T-DNS: Connection Oriented DNS to Improve Privacy and Security

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don't fear connections for DNS

DNS Basics

since 1987 (RFC-1034)

DNS is simple request-response:

client: A www.example.com ?

server: 192.0.2.1

perfect for UDP

(TCP supported too, but as fallback and zone transfers)

Fear of DNS over TCP

- TCP is horribly slow: *bad client latency*

- TCP => server state : *server memory explodes*

community ~~consensus:~~ ~~**orthodoxy**~~ ***dogma***

don't use TCP,* UDP's constraints are OK

* except for fallback and zone transfers

Our Contributions

- analysis: **don't fear connections for DNS**
  - client latency: only modestly more
  - server memory: well within current hardware
- implementation choices to get here
- small protocol addition: TLS upgrade

=> *T-DNS: DNS over TCP+TLS*

T-DNS: TCP and TLS Connections

- introduction
- **why**
- how
- at minimal cost
- better than alternatives
- next steps

Why T-DNS

- protecting privacy
  - connections -> encryption -> privacy
- denying DoS   (Denial of Service)
  - connections -> spoof-proof -> no amplification attacks
- leaving limits
  - connections -> UDP limits don’t drive policies

Protecting Privacy

- principle: *all* traffic should be private (=> encrypted)

- rise of public DNS means many can snoop
  - Google Public DNS, OpenDNS, others
  - traffic over WAN should be private!

- individuals avoiding transparent proxies
  - multiple ISPs intercept DNS to add ads

- DNS is more than addresses
  - anti-spam (DNSBL), embedded user IDs (facebook, etc.)
    - ex: DNSBL's spam check sends IP address of *every incoming mail server* over the WAN
  - even on LAN (where destinations are visible), should protect other content

advocacy of Google public DNS to avoid Turkish censorship of Twitter, 2014-03-21

Denying DoS

- problem: DNS attacks others
  - DNS amplification attacks
  - a growth industry in 2013: >100Gb/s attacks
- problem: DoS on DNS servers
  - work-around: massive over-capacity
- solution: TCP
  - well understood anti-DoS methods:
  - 3-way handshake precludes spoofing
  - TCP cookies shift state to client for non-spoofed

an amplification attack:
attacker, **forging IP** of victim
Q: ANY for example.com ?
(~60 bytes)

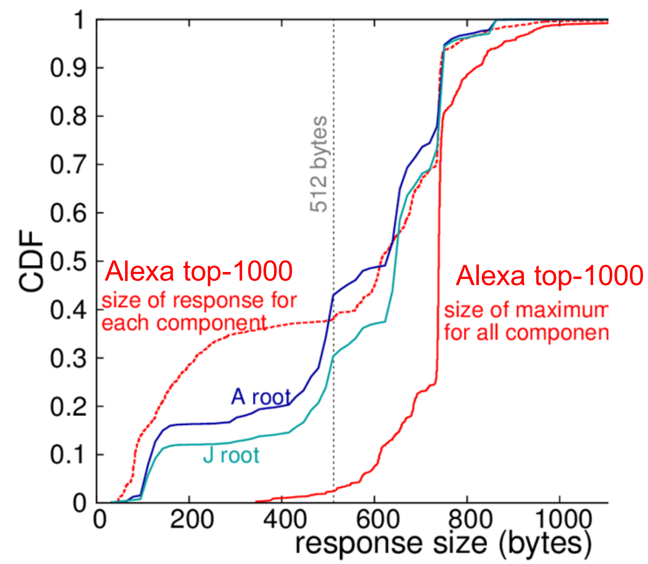
server: let me help you,
here's 4000 bytes
of what I know about
example.com

result: 60x more bits on victim

Leaving Limits

- for >25 years, *policy* decisions forced by UDP packet sizes
  - number of root servers: all fit in 512B
  - DNSsec: required EDNS for >512B
  - crypto algs and key sizes: pkt size limited
  - key rollover: temporary 2x size
- partial fix: EDNS0 deployment (10+ years, since 1999)
- what uses already discarded as too big?

=> *enough already!*



response sizes today

Doesn't DNSsec already *"Secure DNS"*?

A: yes, but…

- DNSsec is about *query integrity*
  - that is: if you are told X, is X true?
  - it signs answers; signatures prove X is true
- DNSsec does *nothing* for problems
  - *everything* sent in the clear: *no privacy*
  - nothing about DoS
  - large signatures stress UDP size limits

=> need DNSsec's integrity ***and*** T-DNS' privacy

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- analysis: **don’t fear connections for DNS**
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3. analysis: **don’t fear connections for DNS**
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1. **small protocol addition: TLS upgrade**

(going in reverse order)

Protocol Changes: Goals

- minimize change
- reuse existing approaches
- follow IETF patterns

(as boring as possible)

- implications:
  - reuse TLS: Transport Layer Security
  - add a STARTTLS-like "upgrade"
  - look at implementation choices

Protocol Changes: Goals

- minimize change
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- **implications:**
  - **reuse TLS: Transport Layer Security**
  - **add a STARTTLS-like “upgrade”**
  - **innovation: careful implementation**

SMTP before STARTTLS

C & S: open TCP connection

S: 220 mail.imc.org SMTP service ready

C: EHLO mail.example.com

S: 250-mail.imc.org hi, extensions are: -8BITMIME -STARTTLS DSN

C: STARTTLS

S: 220 Go ahead

C & S: <negotiate a TLS session, in binary, usin

C: EHLO mail.example.com

S: 250-mail.imc.org hello, extens

problem: cleartext mail is snoop-able (fix: TLS)

C: MAIL FROM:<sender@mail.example.com>

S: 250 2.1.0 <sender@mail.example.com>... Sender OK

C: RCPT TO:<destination@mail.example.com>

S: 250 2.1.5 <destination@mail.example.com>

C: <send mail contents>

SMTP *with* STARTTLS

C & S: open TCP connection

S: 220 mail.imc.org SMTP service ready

C: EHLO mail.example.com

S: 250-mail.imc.org hi, extensions are: -8BITMIME -STARTTLS DSN

prologue: in clear (no privacy here)

C: STARTTLS

S: 220 Go ahead

C & S: <negotiate a TLS session with a new session key, in binary>

transition to TLS

C: EHLO mail.example.com

S: 250-mail.imc.org hello, extensions are: -8BITMIME DSN

C: MAIL FROM:<sender@mail.example.com>

S: 250 2.1.0 <sender@mail.example.com>... Sender OK

C: RCPT TO:<destination@mail.example.com>

S: 250 2.1.5 <destination@mail.example.com>

C: <send mail contents>

contents now private

this example: SMTP;
idea used for IMAP, POP3, FTP, XMPP, LDAP, NNTP…

Our STARTTLS for DNS

(in draft-hzhwm-start-tls-for-dns-01)

prologue

C & S: open TCP connection

transition to TLS

C: QNAME="STARTTLS", QCLASS=CH, QTYPE=TXT with the new TO bit set in EDNS options

S: RCODE=0, TXT="STARTTLS", with the TO bit set

C & S: <negotiate a TLS session, get new session key, in binary>

contents now private

C: <send actual query>

S: <reply to actual query>

pros: no new port (from IANA, or in firewalls)

cons: extra RTT; middleboxes may not like encrypted tfc

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1. small protocol addition: TLS upgrade

(going in reverse order)

Careful Implementation Choices

- problem: no tuning of DNS TCP for queries *(until now!)*
- connection reuse (or restart)
  - persistent connections
  - TCP fast open
  - TLS resumption
- query pipelining
- out-of-order processing

Latency in DNS/TLS

C & S: open TCP connection

TCP 3wh: +1 RTT

STARTTLS: +1 RTT

C: QNAME="STARTTLS", QCLASS=CH, QTYPE=TXT
with the new TO bit set in EDNS options

S: RCODE=0, TXT="STARTTLS" with the TO bit set

C & S: <negotiate a TLS session with a new session key, in binary>

TLS handshake: +2 RTTs

C: <send actual query>

S: <reply to actual query>

query: 1 RTT

Connection Reuse

- basic idea:
  reuse connection -> no setup cost
  - *persistent connections (in client and server)*
- secondary idea:
  if must close, client keeps state to restart quickly
  - *TCP fast open: client has cookie to send data in 3wh*
    - *draft-ietf-tcpm-fastopen-08: in Linux-3.6, default 3.13*
  - *TLS resumption (RFC-5077): client keeps*
    - *RFC-5077: in OpenSSL and GnuTLS*

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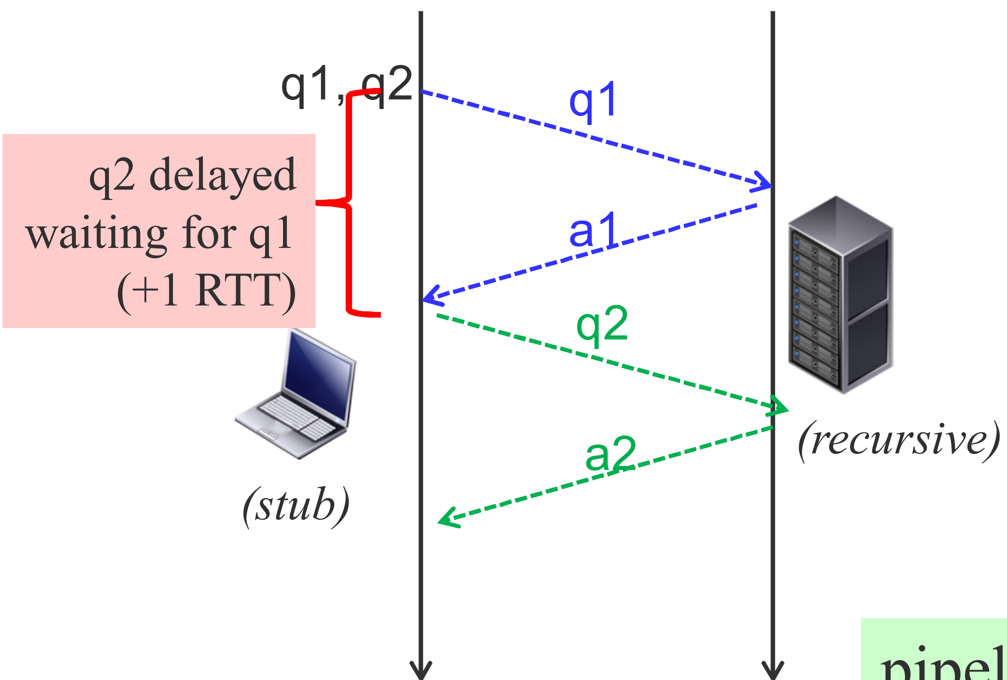
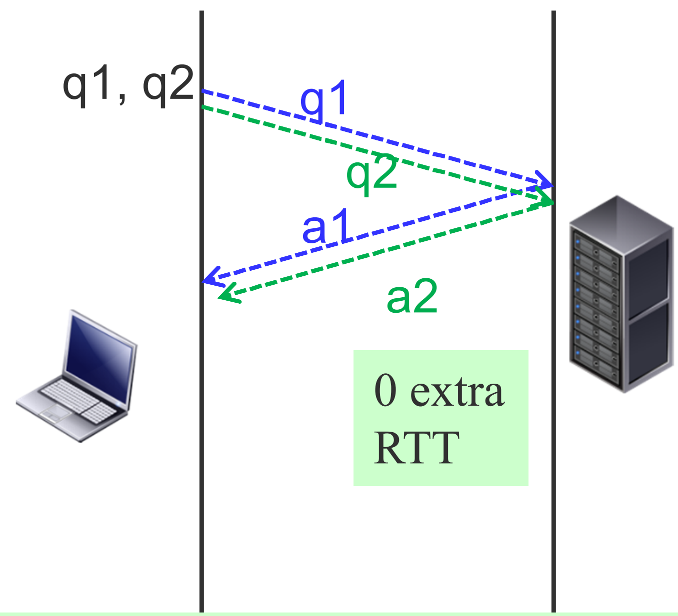
Query Pipelining

send several queries immediately (not stop-and-wait)

before pipelining



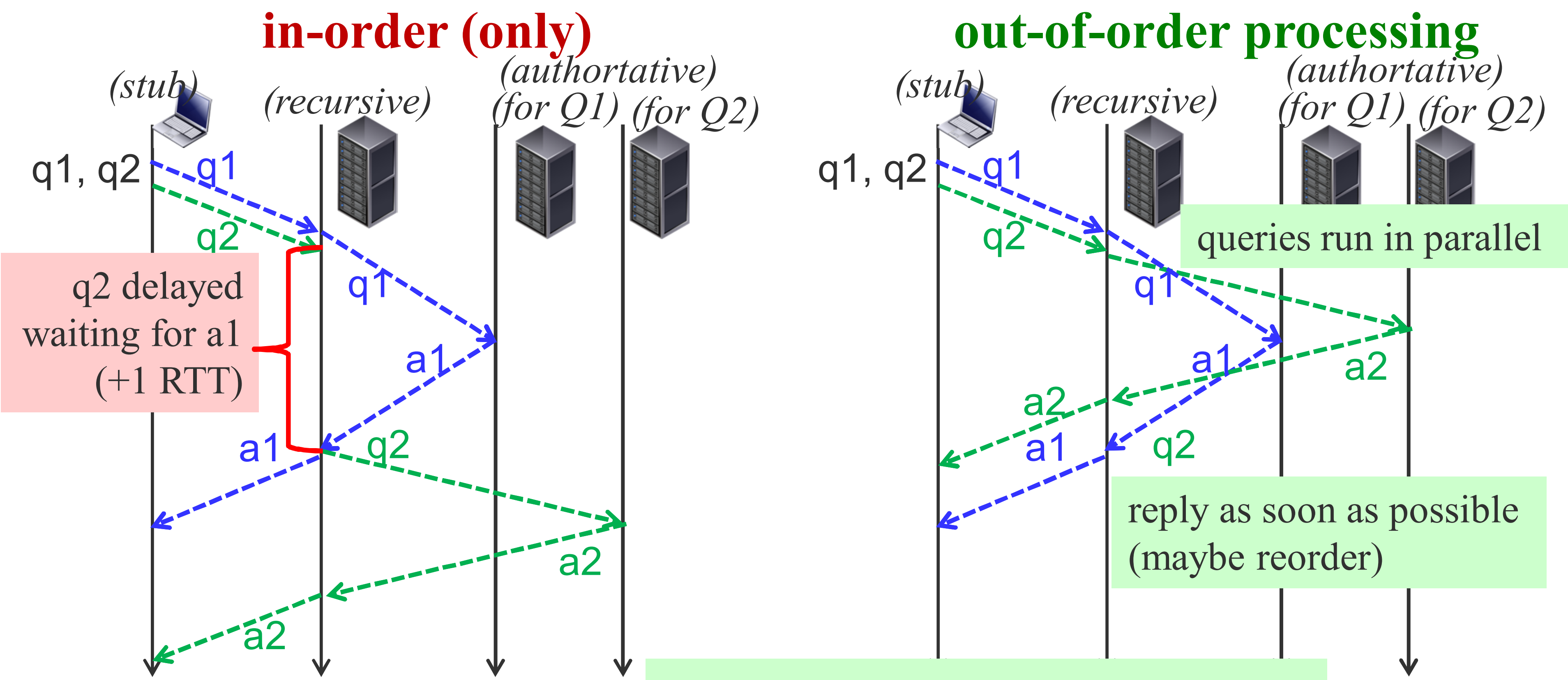
with pipelining



pipelining matters:
62% of web has 4+ domain names
(dataset: common crawl)

Out-of-Order Processing

process queries on same connection in parallel



out-of-order matters:
avoid head-of-line blocking

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questions:

a. connection reuse: hit rate? memory?

b. CPU cost?

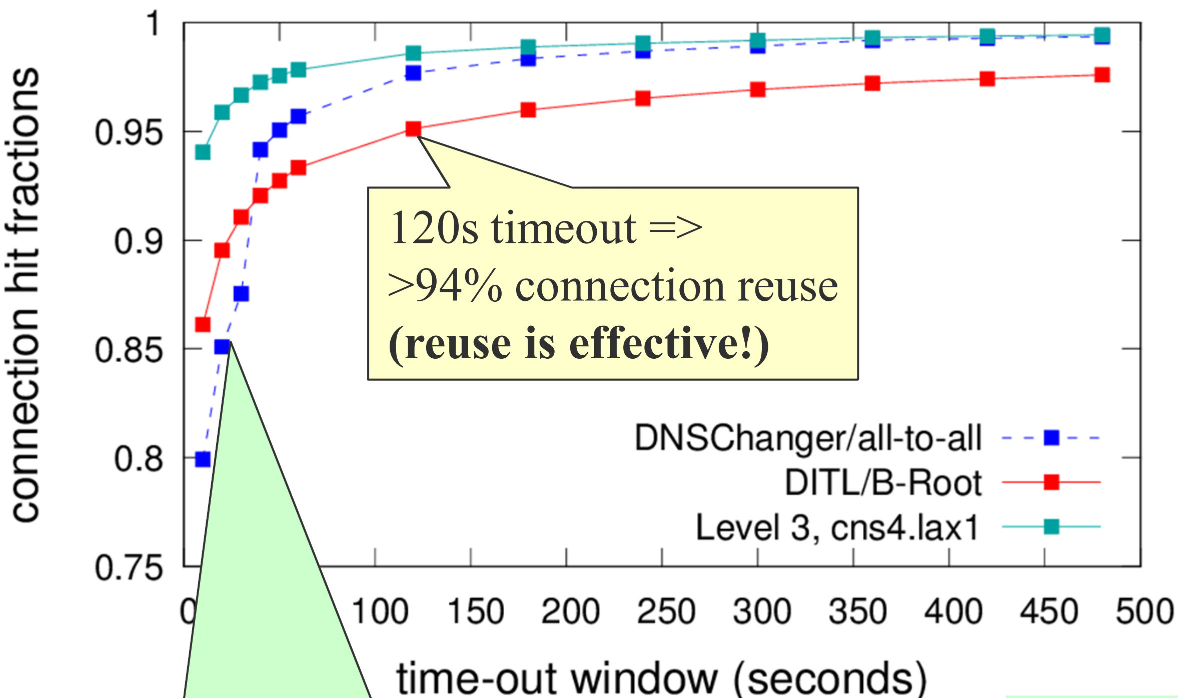
c. latency:

i. stub-recursive?

ii. recursive-authoritative?

iii. end-to-end?

Connection Reuse Helps? (YES!)



120s timeout =>
>94% connection reuse
(reuse is effective!)

we propose 30s/60s (conservative)
=> still >85% connection reuse

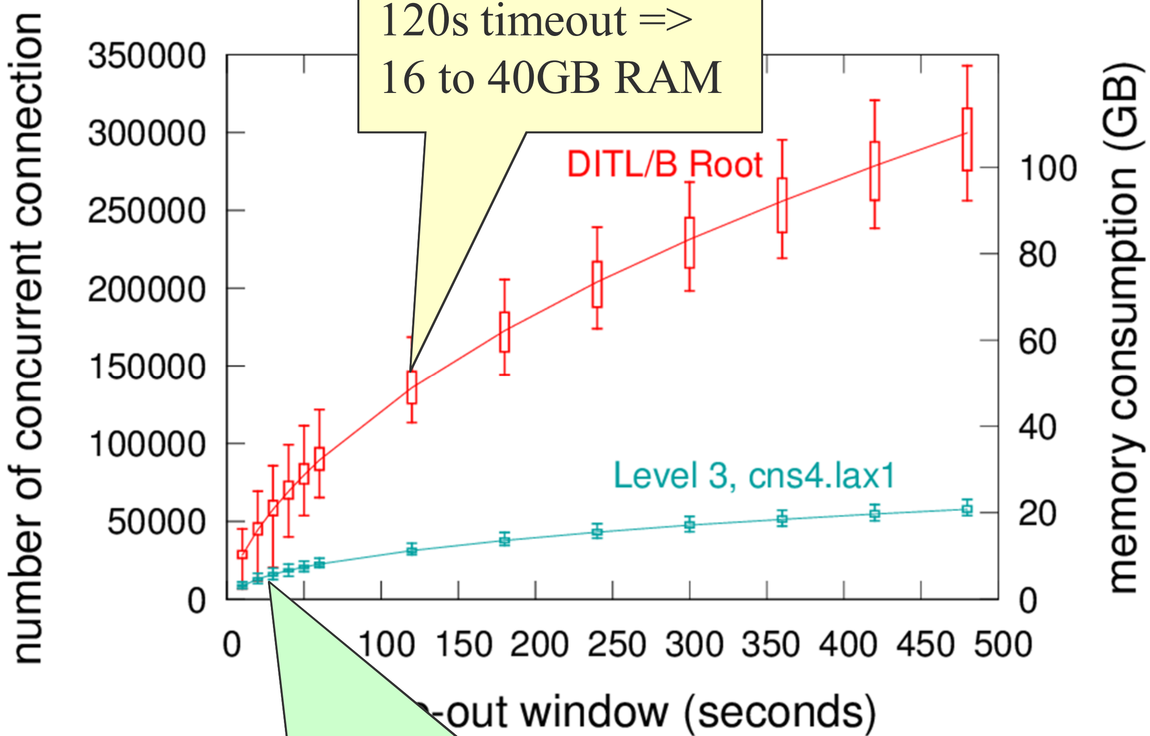
what fraction of queries find open TCP connections?

method: replay 3 traces: recursive (DNSchanger, Level3) and authoritative (B-Root)

(graph shows medians, quartiles are tiny)

conclusion: connection reuse is *often helpful*

Cost of Connection Reuse? (ok!)



120s timeout =>
16 to 40GB RAM

we propose 30s/60s (conservative)
=> 9GB for L3, 18 for B-Root

how many connections?
how much memory?

method: replay same 3 traces (here we show 2 biggest)

experimental estimate of memory: 360kB/connection (very conservative)

(graph shows medians and quartiles)

conclusion: connection reuse is *often helpful* and it's *not too costly*
(easy to add server parallelism if needed)

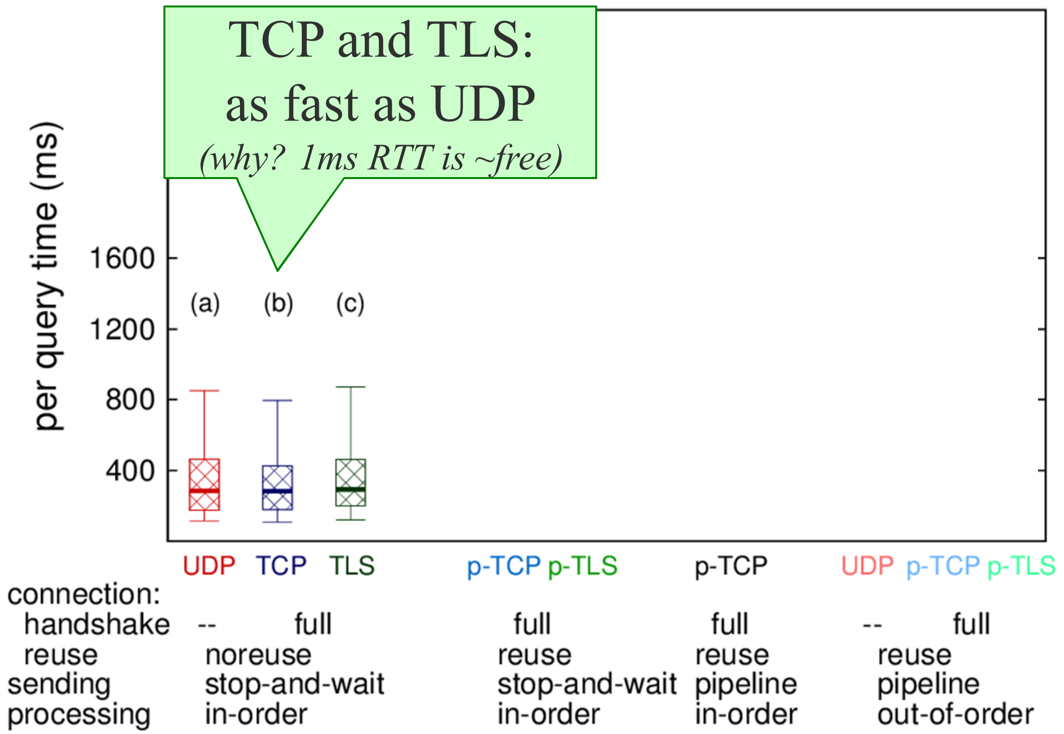
Latency: CPU Cost

- we used micro-benchmarks to study CPU cost

step	OpenSSL	GnuTLS
TCP handshake processing	0.15 ms	
TCP packet handling	0.12 ms	
TLS connection establishment	25.8 ms	8 ms
key exchange	13.0 ms	6.5 ms
CA validation	12.8 ms	1.5 ms
TLS connection resumption	1.2 ms	1.4 ms
DNS resolution (from [52])	0.1–0.5 ms	

TLS setup is noticeable,
but RTT (40-100+ms) more impt.

Latency: Stub to Recursive

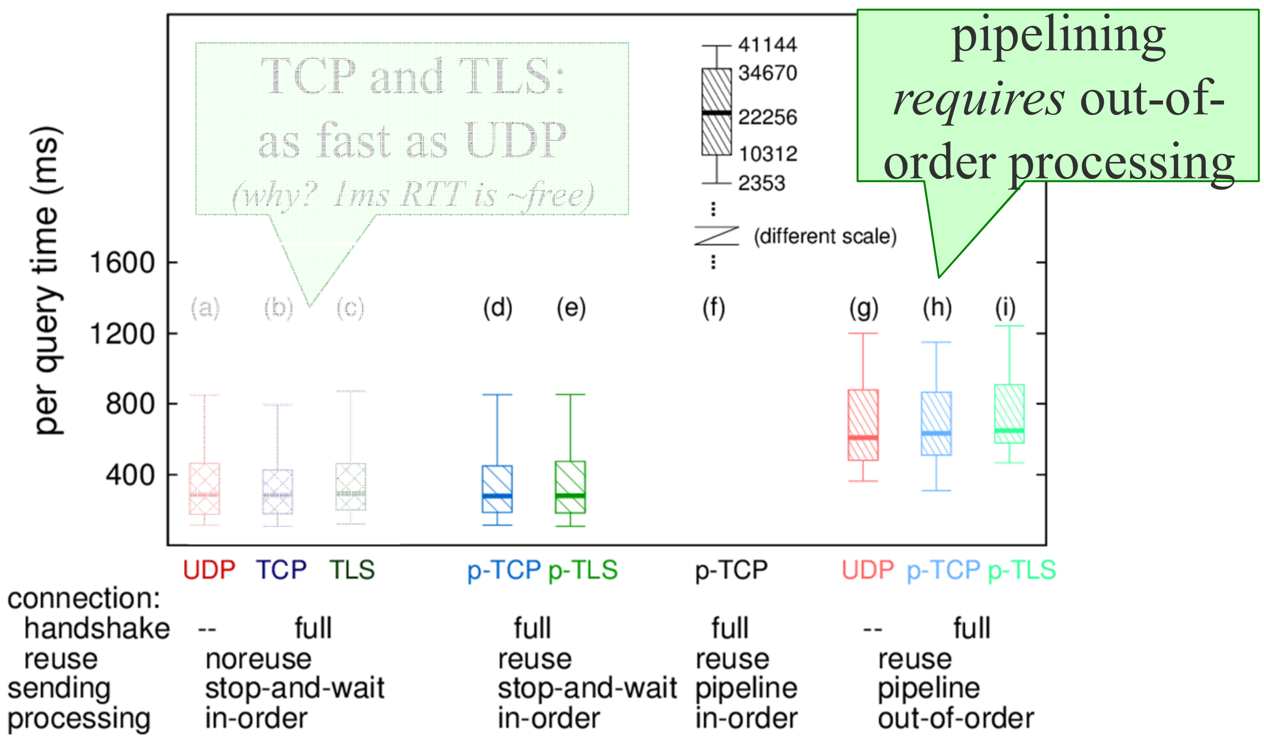


TCP and TLS vs. UDP?
effects of implementation choices?
with short RTT (1ms)

method: live experiments of random 140 names from Alexa top 1000; stub-recursive RTT=1ms

(graph shows medians and quartiles)

Latency: Stub to Recursive



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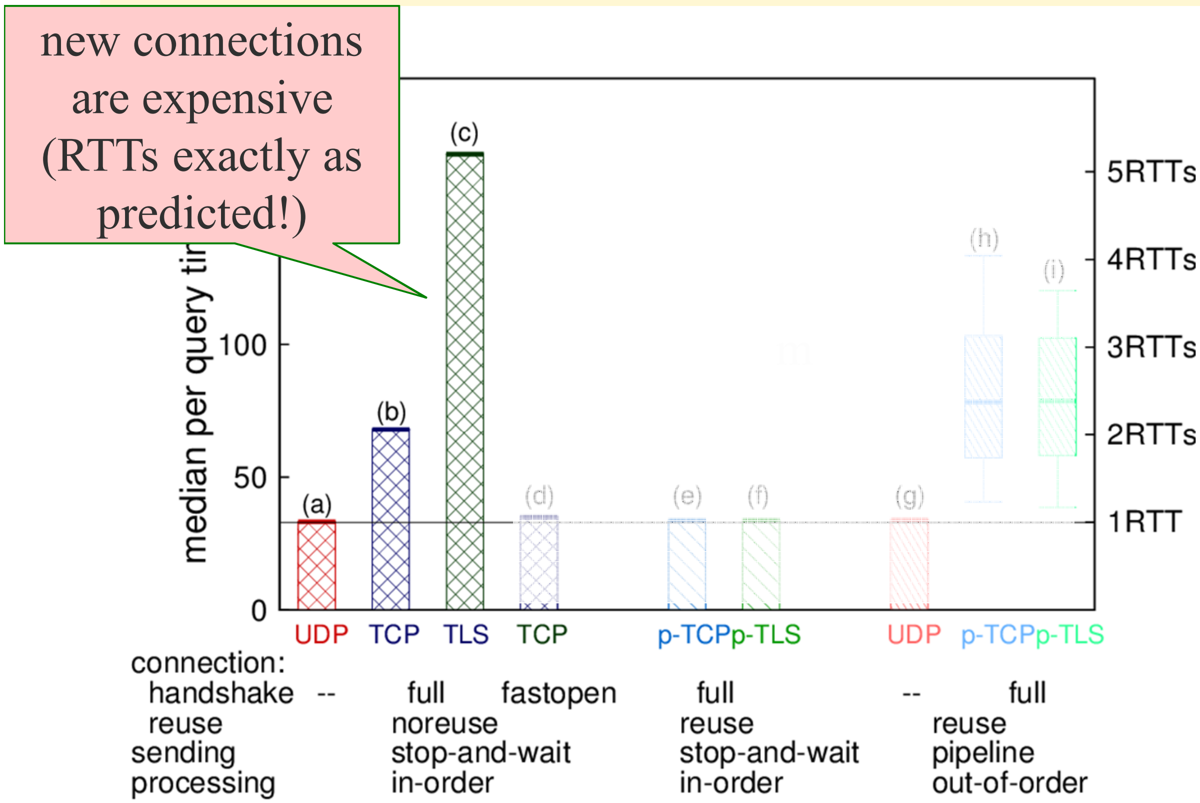
Latency: Recursive to Authoritative

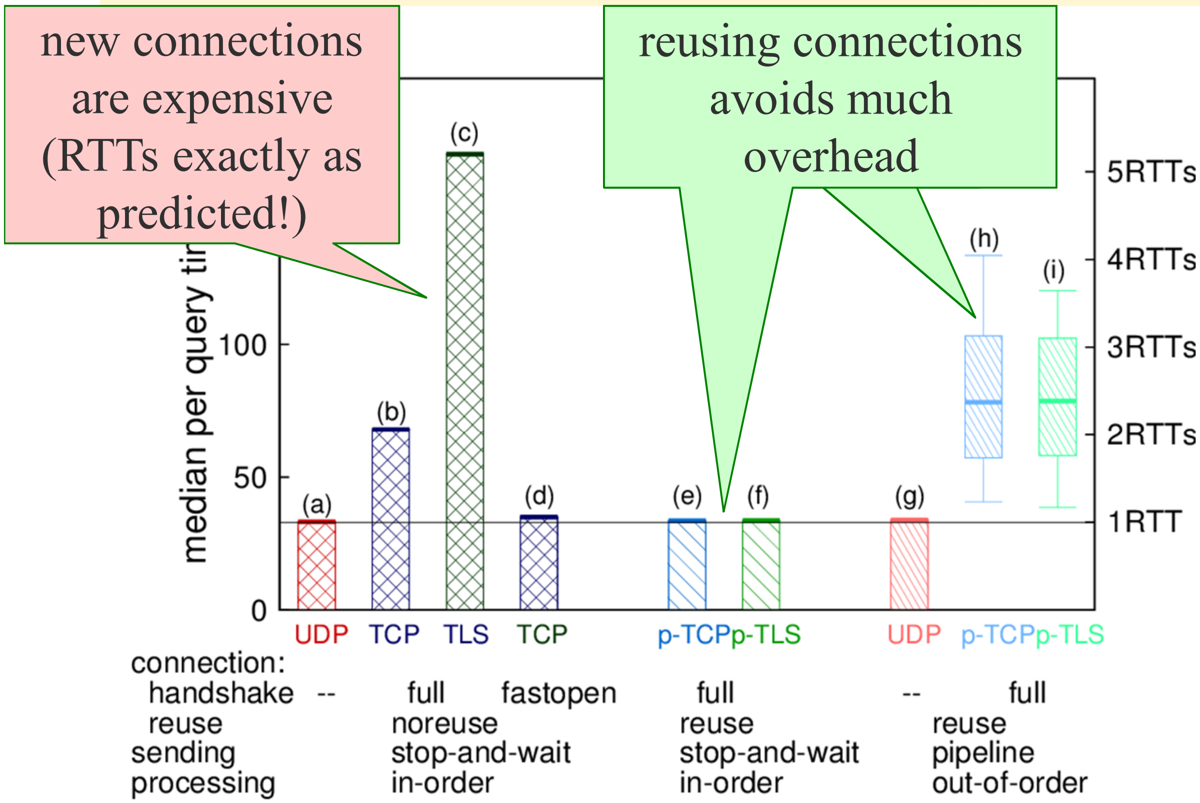


TCP and TLS vs. UDP?
effects of implementation choices?
*with **long** RTT (=35ms)*

method: live experiments of random 140 names, each repeaed 10x; recursive-authoritative RTT=35ms

(graph shows medians and quartiles for (h) and (i), or bars where median and quartiles are the same)

Latency: Recursive to Authoritative



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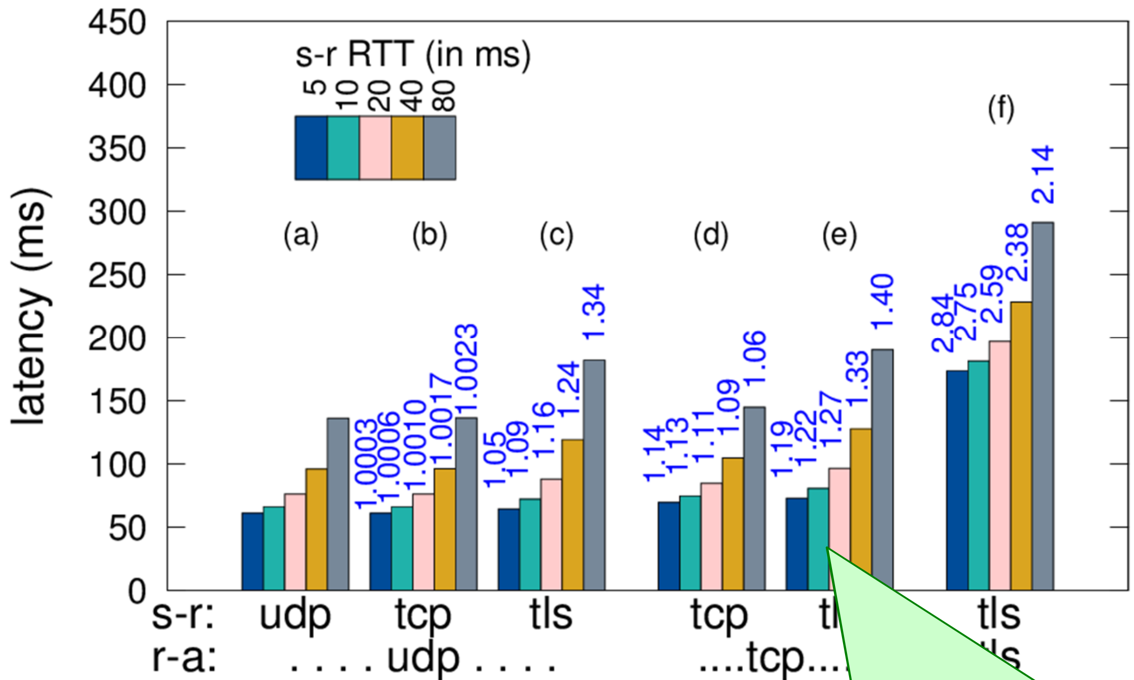
End-to-End Latency: Methodology

- controlled experiments are hard
  - variable stub query timing
  - caching at recursive resolver
  - different RTTs (many stubs and authoritatives)
- approach: *model expected latency*
  - i.e., just averages
  - median connection reuse from trace replay
  - other parameters from experiments

End-to-End Latency: Results



protocol choices: stub-recursive and recursive-authoritative

method: modeling; vary stub-recursive RTT; assumes all optimizations (TCP FO, TLS resumption, pipelining, OOOP)

(graph shows expected values, plus slowdown relative to case (a), UDP/UDP)

TLS (s-r, 30s t.o.) + TCP (r-a, 60s t.o.)
19 to 33% slower: **modest cost -> most benefit**

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Alternatives

- for improving privacy
  - DNScurve/DNScrypt: some neat optimizations to reduce RTTs, but new and fixed stack
  - DNS over DTLS: adds back UDP limits but still stuck with most TLS RTTs
- for anti-DoS
  - on others: rate limiting
- for relaxing limits:
  - seeming alternative: live within UDP limits

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T-DNS Next Steps

- more information:
  - tech report ISI-TR-2014-688 (www.isi.edu/~johnh/PAPERS/Zhu14a/)
  - internet-draft: draft-hzhwm-start-tls-for-dns-01
- code:
  - client, client & server proxies, unbound patch
  - http://www.isi.edu/ant/software/
- do you want DNS privacy? share feedback?
  - johnh@isi.edu