Network Security

DNS (In)security

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A short recap

- Routing means directing (Internet) traffic to its target
- Internet is divided into $\approx 61,000$ Autonomous Systems
- Routing inside an AS uses Interior Gateway Protocols (RIP, OSPF)
- Routing between ASs uses Border Gateway Protocol (BGP)
- Large-scale routing attacks are not suitable for homework...
- Smaller-scale attacks:
  - Source-routing attacks
  - ICMP redirect attacks
  - Rogue DHCP (attacks not only routing)
- Firewalls are concepts to separate networks
- Common firewall concept: Packet filtering (`iptables`)
- `iptables` can also be used for NAT (and port forwarding)
- Tunneling can be used to circumvent a packet filter

DNS and domain names

- So far: Configure hostname/IP pairs in `/etc/hosts`
- Important for local configuration (and overrides), but does not scale
- More flexible solution: *Domain Name System (DNS)*
- Idea: Query a server for a domain name, receive answer
- DNS typically uses UDP on port 53
- Domain names have a hierarchy (different levels separated by '.')
- Highest domain: root domain (empty string)
- Next highest: *top-level domains (TLDs)*, e.g., `.nl`, `.org`, `.sucks`
- Administration of top-level domains by Internet Corporation for Assigned Names and Numbers (ICANN)
- Administrations of domains below a TLD by registries, e.g., Stichting Internet Domeinregistratie Nederland (SIDN) for `.nl`
- DNS servers are typically resposible for one specific domain (DNS zone)

DNS servers and requests

- Two kind of DNS servers: recursive and authoritative
- Recursive servers (or DNS caches)
  - forward requests to other servers,
  - remember (cache) the reply for a certain amount of time
- Authoritative servers are responsible for a certain domain (or DNS zone) and
  - know the hosts in their domain,
  - know the authoritative DNS servers of their subdomains
- Two types of requests: recursive or iterative
- Recursive request (to a DNS cache): give me the answer or an error
- Iterative request (to an authoritative server): give me the answer or tell me who might know

DNS example

- You try to access `sandor.cs.ru.nl`, send request to DNS cache (e.g., 131.174.117.20)
- 131.174.117.20 may know the DNS server for *top-level domain* `.nl`:

  `ns1.dns.nl    193.176.144.5`

- 131.174.117.20 asks `ns1.dns.nl` for `ru.nl` nameserver:

  `ns1.surfnet.nl    192.87.106.101`

- 131.174.117.20 asks `ns1.surfnet.nl` for `cs.ru.nl` nameserver:

  `ns2.science.ru.nl    131.174.16.133`

- 131.174.117.20 asks `ns2.science.ru.nl` for `sandor.cs.ru.nl` IP address:

  `sandor.cs.ru.nl    131.174.142.4`

- 131.174.117.20 tells your client (e.g., SSH client) the IP address of `sandor.cs.ru.nl`

DNS entry types

Type	Meaning
A	Address record: returns a 32-bit IP address, used to map hostnames to addresses
NS	Nameserver: Lists the authoritative nameservers of a DNS zone
CNAME	Canonical Name: Assigns a hostname alias to a hostname
SOA	"Start Of Authority": Lists authoritative information about the zone: primary DNS server, mail address of administrator (with @ replaced by a .), serial number, refresh times and timeouts.
MX	Mail Exchanger: Gives a mail server responsible for the domain
TXT	Text field: Originally arbitrary human-readable text, today often used for machine-readable data

- Four sections in a DNS reply:
  - The QUESTION SECTION (repetition of the question)
  - The ANSWER SECTION
  - The AUTHORITY SECTION
  - The ADDITIONAL SECTION

resolv.conf, dig, and whois

- The list of (recursive) nameservers to access is in `/etc/resolv.conf`
- It's typically dynamically updated from DHCP information
- This is another attack vector for **rogue DHCP**!
- Command-line tool to request DNS information: `dig`, examples:
  - Find IP address of `sandor.cs.ru.nl`
    ```
    dig sandor.cs.ru.nl
    ```
  - Ask `ns1.dns.nl` for `ru.nl` autoritative DNS servers of `ru.nl`:
    ```
    dig @ns1.dns.nl ru.nl NS
    ```
  - Ask `ns1.science.ru.nl` for all information of `science.ru.nl`
    ```
    dig @ns1.science.ru.nl science.ru.nl ANY
    ```
  - Reverse lookup hostname for 131.174.142.4:
    ```
    dig -x 131.174.142.4
    ```
- Find out about ICANN registration information of a domain: `whois`, e.g.:
  ```
  whois cryptojedi.org
  ```

The DNS root servers

- Whenever a DNS server does not know the authoritative DNS servers of a Domain, it asks the *DNS root servers*
- DNS root servers are extremely critical piece of Internet infrastructure
- How many are there? Answer: 13
- Names of these servers: `a.root-servers.net` ... `m.root-servers.net`
- Those servers are actually highly redundant, some even distributed over the globe
- Example: K-root server, run by RIPE-NCC
  - Used to be in Amsterdam
  - Now at 18 different locations

DNS root servers hit by largest DDoS ever

News By Oct. 23, 2002 12:38 pm

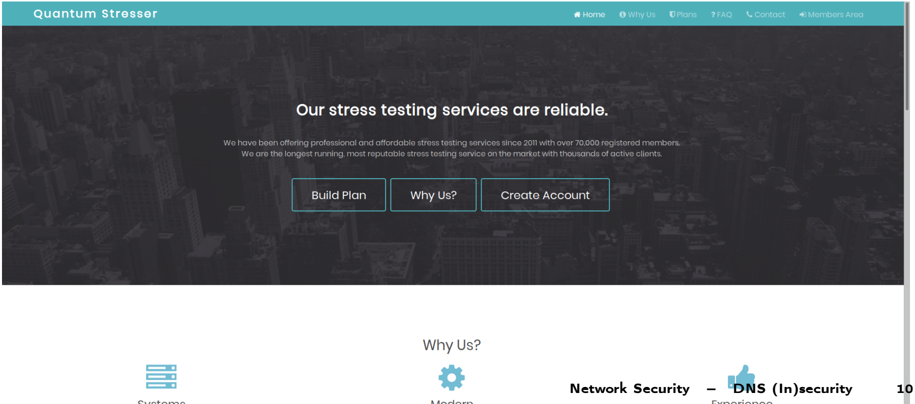
The largest Distributed Denial of Service (DDoS) attack in history went largely unnoticed by the general public on October 21, 2002, but it was almost a disaster, say several Internet backbone operators.

DNS tunneling

- Firewalls may block anything, but typically not DNS
- Idea: set up authoritative DNS server for some subdomain `tunnel.mydomain.nl`
- Encode SSH traffic as DNS requests to this server
- Tunnel SSH traffic through DNS
- This is slow (small payload, UDP is not reliable)
- Ready-made client/server: `ozymandns` by Kaminsky: http://dankaminsky.com/2004/07/29/51/
- Tutorial for DNS tunneling (with `ozymandns`): http://dnstunnel.de/

DNS DDoS amplification

- DNS (typically) uses UDP
- No session establishment: send request, get answer
- Answer can be much larger than the request
- Idea: Spoof IP address of DOS victim in DNS request
- Victim will receive much more data than attacker has to send
- This is called *DNS (D)DOS amplification*



DNS DDoS countermeasures?

- Very hard to defend against DDOS (and DNS amplification)
- Can (temporarily) block packets from open DNS servers
- Can (temporarily) block large DNS reply packets
- Can try to filter spoofed IP addresses ("ingres and egress filtering")

DNS spoofing

- Probably most obvious DNS attack: send wrong answer
- Send wrong answer to client: hit one target
- Send wrong answer to DNS cache: hit many targets
- Answers contain “validity period”
- It’s possible to poison DNS caches for a pretty long time

In the old days

```
$ dig @ns1.attacker.com www.attacker.com
    ;; ANSWER SECTION:
    www.attacker.com.    120      IN    A    123.45.67.8

    ;; AUTHORITY SECTION:
    attacker.com.        86400    IN    NS   ns1.attacker.com.

    ;; ADDITIONAL SECTION:
    ns1.attacker.com.    604800   IN    A    123.45.67.89
    www.target.com.       43200   IN    A     66.66.66.66
```

The bailiwick check

- Idea of the attack: wrong entry for `www.target.com` ends up in cache
- Countermeasure (since 1997): use *bailiwick* check
- Reject ADDITIONAL information if the requested server is not authorized to answer for the domain

Short interlude: A bailiwick

Definition of BAILIWICK

1. the office or jurisdiction of a bailiff
2. a special domain

Source: http://www.merriam-webster.com/dictionary/bailiwick

Definition of BAILIFF

1. **a:** an official employed by a British sheriff to serve writs and make arrests and executions
   b: a minor officer of some United States courts usually serving as a messenger or usher
2. chiefly British: one who manages an estate or farm

Source: http://www.merriam-webster.com/dictionary/bailiff

The race for the answer

- A client is asking for an IP address; if attacker answers first, he wins
- Not quite that easy: Request contains 16-bit Query ID (QID)
- DNS reply has to have the right ID
- Attacker has to guess the ID
- This is a bit similar to the TCP ISN in a session-stealing attack
- In the old days use simply increasing IDs: easy for an attacker to figure out
- Nowadays use randomized 16-bit ID
- The attacker can start the race:
  - Lure victim to website at `www.attacker.com`
  - Include picture from `www.target.com`
  - Attacker sees website request, knows that DNS request for `www.target.com` will follow
- Attacker can send *many packets*
- Attacker can also try to run DOS against real DNS server

Kaminsky's attack (2008)

- Idea: Use website with many links on *subdomains*:

```
<img src="http://aaaa.target.com/image.jpg"/>
<img src="http://aaab.target.com/image.jpg"/>
<img src="http://aaac.target.com/image.jpg"/>
...
```

- Victim will request all of those subdomains, race for each query
- Attacker crafts answer packet for each of those requests:

```
;; ANSWER SECTION:
    aaaa.target.com.    120     IN    A    10.10.10.10

    ;; AUTHORITY SECTION:
    target.com.         86400   IN    NS   ns.target.com.

    ;; ADDITIONAL SECTION:
    www.target.com.     604800  IN    A    66.66.66.66
```

- The client requested the IP address with `target.com` domain
- The answer for `www.target.com` *passes the bailiwick check*!
- The value 604800 defines the validity period of the information: 7 days

Impact of Kaminsky's attack

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The Top Five Worst DNS Security Incidents

By Ram Mohan on August 11, 2010

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1. "The Kaminsky Bug" puts the whole Internet at risk

Often regarded as possibly the greatest security threat the Internet has ever faced, the so-called "Kaminsky Bug" emerged in July 2008, creating great unease and even greater hype. Researcher Dan Kaminsky discovered that it was easy to exploit a weakness in the DNS and built the software to do it. This weakness would enable malicious hackers to transparently imitate any Web page or e-mail account by poisoning the DNS information cached by Internet service providers.

Los Angeles Times LOCAL U.S. WORLD BUSINESS SPORTS ENTERTAINMENT HEALTH STYLE TRAVEL

Technology

Source-port randomization

- Kaminsky's attack hit most big DNS server suites
- `djbdns`, PowerDNS, MaraDNS, and Unbound were not affected
- Those suites randomized the UDP source port
- Not just 16 bits of entropy to guess for an attacker but 32 bits
- Today, all DNS servers randomize the source port
- Potential problem with NAT: source port is rewritten

Birthday attacks

- Imagine that a DNS server is sending out many *identical requests* (with different source port and QID)
- Attacker spoofs replies with different port+QID combinations
- Any collision with one of the requests wins
- Do servers send out identical requests?
- Some do, e.g., `djbdns`'s `dnscache` (Kevin Day, 2009):
  - Trigger 200 identical queries (default size of query queue)
  - Need to be fast, send these queries before first reply is received
  - Increase attacker's success probability from $1/2^{32}$ to $200/2^{32}$

More randomization?

- The QUESTION section of a DNS request is copied to the reply
- Some bits in the QUESTION section, don't matter: `www.ExAMPle.com` is the same as `www.example.com`
- The `0x20` bit changes capitalization of letters
- Idea: Use this bit for extra entropy
- Slight problem: DNS standard does not *require* the QUESTION section to be copied bit-by-bit
- Other idea: query repetition (another 32 bits of entropy)
- Adds additional complications (not broadly implemented)
- Bernstein on randomization:

  "It is clear that enough randomization effort would be able to stop all blind forgeries."

The easy way. . .

- A passive MitM can read DNS requests
- Becoming a passive MitM is not that hard:
  - Sniff WiFi
  - ARP spoofing
  - Be an ISP
  - Be a network administrator in a company
- A DNS attacker can poison a DNS cache
- Affects many more clients than a MitM between clients!

DNS censorship

- DNS can be used for censorship:
  - April 1997: German provider DFN blocks IPs of xs4all.nl
  - German "Zugangserschwerungsgesetz"
  - "Child Sexual Abuse Anti Distribution Filter" (CSAADF) by CIRCAMP used in Denmark, Finland, Italy, Newzealand, Norway, Sweden und der Switzerland
  - Idea in all these cases: "redirect" (spoof) DNS
  - Circumvention: Use alternative DNS

Source: http://xkcd.com/1361/

DNSSEC

- Idea: Use cryptographically signed DNS entries
- Initial design decision: sign information offline:
  - No need for expensive public-key crypto for each reply
  - No need to hold the private keys on DNS servers
- Public keys are authenticated through a chain of trust
- Root of trust: public keys of the DNS root servers
- Additional (cryptographic) information in new DNS entry types:
  - RRSIG: DNSSEC signature
  - DNSKEY: public key to verify signature

More amplification!

- DNSSEC does not increase the size of DNS requests
- DNSSEC does significantly increase the size of DNS replies
- Modern DDOS uses DNS+DNSSEC
- RFC 4033: "DNSSEC provides no protection against denial of service attacks. Security-aware resolvers and security-aware name servers are vulnerable to an additional class of denial of service attacks based on cryptographic operations."

DNS zone enumeration

- You want DNS to answer a request for domain names
- You *do not* want to hand out a list of all domain names
- Finding all hosts in a DNS zone is called *zone enumeration*
- Problem for DNSSEC: offline-signed answer for *non-existing* entries (negative answer)
- First solution: Don't sign (bad idea, can use for attack)
- Second idea: Sign "There is no name between `smtp.example.com` and `www.example.com`"
- This trivially allows zone enumeration:
  - Try some hostname, this will give you 1 or 2 valid hostnames
  - Try just before (alphabetically) a valid hostname: find previous
  - Try just after (alphabetically) a valid hostname: find next
- RFC 4033: "DNSSEC introduces the ability for a hostile party to enumerate all the names in a zone by following the NSEC chain."

NSEC3

- Idea: Hash domain names, sign information on gaps between existing *hashes*
- Example:
  - request for (non-existing) `test.example.com`
  - Hash `test.example.com` (with SHA-1), obtain: `401f83bc96721eeeba6f5c1c54cf0a83dc08a30b`
  - Signed answer: "There is no name with hash between `068503358dddd23cf6cf00f5d6ad9a45cd0a8e03` and `512e9305c87f4f1ccdbacb80c559f3dce496ae29`.
- Problem: Can revert these hashes
- Wait, shouldn't it be hard to compute preimages of hashes?
- Well, domain names are not that hard to guess, can just try valid domain names, e.g.

```
www.example.com    068503358dddd23cf6cf00f5d6ad9a45cd0a8e03
smtp.example.com   512e9305c87f4f1ccdbacb80c559f3dce496ae29
```

- Software by Niederhagen: Try 6000 billion hashes per week on NVIDIA GTX295 GPU
- This is *much* faster than trying domain names through DNS queries

More DNSSEC problems

- Second implication of offline-signed records: *replay attacks*
- Attack scenario:
  - Company runs server `www.example.com` at 123.45.67.89
  - DNS server sends signed name resolution for this name/IP, attacker records it
  - Company moves or changes provider, now `www.example.com` is at 98.76.54.32
  - Attacker replays name resolution to 123.45.67.89
- DNSSEC uses bleeding-edge crypto (1024-bit RSA)
- DNSSEC does not encrypt queries; from RFC 4033:
  "Due to a deliberate design choice, DNSSEC does not provide confidentiality"

DNSCurve

- Alternative to DNSSEC proposed by Bernstein: DNSCurve
- Idea is to encrypt and authenticate DNS traffic (not sign records)
- The idea is a bit similar to SSL/TLS (next lecture)
- DNSCurve does not have the problems that come with offline signing:
  - No zone enumeration
  - No replay attacks
- It also has other advantages over DNSSEC:
  - Much stronger (and faster) crypto
  - Much more limited amplification issues (replies grow, but so do requests)
  - Confidentiality of DNS requests (encryption)
- Potential disadvantage of DNSCurve: crypto keys need to be on DNS servers
- Addional disadvantage: It's much easier to deploy than DNSSEC, does not create as many jobs for consultants

More reading. . .

- Dan Bernstein about DNSCurve (and DNSSEC vulnerabilities):
  - http://dnscurve.org/
  - http://cr.yp.to/talks/2010.12.28/slides.pdf
  - Updated: http://cr.yp.to/talks/2016.12.08/slides-djb-20161208-dnssec-a4.pdf
- Dan Kaminsky's answer:
  http://dankaminsky.com/2011/01/05/djb-ccc/

  "DNSSEC Is Not Necessarily An Offline Signer – In Fact, It Works Better Online!"
- Dan Bernstein's answer:
  http://marc.info/?l=djbdns&m=129434351607605&w=2