and Trust Chaining



Data can be trusted if signed by a ZSK

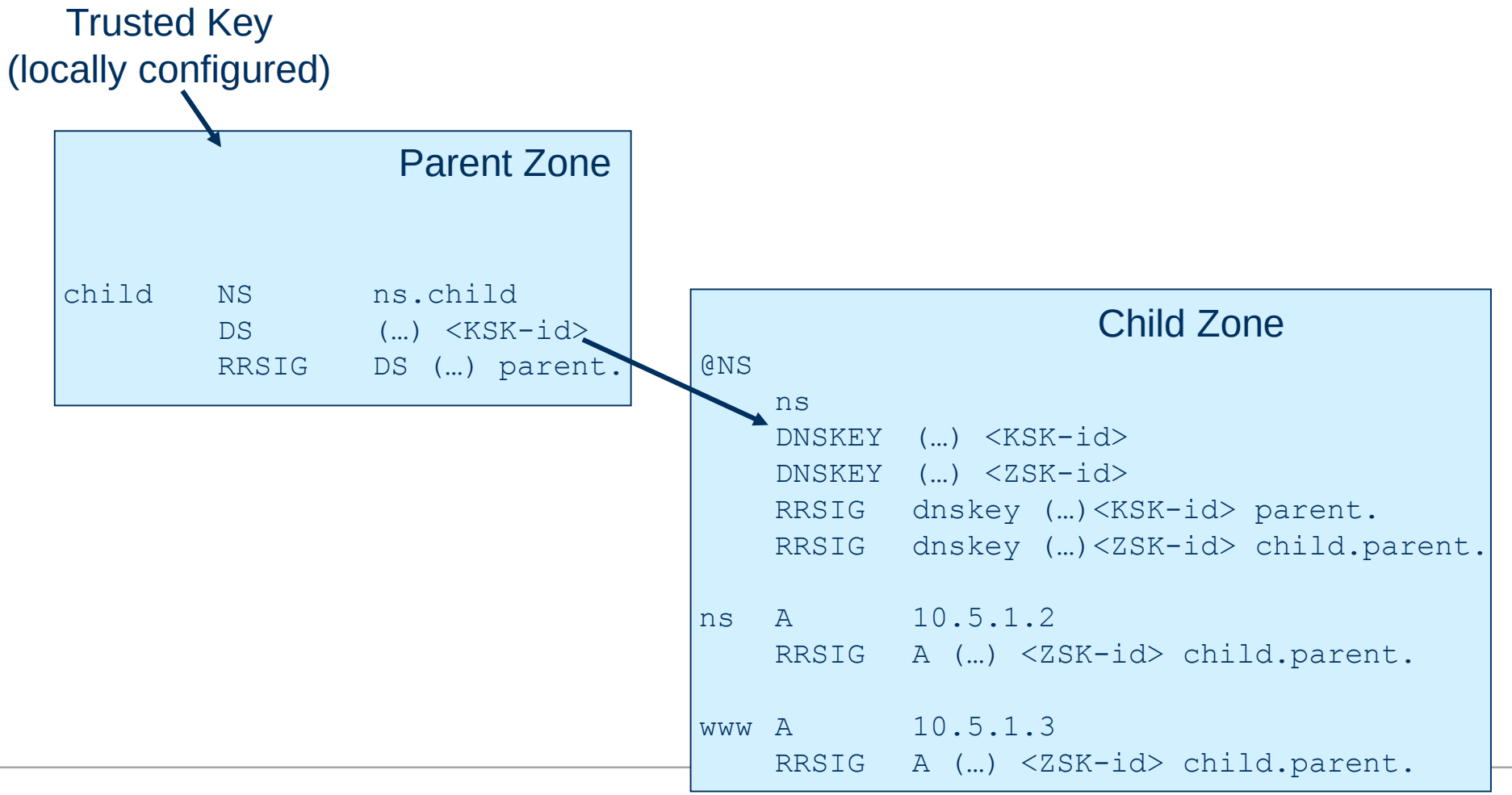
ZSK can be trusted if signed by a KSK

KSK can be trusted if pointed to by trusted DS record

DS record can be trusted if

- Signed by parents ZSK
- Signed by locally configured trusted key

DNS – Authority Delegation and Trust Chaining (Example)



DNSSEC – New Resource Records: NSEC

Next Secure (NSEC) gives information about the next zone / sub domain in canonical order (last entry points to first entry for the construction of a closed ring)

Gives the ability to prove the non-existence of a DNS entry: *Authenticated Denial*

`NSEC` (Name, Type, Next Domain)

- `Name` – Name of the signed RR
- `Type` – NSEC (47)
- `Next Domain` – Name of the next domain in alphabetical order

Allows adversary to crawl entire name zone ("zone walking")

DNSSEC – New RRs: NSEC3 (1)

PRIVACY AND SECURITY

Successor to NSEC: NSEC3 and NSEC3PARAM

Uses hashed domain names to make zone walking more difficult

Hashing based on salt and multiple iterations to make dictionary attacks more difficult

NSEC3

– Name	– Name of the signed RR
– Type	– NSEC3 (50)
– Hash Algorithm	– SHA-1 (1)
– Flags	– To Opt-Out unsigned names
– Iterations	– Number of iterations of Hash Algorithm
– Salt Length	– Length of the salt value
– Salt	– Actual salt value
– Hash Length	– Output length of hash function
– Next Hashed Owner Name	– Next Hash of domain name in alphabetical order

DNSSEC – New RRs: NSEC3 (2)

Potential advantage: Salting and hashing does not allow for easily deducting hostnames from zone walks

Problem:

- Hostnames usually have very low entropy (to remember them)
- Easy dictionary attacks - despite the usage of salts & iterations
- But not used heavily anyways:

- .: Uses NSEC
- .com: No salt, No iterations
- .de: Static salt BA5EBA11, 15 Iterations

DNSSEC: NSEC5 / Record Type Denial

Provide authenticated denial of existence without leaking names requires online signing.

Providers do not want to trust the DNS servers with keys…

Cloudflare Record Type Denial

- Send positive response but deny requested record type

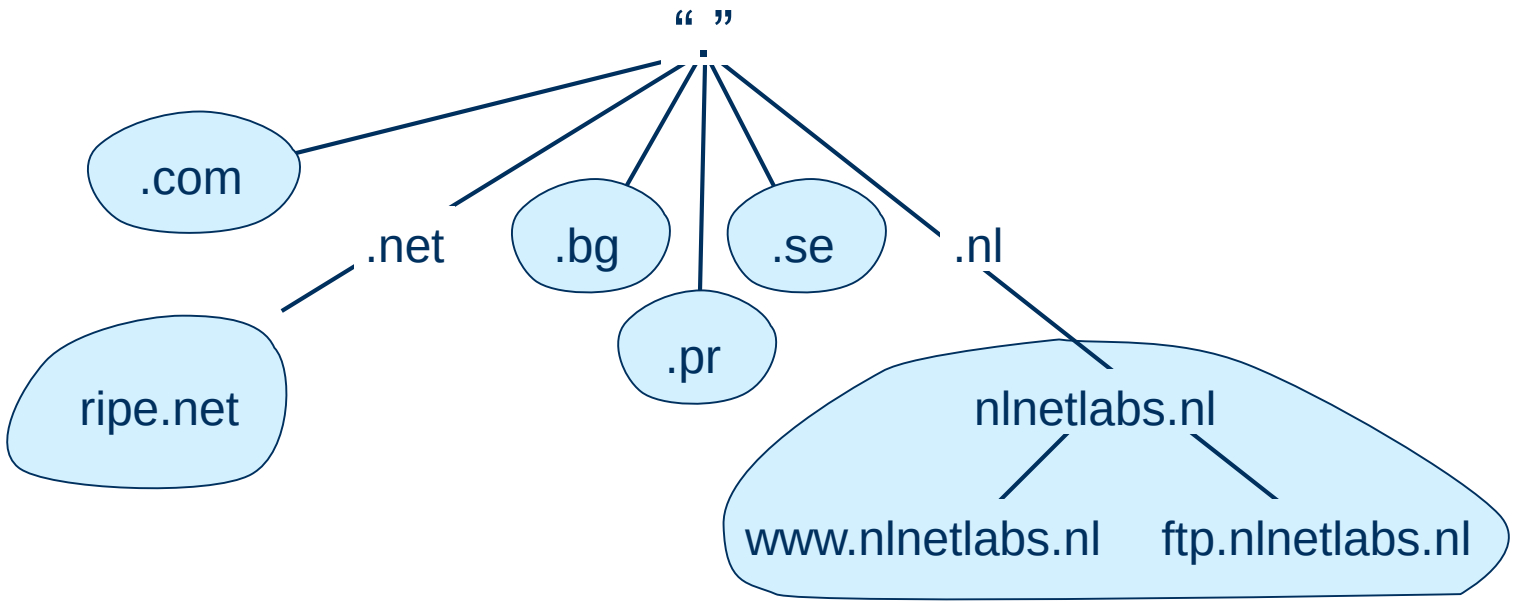
DNSSEC – Trusted Zones

PRIVACY AND SECURITY

Potential anchors

TLD: .com, .net, .nl, .se, .cz, ..., .de

Diversity of others: 892208 DNSSEC enabled zones



http://secspider.cs.ucla.edu/islands.html
http://secspider.verisignlabs.com/

DNSSEC Issues

Pro's:

- DNSSEC allows to prevent unauthorized/spoofed DNS records

Con's:

- Added complexity (signing, checking, key distribution) **eases DoS attacks** on DNS servers
- Zones need to be signed completely (performance challenge for large companies or registries)
- Authenticated denial with NSEC gives the possibility to "walk" the chain of NSEC and to gain knowledge on the **full zone content** (all zones/ sub domains) in O(N) ==> NSEC3, …
- Distribution of anchor keys still a **manual task** (allows for human error, social engineering)

Deployment:

- https://www.internetsociety.org/deploy360/dnssec/maps/

DNS Cookies

Goals

- DNS transaction security
  - Prevent off-path attacks (poisoning)
  - Limit spoofing, DoS

Core ideas:

- „Authenticate“ query in DNS response
- Establish semi-state between clients and servers

Approach:

- EDNS option
- Include client/server cookies (extending query ID)

[Eastlake, Andrews: „RFC 7873: Domain Name System Cookies “]

DNS Cookies – States and Behavior

States of communication

1. „Unauthenticated“: Client contacts server for the first time
2. „Authenticated“: Client and server share some state

Server behavior:

1. Provide service at low priority, offer server cookie
2. Provide normal DNS service (return server cookie)

Client behavior:

1.
    a. Send DNS query, client cookie and ask for server cookie, OR
    b. Query for server cookie, then (2)
2. Send server cookie, DNS query, client cookie

DNS Cookies – Cookies and OPT RR

PRIVACY AND SECURITY

Generating DNS cookies:

```
cookie <- PRNG(Client IP, Server IP, k)
```

with temporary secret k at server/client

Message format:

0	1	2	3
Option Code = 10		Option Length	
Client Cookie ([0-3])			
Client Cookie ctd. ([4-7])			
Server Cookie			
Server Cookie ctd.			

Option length: [8 (only client cookie), {>=16, <=40} (client/server cookies)]

Client cookie: fixed size 8 octets

Server cookie: variable size, 8-32 bytes

DNS Cookies - Protection

So what do DNS cookies actually achieve?

Protects transactions between resolvers/caches and caches/servers

Validation of cookies:

- Valid client cookie for server (probably no off-path poisoning)
- Valid server cookie for client (previous transactions with same IP address, probably no IP address spoofing)

Critical assessment:

- Very low overhead, no protocol changes, little software adaptation
- Currently rolled out
- However: very weak protection *(on-path adversaries? Leaked cookies?)*
- Unclear how servers should behave in phase 1

Alternatives to DNS(SEC)

Some exotic approaches

„Transport Layer“ Encryption

- DNSCurve

Distributed Name Resolution

- Peer Name Resolution Protocol
- GNU Name System

Try different strategies to deal with Zookos triangle, informally stating that global name resolution can only offer any two of the following properties:

- Security
- Distributed system
- Human-memorable Names

DNSCurve (I)

- Developed by Daniel Bernstein as an alternative to DNSSEC [Ber09]
- Uses online cryptographic functions, i.e., more like transport layer encryption
- Exchanges (either binary or tunneled in DNS TXT records)

- Online operation possible using very efficient ciphers: Curve25519 (ECC based pub key system), Poly1305 (hash function) and Salsa20 (stream cipher) all developed by djb

DNSCurve (II) – Distribution of public keys

- Public keys are not validated using novel records, but DNS names
- Name servers are no longer called ns.example.org but like *uz5<public_key>.example.org*
  - uz5 means name server speaks DNSCurve
  - Rest of the string encodes 256 bit public key

- Parent zones pointing to DNSCurve names allow to verify sub zones
- DNSCurve names in hyperlinks etc. allow to verify DNSCurve servers independent of DNS hierarchy

  → No more trust in root zone

DNSCurve (III) – Discussion

- Slimmer design compared to DNSSEC
- Independent trust paths possible
- Support for confidentiality
- No amplification attacks possible

- But use of hard defined cryptographic operations is not globally acceptable
- Cipher operations are not as well examined as ciphers in DNSSEC
- *Hasn't caught on.*

Peer Name Resolution Protocol (PNRP)

- Distributed protocol invented by Microsoft based on Pastry
- Deployed with Windows systems (disabled by default , requires IPv6)
- All computers are equal nodes in structured overlay networks (called clouds here)
  - Link cloud (for all local computers)
  - Site cloud (e.g. for all computers of a company)
  - Global cloud (for all PNRP speakers in the Internet)

- Names in the form *name.pnrp.net* can be resolved insecurely (pnrp.net being a special domain to map PNRP names in the DNS name space)
- Names in the form [p]classifier.[p]*h(pkey)<authority>.pnrp.net,* with authority being a SHA-1 hash of a node's public key can be resolved securely

PNRP – Properties

- Abandoning servers might increase robustness and availability of overall system, but no wide research (yet)
  - Some mechanisms to prevent well known eclipse and sybil attacks
- Different clouds allow for increased performance and robustness within same network locations
- Secure names can be verified independently of a trust hierarchy

- Secure names cannot be remembered
- Secure names cannot be verified by a trust hierarchy
- In the insecure name space: anarchy!
  - No security guarantees at all
  - Anybody may register and reregister addresses…

GNU Name System (GNS)

PRIVACY AND SECURITY

- Distributed name resolution system based on GNUnet (spanning a Kademlia-like structured peer-to-peer overlay)
- Offers secured names in the form *hash*.zkey
- Not memorable, but GNS offers aliases (so called *petnames*)
  - Every participant may create aliases like *alias*.gnu pointing to *something*.zkey
  - and aliases may be recursive (if users permit)… thus bob.alice.gnu points to a system that Alice (known by local system) calls bob

- Allows locally unambiguous names with a clear trust hierarchy
- Global names still possible by unmemorizable names

Summary

DNS a central service of the Internet, implemented on layer 7

Vital for secure operations

Vulnerabilities:
- DoS
- Poisoning

Countermeasures
- Better PRNG
- Split/Split DNS
- TSIG
- DNSSEC
- DNS Cookies
- *DNSCurve, PNRG, GNS*