

DNSCurve

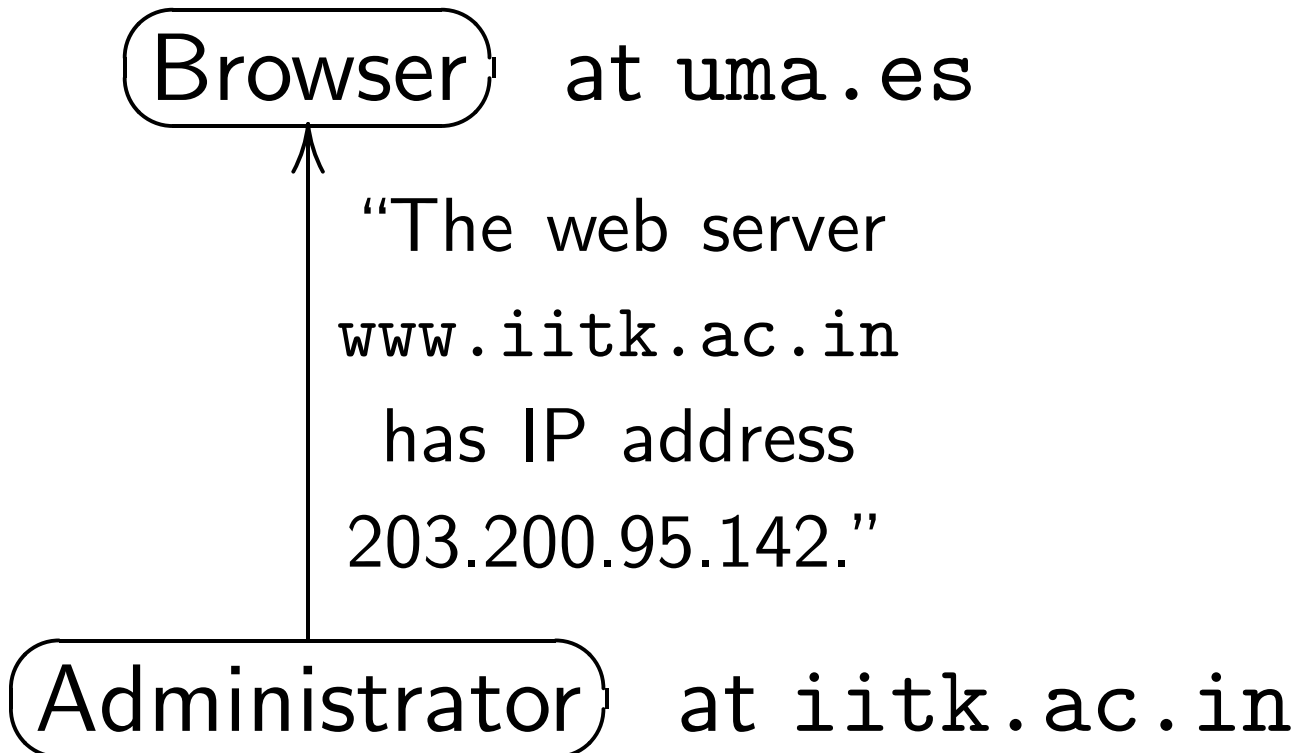
D. J. Bernstein

University of Illinois at Chicago

The Domain Name System

uma.es wants to see

`http://www.iitk.ac.in`.



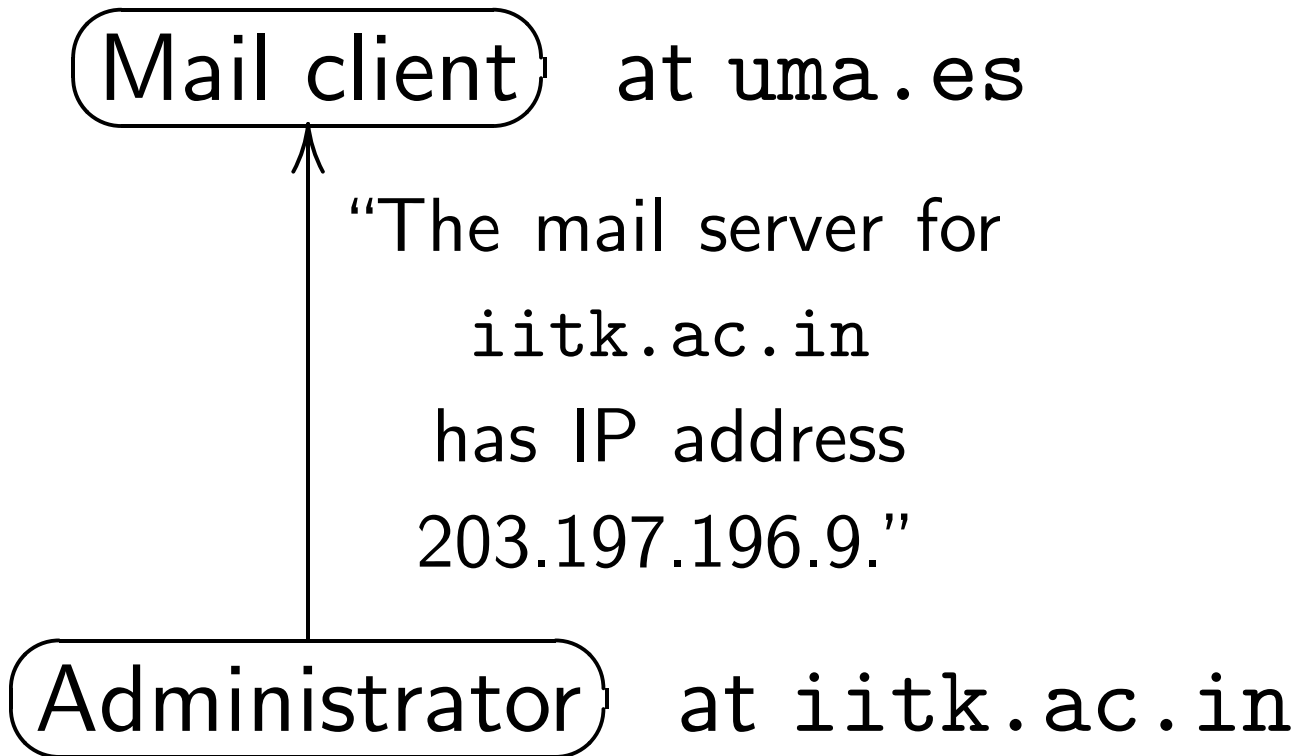
Now uma.es

retrieves web page from

IP address `203.200.95.142`.

Same for Internet mail.

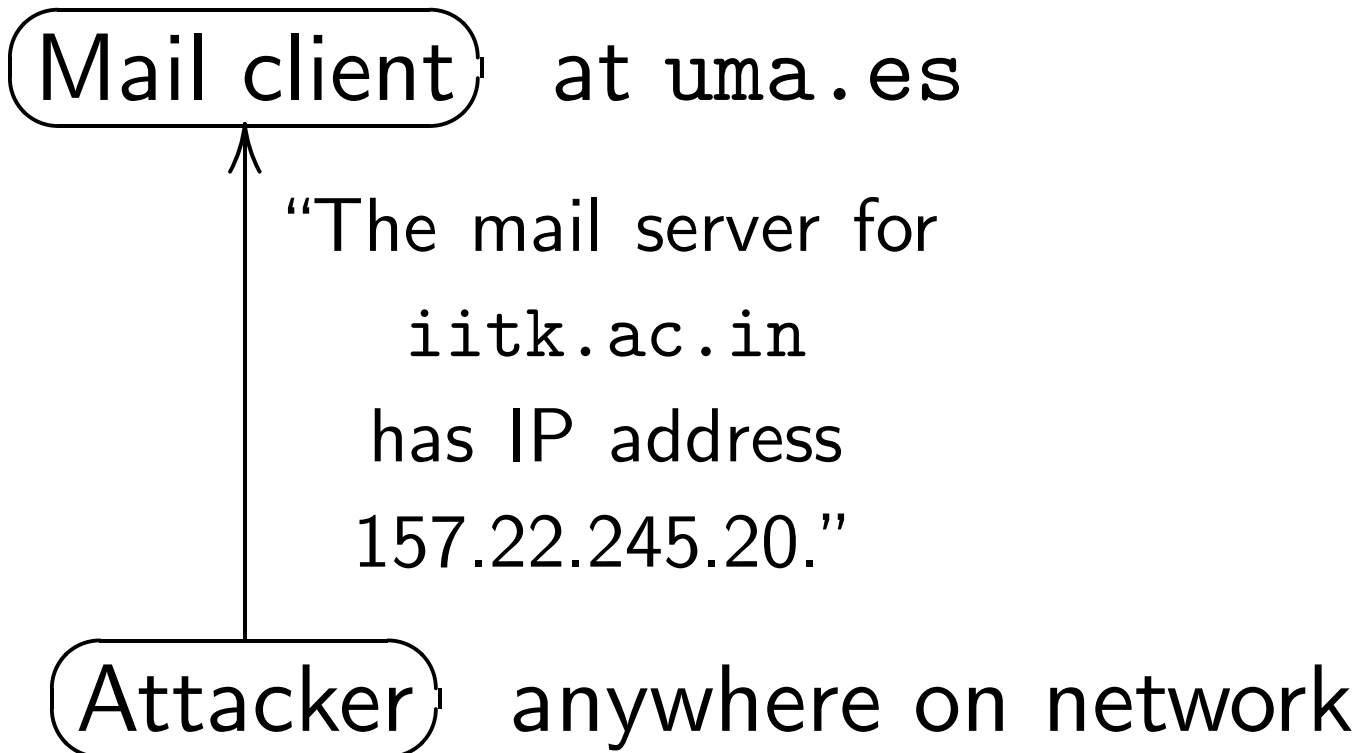
uma.es has mail to deliver to
someone@iitk.ac.in.



Now uma.es
delivers mail to
IP address 203.197.196.9.

Forging DNS packets

uma.es has mail to deliver to
someone@iitk.ac.in.



Now uma.es
delivers mail to
IP address 157.22.245.20,
actually the attacker's machine.

Actually: Client sends query;
attacker has to repeat
some bits from the query.

Actually: Client sends query;
attacker has to repeat
some bits from the query.

Network probably has at least
one attacker-controlled machine.
That machine sniffs network,
trivially forges DNS packets.

Actually: Client sends query;
attacker has to repeat
some bits from the query.

Network probably has at least
one attacker-controlled machine.
That machine sniffs network,
trivially forges DNS packets.

“No sniffers on *my* network!”
... so a blind attacker
guesses the bits to repeat,
eventually gets lucky.

After analysis, optimization:
blind forgery is about as easy
as downloading a movie.

Some general questions

Why doesn't the Internet use cryptography?

Some general questions

Why doesn't the Internet use cryptography?

“The Internet does use cryptography! I just made an SSL connection to my bank.”

Some general questions

Why doesn't the Internet use cryptography?

“The Internet does use cryptography! I just made an SSL connection to my bank.”

Indeed, many connections use SSL, Skype, etc.

But *most* connections don't.

Why is there so much unprotected Internet communication?

Why is there so much unprotected Internet communication?

“Because nobody cares.
Cryptography is pointless.
Attackers are exploiting
buffer overflows; they aren't
intercepting or forging packets.”

Why is there so much unprotected Internet communication?

“Because nobody cares. Cryptography is pointless. Attackers are exploiting buffer overflows; they aren’t intercepting or forging packets.”

In fact, attackers are forging packets *and* exploiting buffer overflows *and* doing much more. Users want *all* of these problems fixed.

Why are typical Internet packets unencrypted and unauthenticated?

Why are typical Internet packets unencrypted and unauthenticated?

“It’s too easy to write Internet software that exchanges data without any cryptographic protection. Most Internet clients and servers don’t know how to make cryptographic connections.”

Why are typical Internet packets unencrypted and unauthenticated?

“It’s too easy to write Internet software that exchanges data without any cryptographic protection. Most Internet clients and servers don’t know how to make cryptographic connections.”

True for most protocols.

But let’s focus on HTTP.

Most HTTP servers and browsers (Apache, Internet Explorer, Firefox, etc.) support SSL.

Why is SSL used for only a tiny fraction of all HTTP connections?

Why is SSL used for only a tiny fraction of all HTTP connections?

“Have you ever tried to set up SSL? Do you want to go through all these extra Apache configuration steps? Do you want to pay for a certificate? Do you want to annoy your web-site visitors with self-signed certificates?”

Why is SSL used for only a tiny fraction of all HTTP connections?

“Have you ever tried to set up SSL? Do you want to go through all these extra Apache configuration steps? Do you want to pay for a certificate? Do you want to annoy your web-site visitors with self-signed certificates?”

Indeed, usability is a major issue. Only $\approx 1\%$ of the Apache servers on the Internet have SSL enabled.

But let's focus on Google.

Google has already
paid for a certificate.

Google uses SSL for

`https://mail.google.com.`

But let's focus on Google.

Google has already
paid for a certificate.

Google uses SSL for
`https://mail.google.com`.

If you connect to
`https://www.google.com`,
Google redirects your browser to
`http://www.google.com`.

Why does Google actively
turn off cryptographic protection?

Why does Google actively
turn off cryptographic protection?

“Enabling SSL
for more than a small fraction
of Google connections would
overload the Google servers.
Google doesn't want to pay for
a bunch of extra computers.
Too slow \Rightarrow unusable.”

Why does Google actively
turn off cryptographic protection?

“Enabling SSL
for more than a small fraction
of Google connections would
overload the Google servers.
Google doesn't want to pay for
a bunch of extra computers.
Too slow \Rightarrow unusable.”

Many companies sell
SSL-acceleration hardware,
but that costs money too.

Why are cryptographic computations so expensive?

Can crypto be faster, without being easy to break?

Can crypto be fast enough to solidly protect all of Google's communications?

Can crypto be fast enough to protect every Internet packet?

Can universal crypto be *usable*?

What cryptography can do

Cryptography can stop sniffing attackers by scrambling legitimate packets.

Cryptography is often described as protecting confidentiality: attackers can't understand the scrambled packets.

Can also protect integrity: attackers can't figure out a properly scrambled forgery.

Traditional cryptography requires each legitimate client-server pair to share a secret key.

Public-key cryptography has much lower requirements. (1976 Diffie–Hellman; many subsequent refinements)

Each party has one public key. Two parties can communicate securely if each party knows the other party's public key.

1993: IETF begins “DNSSEC” project to add public-key signatures to DNS.

After fifteen years and millions of dollars of U.S. government grants (e.g., DISA to BIND company; NSF to UCLA; DHS to Secure64 Software Corporation),
how successful is DNSSEC?

The Internet has about
78000000 *.com names.

After fifteen years and millions of dollars of U.S. government grants (e.g., DISA to BIND company; NSF to UCLA; DHS to Secure64 Software Corporation),
how successful is DNSSEC?

The Internet has about
78000000 *.com names.

Surveys by DNSSEC developers,
last updated 2009.03.12,
have found 253 *.com
names with DNSSEC signatures.
116 on 2008.08.20; 253 > 116.

Why is nobody using DNSSEC?

Some of the Internet's DNS servers are extremely busy: e.g., the root servers, the .com servers, the google.com servers.

DNSSEC tries to minimize server-side costs by *precomputing* signatures of DNS records.

Signature is computed once; saved; sent to many clients.

Hopefully the server can afford to sign each DNS record once.

Clients don't share the work of *verifying* a signature.

DNSSEC tries to reduce client-side costs through choice of crypto primitive.

DNSSEC RFCs

say DSA is "10 to 40 times as slow for verification" as RSA; recommend RSA "as the preferred algorithm" for DNSSEC; suggest RSA key size of only 1024 bits for "leaf nodes in the DNS."

I say:

1024-bit RSA is irresponsible.

2003: Shamir–Tromer et al.
concluded that 1024-bit RSA
was already breakable by
large companies and botnets.

2003: RSA Laboratories
recommended a transition to
2048-bit keys “over the remainder
of this decade.” 2007: NIST
made the same recommendation.

I say:

1024-bit RSA is irresponsible.

2003: Shamir–Tromer et al.
concluded that 1024-bit RSA
was already breakable by
large companies and botnets.

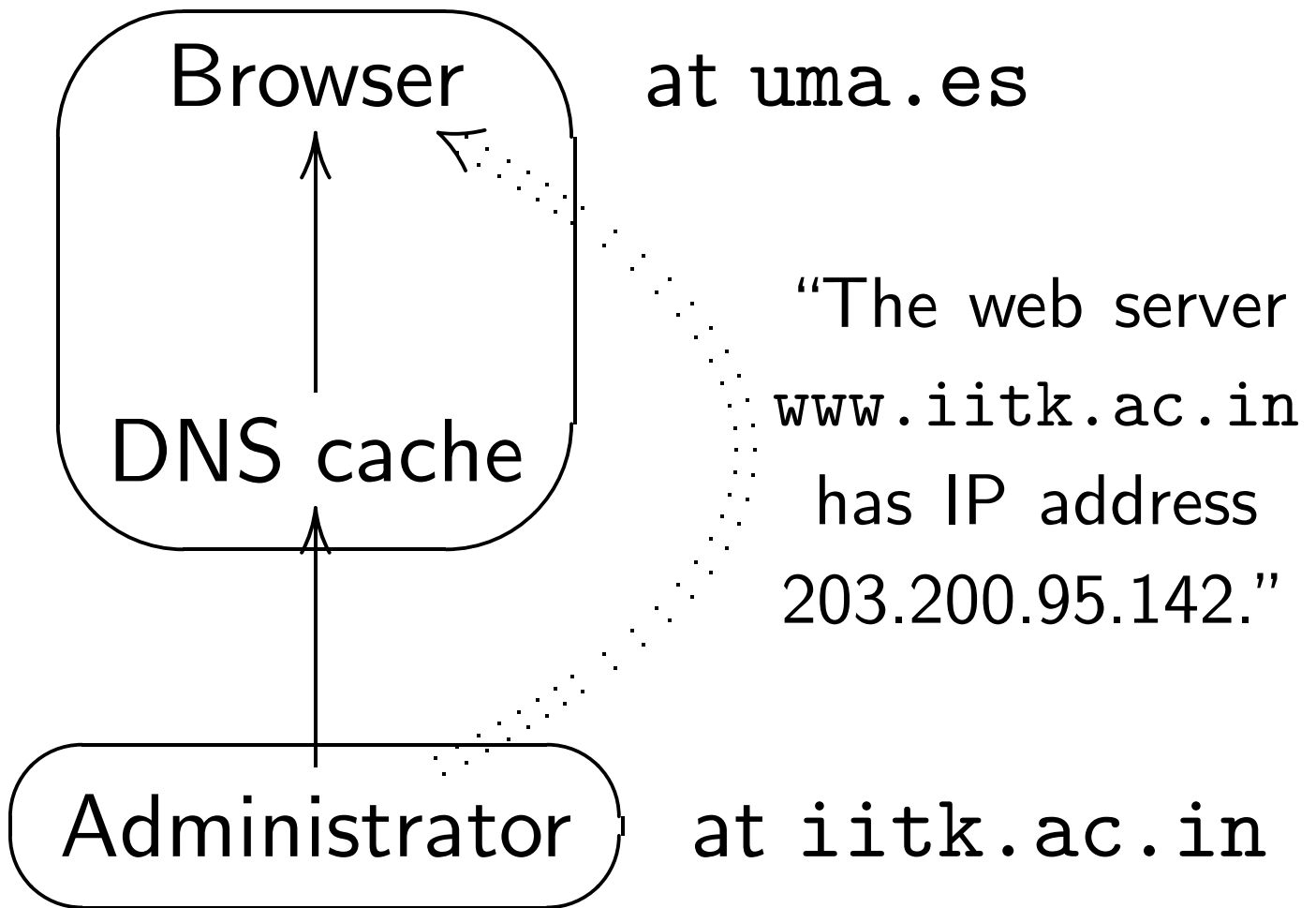
2003: RSA Laboratories
recommended a transition to
2048-bit keys “over the remainder
of this decade.” 2007: NIST
made the same recommendation.

But most users don't know this.

Why aren't they using DNSSEC?

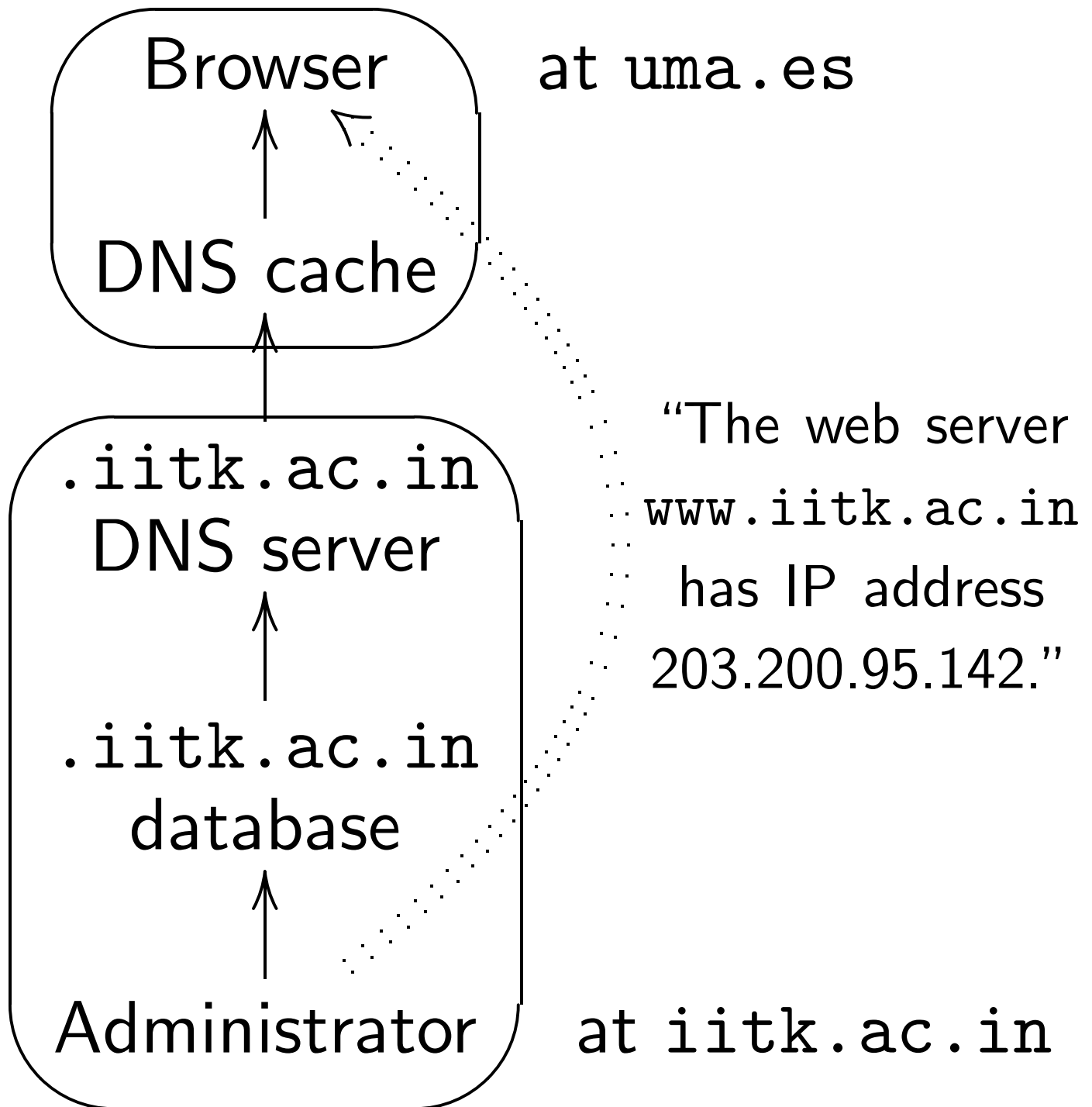
DNS architecture

Browser pulls data from
DNS cache at `uma.es`:

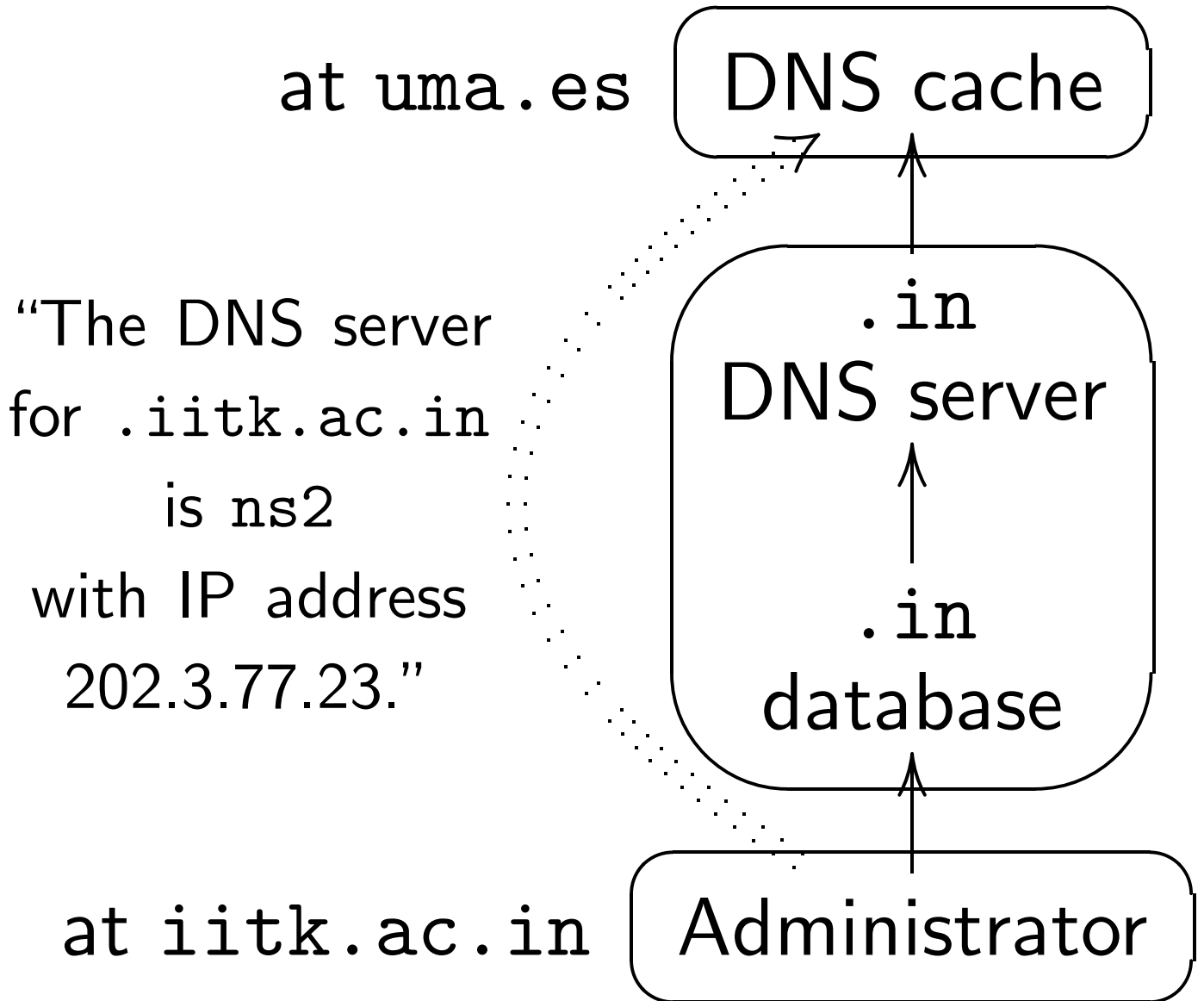


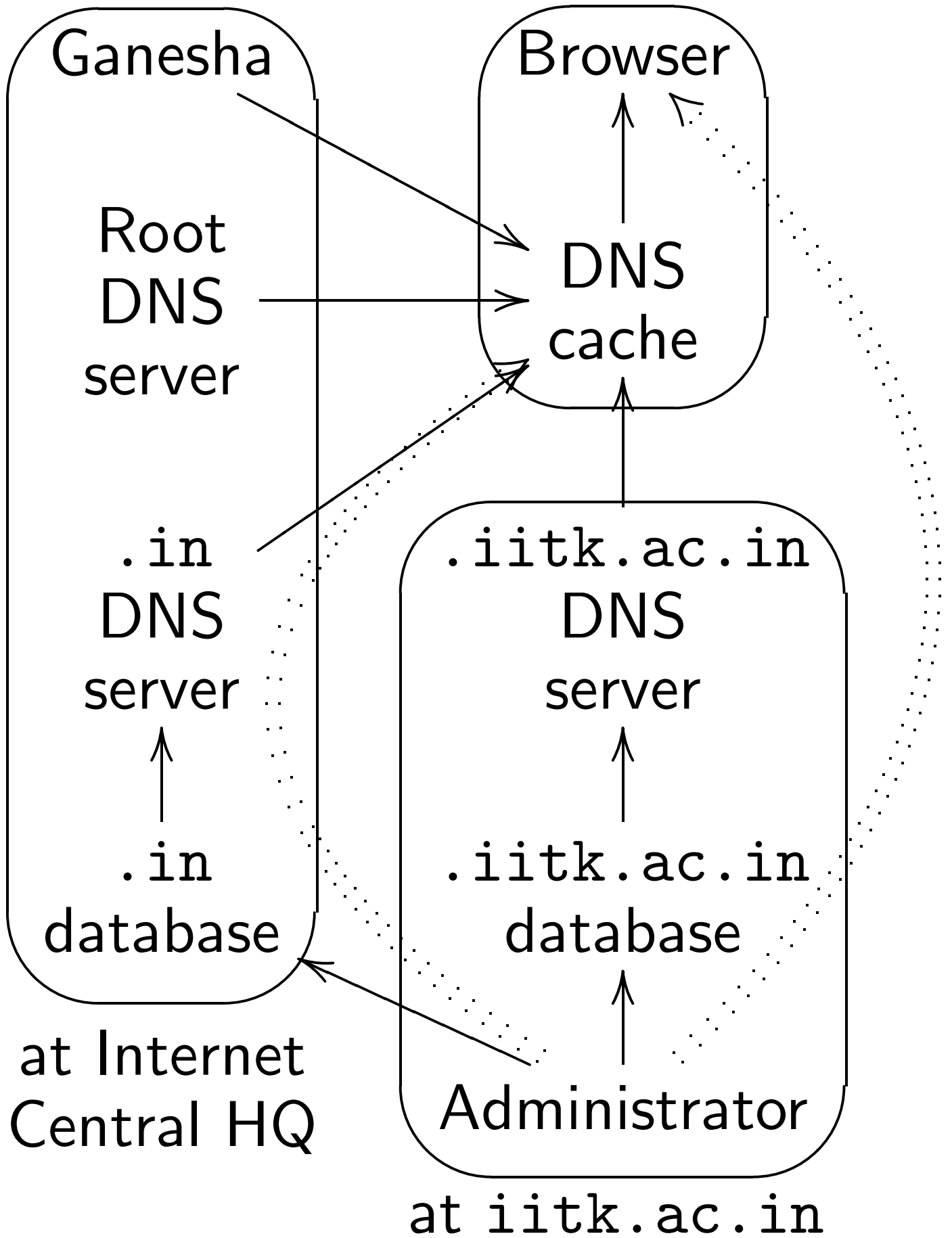
Cache pulls data from
administrator if it
doesn't already have the data.

Administrator pushes data
through local database into
.iitk.ac.in DNS server:



DNS cache learns location of
.iitk.ac.in DNS server from
.in DNS server:





DNS server software listed in Wikipedia: BIND, Microsoft DNS, djbdns, Dnsmasq, Simple DNS Plus, NSD, PowerDNS, MaraDNS, ANS, Posadis, Secure64 DNS.

DNS database-management tools listed by 2008 Salomon: BPP, DNS Boss, DNSStool, gencidrzone, h2n, makezones, NSC, nsupdate, SENDS, updatehosts, Utah Tools, webdns, zsu. Plus hundreds of homegrown tools written by DNS registrars etc.

DNSSEC requires new code in every DNS-management tool.

Whenever a tool adds or changes a DNS record, also has to precompute and store a DNSSEC signature for the new record.

Often considerable effort for the tool programmers.

Example: Signing 2GB database can produce 10GB database (2005 NIST study).

Tool reading database into RAM probably has to be reengineered.

Because of engineering costs and redeployment costs, very few database-management tools have added DNSSEC support.

Administrator has to manually mix existing management tools with separate signature generation for every change to DNS data.

Because of engineering costs and redeployment costs, very few database-management tools have added DNSSEC support.

Administrator has to manually mix existing management tools with separate signature generation for every change to DNS data.

2008 slideshow “DNSSEC in six minutes” (79 pages): “Any time you modify a zone . . . you must re-run `dnssec-signzone`.”

Administrator also has to send public key to `.in`.

The `.in` server *and* database software *and* web interface need to be updated to accept these public keys and to sign everything.

Big zones such as `.com` refuse to sign complete database. Full DNSSEC signing would be much too slow and much too big.

DNS cache needs new software to fetch keys, fetch signatures, and verify signatures.

Often many more packets than original DNS.

Higher latency for user.

More frequent failures.

Also, much easier for attacker to deny service.

> 100× amplification!

Official DNSSEC response,

RFC 4033: “DNSSEC

provides no protection

against denial of service attacks.”

Replay attack on DNSSEC:

Attacker inspects DNSSEC signatures from `iitk.ac.in`.

`iitk.ac.in` changes location, acquires new IP addresses, changes DNS records.

Replay attack on DNSSEC:

Attacker inspects DNSSEC signatures from `iitk.ac.in`.

`iitk.ac.in` changes location, acquires new IP addresses, changes DNS records.

Attacker buys the old addresses, forges DNS responses with the *old* DNS records and the *old* signatures.

Passes signature verification.

Successfully steals mail!

DNSSEC has a partial defense.

Signature has an expiration date,
normally signing date + 30 days.

Not very good security:

replay attack continues to work
for up to 30 days!

DNSSEC has a partial defense.

Signature has an expiration date,
normally signing date + 30 days.

Not very good security:

replay attack continues to work
for up to 30 days!

Also a major administrative
hassle: administrator must
generate new signatures
before old signatures expire.

If administrator forgets,
domain is destroyed.

“DNSSEC suicide.”

Imagine an “HTTPSEC”
that works like DNSSEC.

Imagine an “HTTPSEC”
that works like DNSSEC.

Install HTTPSEC software.

Set up a public key.

After every web-page update,
wiki edit, database change, etc.,
log in to web server
and run `httpsec-signpages`
with appropriate options
to precompute new signatures.

Imagine an “HTTPSEC”
that works like DNSSEC.

Install HTTPSEC software.

Set up a public key.

After every web-page update,
wiki edit, database change, etc.,
log in to web server
and run `httpsec-signpages`
with appropriate options
to precompute new signatures.

Replay attacks work for 30 days.
Have to run `httpsec-signpages`
again before 30-day expiration or
your web pages are destroyed.

But wait, there's more!

NXDOMAIN attack on DNSSEC:

Attacker forges DNS response
from google.com saying that
citronella.google.com
doesn't exist.

But wait, there's more!

NXDOMAIN attack on DNSSEC:

Attacker forges DNS response from `google.com` saying that `citronella.google.com` doesn't exist.

Cache can't accept this without a signature: otherwise attacker can knock names off the Internet.

But wait, there's more!

NXDOMAIN attack on DNSSEC:

Attacker forges DNS response from `google.com` saying that `citronella.google.com` doesn't exist.

Cache can't accept this without a signature: otherwise attacker can knock names off the Internet.

When is the signature precomputed? Does Google precompute signatures for *all* possible names? Too many!

DNSSEC solution: Sign multi-NXDOMAIN such as “there are no names between `chrome.google.com` and `code.google.com`.”

DNSSEC server issues this signed data in response to any name between `chrome` and `code`.

Tricky definition of “between”; theoretically implementable.

DNSSEC solution: Sign multi-NXDOMAIN such as “there are no names between `chrome.google.com` and `code.google.com`.”

DNSSEC server issues this signed data in response to any name between `chrome` and `code`.

Tricky definition of “between”; theoretically implementable.

Consequence: If you deploy DNSSEC then you are exposing *all* of your DNS names!

Newest DNSSEC variant:

“NSEC3” (2008 Laurie),
exposing *hashes* of DNS names.
Hash is 150 SHA-1 iterations.

Hash-enumeration attack:

Attacker guesses many names,
computes their hashes,
compares to the hashes
exposed by DNSSEC+NSEC3.

Small 10-computer cluster:

$\approx 2^{44}$ guesses/year.

Large company or botnet:

$\approx 2^{64}$ guesses/year.

Without DNSSEC,
attacker has to send query
for each guessed name.

Flooding a 4Mbps connection:
 $\approx 2^{37}$ guesses/year.

Compared to normal DNS,
DNSSEC+NSEC3
makes guessing *silent* and
makes it *millions of times faster*
for a well-equipped attacker.

DNSSEC+NSEC3 is advertised
as being better than DNSSEC;
but it still loses privacy
compared to normal DNS.

Precomputation impact summary:

DNSSEC is pain for implementors.

Hundreds of DNS programs—

all caches, all servers,

and all management tools—

need to be modified to

precompute and store signatures.

DNSSEC is pain for

administrators, far beyond a

simple upgrade.

DNSSEC hurts privacy.

DNSSEC hurts reliability.

DNSSEC aids denial of service.

Rethinking signatures

Conventional wisdom:

DNSSEC's precomputation,
sacrificing security while
creating severe usability problems,
is necessary for speed.

Can we achieve adequate speed
without precomputation?

Let's change the design.

Rethinking signatures

Conventional wisdom:

DNSSEC's precomputation, sacrificing security while creating severe usability problems, is necessary for speed.

Can we achieve adequate speed *without* precomputation?

Let's change the design.

1. Add encryption.

Want to protect against sabotage *and* against espionage.

So use public-key signatures *and* public-key encryption.

2. Merge signing with encryption.

“Public-key signcryption” protects against forgery and eavesdropping in one step.

“Public-key authenticated encryption” is even faster.

No need to partition the algorithms into an encryption component and an authentication component. Combined algorithms are faster.

3. Merge public-key operations across multiple messages.

It's silly for a sender to authcrypt two messages to the same recipient.

“Hybrid cryptography” is much faster.

Example: Sender generates a random AES key, authcrypts the AES key, uses the AES key to encrypt and authenticate both messages.

4. Choose sensible primitives.

256-bit elliptic-curve cryptography
using public-domain software:

489069 Core 2 cycles to handle a
new communication partner.

5355 cycles to encrypt and
authenticate a 510-byte message.

6786 cycles to verify and decrypt
a legitimate 510-byte message.

3465 cycles to reject a forged
510-byte message.

A 2.5GHz Intel Core 2 Quad Q9300 CPU costs US\$225.

Complete computer: \$400.

This CPU has 4 cores.

Each core carries out
2.5 billion cycles/second.

On this computer,
the same software takes just
49 seconds to handle 1000000
new communication partners,
and just 12 seconds to handle
10000000 incoming packets *and*
10000000 outgoing packets.

VeriSign is spending
>\$1000000000 to upgrade the
Internet's .com DNS servers.

In a typical day, these servers
together handle 35 billion queries
from 5 million clients.

VeriSign is spending
>\$1000000000 to upgrade the
Internet's .com DNS servers.

In a typical day, these servers
together handle 35 billion queries
from 5 million clients.

Total cryptographic cost:
about half a day on a single
\$400 computer with this software.

VeriSign is spending
>\$1000000000 to upgrade the
Internet's .com DNS servers.

In a typical day, these servers
together handle 35 billion queries
from 5 million clients.

Total cryptographic cost:
about half a day on a single
\$400 computer with this software.

Verisign says that it wants to be
prepared for 4 trillion packets/day.

Cryptographic cost of
4 trillion partners/day with this
software: < 3000 computers.

What is this software?

It's the new "Networking and Cryptography library" ("NaCl") developed within the EU FP7 "Computer Aided Cryptography Engineering" ("CACE") project.

What is this software?

It's the new "Networking and Cryptography library" ("NaCl") developed within the EU FP7 "Computer Aided Cryptography Engineering" ("CACE") project.

News: All parts of NaCl needed for DNS are done!

What is this software?

It's the new "Networking and Cryptography library" ("NaCl") developed within the EU FP7 "Computer Aided Cryptography Engineering" ("CACE") project.

News: All parts of NaCl needed for DNS are done!

Actually done three months ago. Subsequent time has been QA.

NaCl is now released:

<http://nacl.cace-project.eu>

The DNSCurve project

DNSCurve uses NaCl
to add heavy-duty integrity
(RSA-1024 has 80-bit security;
DNSCurve has 128-bit security)
and some confidentiality
and availability
to the Domain Name System.

Despite all this security,
DNSCurve is very easy for DNS
software authors to implement
and very easy for
administrators to deploy.

Administrator has to change the `iitk.ac.in` server to support DNSCurve, *or* install a DNSCurve forwarder alongside the server.

Administrator does *not* need to change database software, does *not* need to store signatures, does *not* need new procedures for updating DNS records, and does *not* risk DNSSEC suicide.

Administrator changes
server name such as ns2
to a server name that encodes
the DNSCurve public key.

The .in server
and database software
and web interface
already support
iitk.ac.in server names
selected by the
iitk.ac.in administrator!

Cache has to be upgraded to support DNSCurve.

Cache naturally sees the encoded DNSCurve public key.

Cache encrypts and authenticates DNS packets sent to that server.

Cache verifies and decrypts DNS packets received from that server.

No extra packets.

Forged packets are very efficiently discarded.

Denial of service becomes much more difficult.

Does DNSCurve mean that
DNSSEC is completely useless?

No. DNSSEC can protect against
compromise of DNS servers
if administrator generates
signatures on another machine
that has not been compromised.

Does DNSCurve mean that DNSSEC is completely useless?

No. DNSSEC can protect against compromise of DNS servers if administrator generates signatures on another machine that has not been compromised.

Analogy: HTTPSEC, unlike HTTPS, can protect against compromise of HTTP servers if administrator signs web pages on another machine.

But does this justify the pain of DNSSEC+HTTPSEC?

More information on DNSCurve:

See <http://dnscurve.org>.

Software release coming soon.

More information on DNSCurve:
See <http://dnscurve.org>.
Software release coming soon.

Thinking beyond DNS:
Can every Internet packet
be protected in a similar way?

More information on DNSCurve:
See <http://dnscurve.org>.
Software release coming soon.

Thinking beyond DNS:
Can every Internet packet
be protected in a similar way?

Thinking beyond networking:
When people sacrifice security
and usability for the sake of
performance, are they really
improving performance?

