TLS in the wild

Internet scans for security

Presented by

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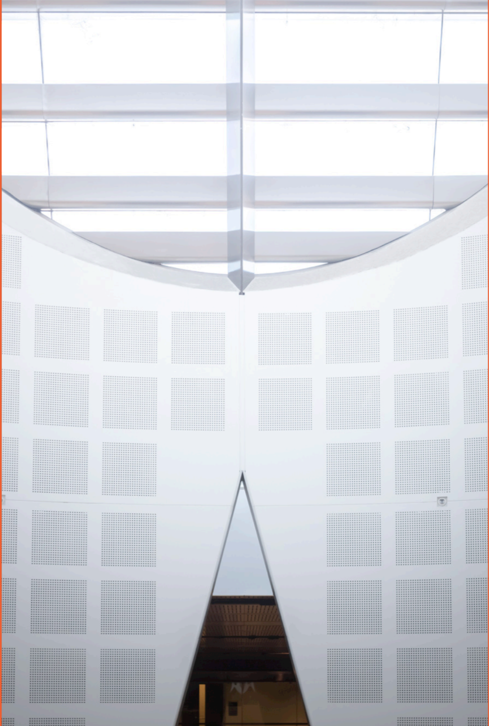
THE UNIVERSITY OF SYDNEY



This is joint work

Team TLS

- Johanna Amann (ICSI)
- Olivier Mehani, Dali Kafaar (Data61)
- Matthias Wachs (TUM)

Team BGP

- Johann Schlamp, Georg Carle (TUM)
- Quentin Jacquemart, Ernst Biersack (Eurecom)

About me

Quick CV

- Lecturer at University of Sydney
- Visiting Fellow at UNSW
- Previously Researcher at Data61 (ex-NICTA)
- PhD from Technical University of Munich
- And I do Internet security measurement…
- (Also: blockchains)

About this lecture

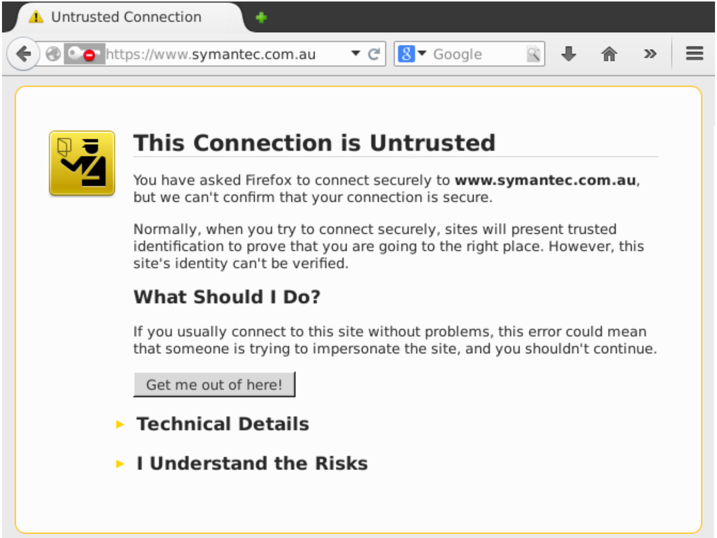
This is a story about

- …how security measurements can identify shortcomings in deployed technology
- …how data from active scans can be reused for further, benign purposes

There are three parts to this story

- From identifying the problem to scanning the Web
- New insights about electronic communication: email and chat
- Reusing data in new contexts. Here: security of Internet routing!

Background: a typical Internet experience



Reason (not a UX fail)

Technical Details

www.symantec.com.au uses an invalid security certificate.

The certificate is only valid for the following names:
symantec.com, norton.com, careers.symantec.com, customercare.symantec.com, jobs.symantec.com, www.account.norton.com, account.norton.com, mynortonaccount.com, www.nortonaccount.com, nortonaccount.com, downloads.guardianedge.com, www.pgp.com, store.pgp.com, na.store.pgp.com, eu.store.pgp.com, uk.store.pgp.com, row.store.pgp.com, nukona.com, www.nukona.com

(Error code: ssl_error_bad_cert_domain)

The X.509 Public Key Infrastructure (PKI)

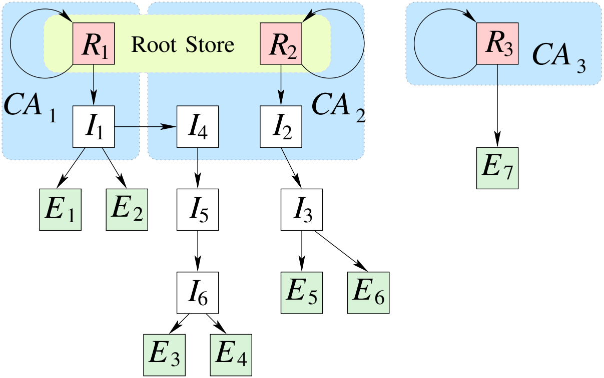
Much of our Internet security is built on X.509

- Every TLS-secured protocol uses X.509
- Further use cases: email, code-signing, …

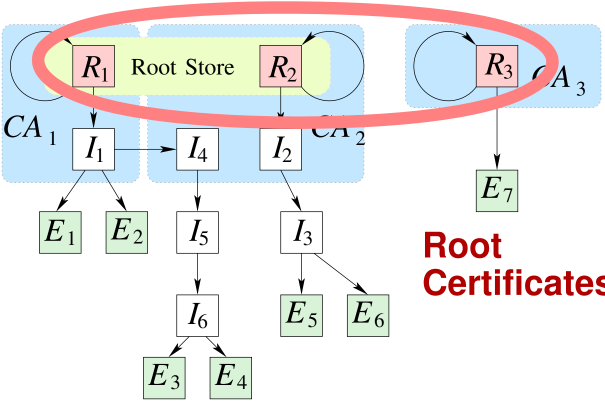
All X.509 PKIs share the same principle

- Certificates bind an entity name to a public key
- Certification Authorities (CAs) act as certificate issuers
- Browsers/OSes preconfigured with CAs' 'root' certificates

Basic idea of X.509 PKI

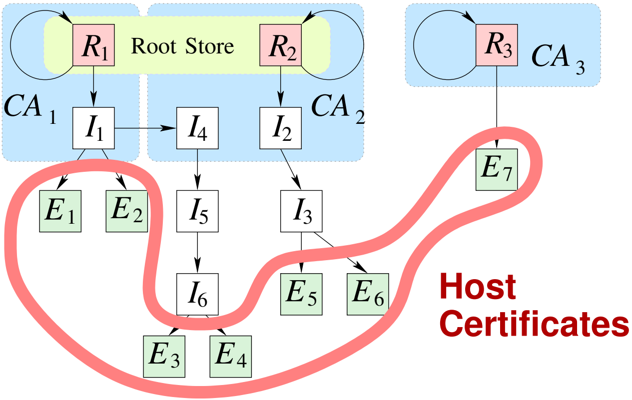


Basic idea of X.509 PKI



Root Certificates

Basic idea of X.509 PKI



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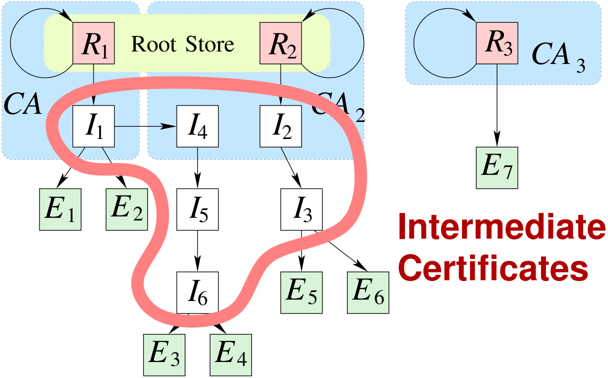
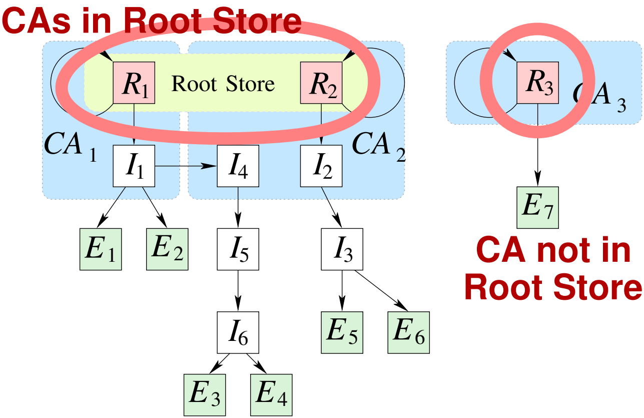


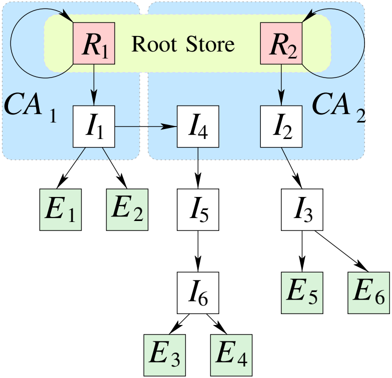
Basic idea of X.509 PKI

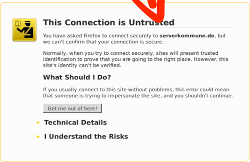


Basic idea of X.509 PKI

如果你的电脑中没有存这个ca的话就会出现以下情况

Root certificate not in Root Store





Best-of attacks on X.509

- Dec 2008:
  - ‘Error’ in Comodo subseller: no identity check
- Mar 2011: Comodo CA hacked
  - Blacklisting of $\approx$ 10 certificates
- Jul 2011: DigiNotar CA melt-down
  - 531 fake certificates *in the wild*
- 2012: Türktrust’s ‘accidental Man-in-the-middle’
- 2012: Trustwave: issued surveillance certs for years
- I stopped tracking it in around that time (PhD was done)

2008–2011: we assess the quality of X.509 for the Web

X.509 should:

- …allow HTTPS on all WWW hosts
- …contain only valid certificates
- …offer good cryptographic security

And there should be:

- Long keys, only strong hash algorithms, …
- Correctly deployed certs

Does it?

Data sets: 25m certificates

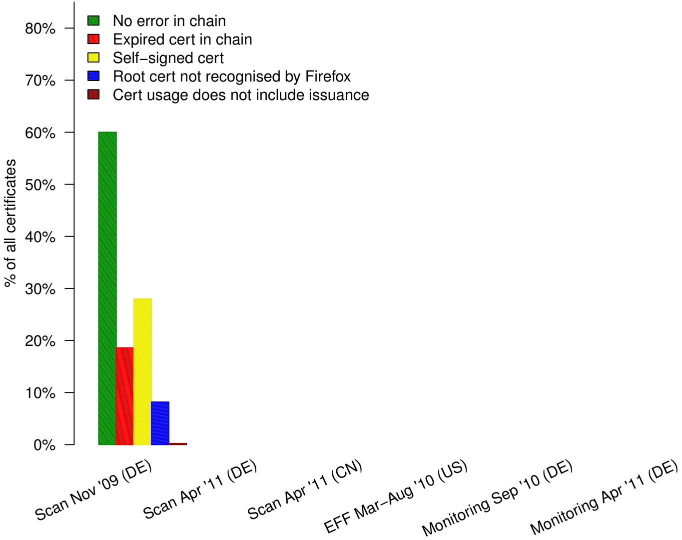
Active scans to measure *deployed* PKI

- Scan hosts on Alexa Top 1 million Web sites
- Nov 2009 – Apr 2011: 8 scans from Germany
- April 2011: 8 scans from around the globe

Passive monitoring to measure *user-encountered* PKI

- Munich Research Network
- Real SSL/TLS as caused by *users*

Correctness of certificate chains



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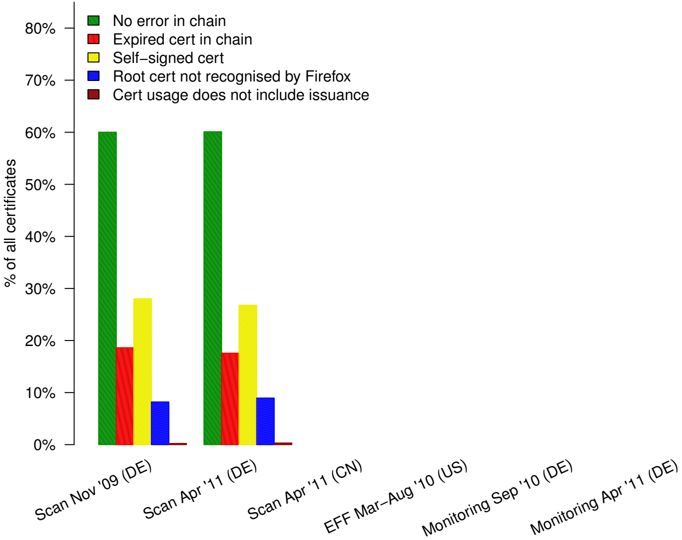
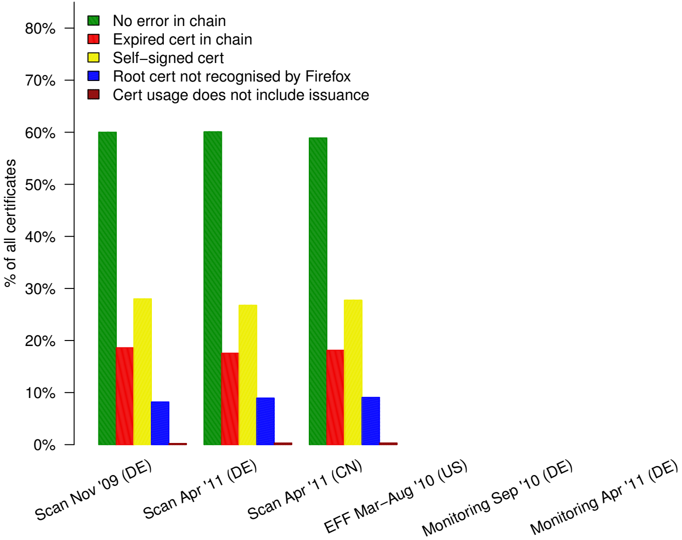
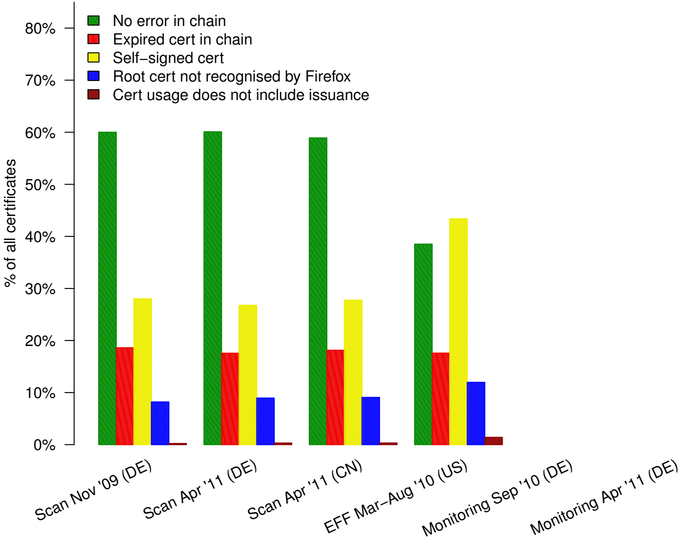


Correctness of certificate chains



Correctness of certificate chains



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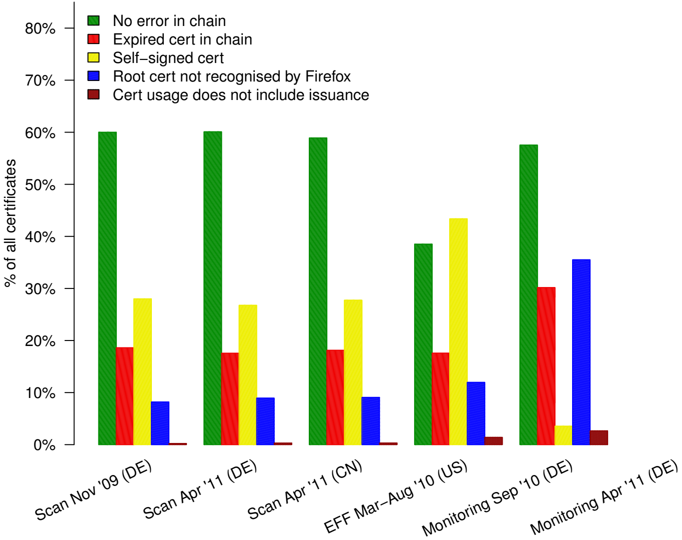
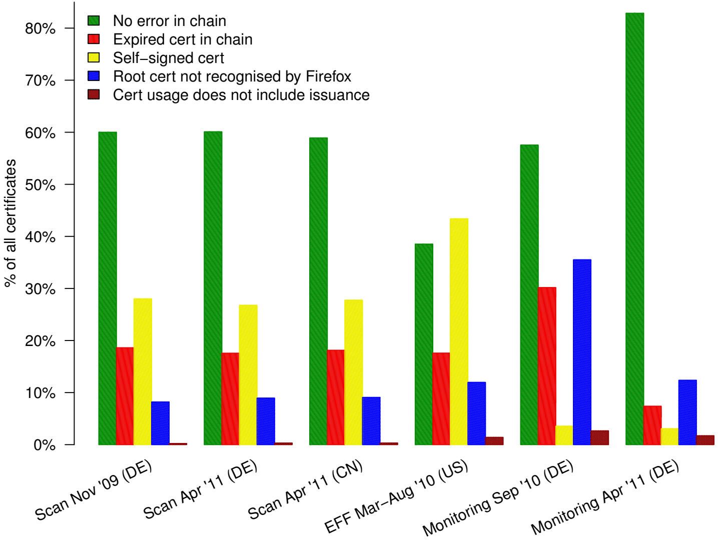


Correctness of certificate chains



Domain names in certificates

Are certificates issued for the right domain name?

- Tested for scans of Alexa Top 1m
- Compare name in certificate against domain name, incl. wildcard matching
- Only **18%** of certificates are fully verifiable
- **More than 80%** of the deployed certificates show errors

What about…

Email?

- Email: 4.1B accounts in 2014; 5.2B in 2018
- Most prevalent, near-instant form of communication

Chat?

- Once dominant instant-messaging (IRC!)
- Newer: XMPP (also proprietary use)

Research question: how secure are these?

Securing email and chat

SSL/TLS is the common solution

- Responder authenticates with certificate
- Initiator usually uses protocol-specific method
- Direct SSL/TLS vs. STARTTLS in-band upgrade
  - Susceptible to active man-in-the-middle attack

Email protocols

- Email submission: SMTP, SUBMISSION (= SMTP on 587)
- Email retrieval: IMAP, POP3

Investigated properties

In this lecture:

- Deployment numbers
- STARTTLS
- Versions
- Ciphers used/negotiated
- Responder authentication
- Initiator authentication

Focus mostly on email. There is more in the paper.

Data collection (July 2015)

Active scans

- To determine state of *deployment*
- `zmap` in the 'frontend', `openssl`-based 'backend'

Passive monitoring

- To determine *actual use*
- Bro monitor, UCB network

Active scans (July 2015)

Protocol (port)	No. hosts	SSL/TLS	Certs	Interm. (unique)
SMTP†,‡ (25)	**12.5M**	3.8M	**1.4M**	2.2M (1.05%)
SMTPS‡ (465)	**7.2M**	3.4M	**801k**	2.6M (0.4%)
SUBMISSION†,‡ (587)	**7.8M**	3.4M	**754k**	2.6M (0.62%)
IMAP†,‡ (143)	**8M**	4.1M	**1M**	2.4M (0.54%)
IMAPS (993)	**6.3M**	4.1M	**1.1M**	2.8M (0.6%)
POP3†,‡ (110)	**8.9M**	4.1M	**998k**	2.3M (0.44%)
POP3S (995)	**5.2M**	2.8M	**748k**	1.8M (0.44%)
IRC† (6667)	2.6M	3.7k	3k	0.6k (13.17%)
IRCS (6697)	2M	8.6k	6.3k	2.5k (12.35%)
XMPP, C2S†,‡ (5222)	2.2M	54k	39k	5.9k (32.28%)
XMPPS, C2S (5223)	2.2M	70k	39k	33k (8.5%)
XMPP, S2S†,‡ (5269)	2.5M	9.7k	6.2k	5.9k (32.28%)
XMPPS, S2S‡ (5270)	2M	1.7k	1.1k	0.8k (18.77%)
HTTPS (443)	42.7M	27.2M	8.6M	25M (0.93%)

$\dagger$ = STARTTLS, $\ddagger$ = fallback to SSL 3.

Passive observation (July 2015)

Protocol	Port	Connections	Servers
SMTP†	25	**3.9M**	**8.6k**
SMTPS	465	37k	266
SUBMISSION†	587	**7.8M**	**373**
IMAP†	143	26k	239
IMAPS	993	**4.6M**	**1.2k**
POP3†	110	19k	110
POP3S	995	**160k**	**341**
IRC†	6667	50	2
IRCS	6697	18k	15
XMPP, C2S†	5222	14k	229
XMPPS, C2S	5223	**911k**	**2k**
XMPP, S2S†	5269	175	2
XMPPS, S2S	5270	0	0

† = STARTTLS.

STARTTLS support and use

	Active probing	Passive monitoring		
Protocol	Supported & upgraded	Supporting servers	Offering connections	Upgraded connections
SMTP	30.82%	59%	97%	94%
SUBMISSION	43.03%	98%	99.9%	97%
IMAP	50.91%	77%	70%	44%
POP3	45.62%	55%	73%	62%

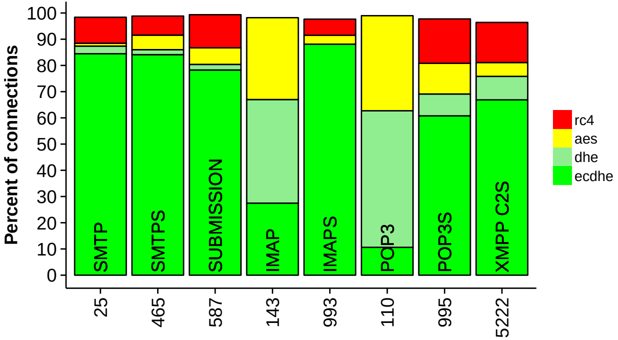
- **Deployment** as scanned: 30-50%—not good
- **Use** as monitored: better, but still not very good
  - SMTP: almost all connections upgrade
  - But not in IMAP/POP3

SSL/TLS versions in use (passive observation)

Version	Active probing Negotiated with server	Passive monitoring Observed connections
SSL 3	0.02%	1.74%
TLS 1.0	39.26%	58.79%
TLS 1.1	0.23%	0.1%
TLS 1.2	60.48%	39.37%

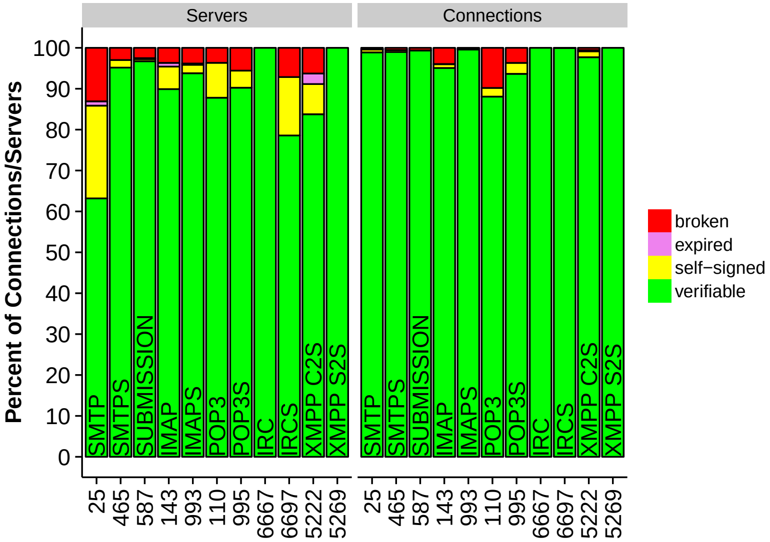
- SSL 3 is almost dead, some use left—are these old clients?
- TLS 1.2 most common in deployments, but not in use (not good)

Ciphers and forward secrecy (from monitoring)

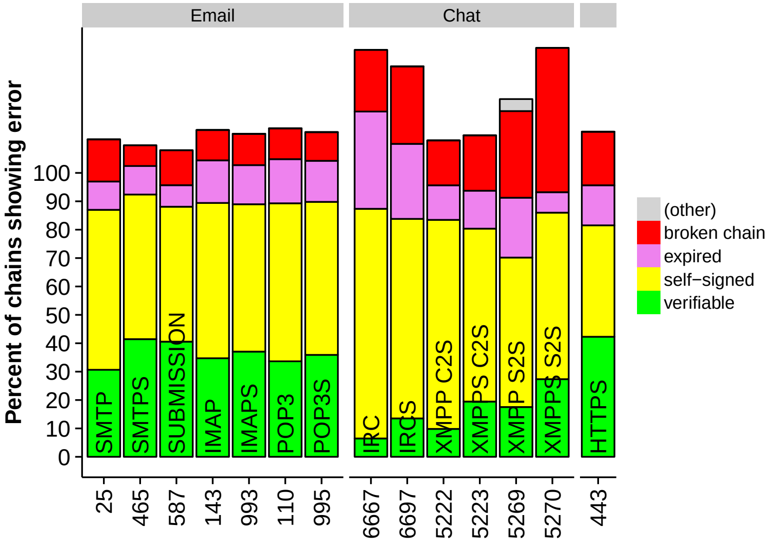


- RC4 has use (up to 17%, not good)
- ECDHE has much use
- DHE: 76% are 1024 bit, 22% 2048 bit, 1.4% are 768 bit

Responder authentication (monitored → use)



Responder authentication (scanned → deployed)



Initiator authentication: SUBMISSION

Combinations offered	Advertised	Servers
PLAIN, LOGIN	**2.1M**	**75.15%**
LOGIN, PLAIN	**224k**	**8.51%**
LOGIN, CRAM-MD5, PLAIN	96k	3.45%
LOGIN, PLAIN, CRAM-MD5	45k	1.63%
DIGEST-MD5, CRAM-MD5, PLAIN, LOGIN	36k	1.30%
CRAM-MD5, PLAIN, LOGIN	29k	1.04%
PLAIN, LOGIN, CRAM-MD5	25k	0.89%
…	…	…

- Plaintext-based methods the vast majority
- Even where CRAM is offered, it’s usually not first choice
- No SCRAM

Risks and threats: SSL/TLS-level

STARTTLS

- Less than 50% of servers support upgrade
- But big providers do, have large share of traffic
- MITM vulnerability (reported to be exploited)

Ciphers

- For some protocols, 17% of RC4 traffic (WWW: 10%)
- For some protocols, $\approx$ 30% of connections not forward-secure
- Diffie-Hellman keys $\leq$ 1024 bit in $>$ 60% of connections

Risks and threats: authentication

Responder

- Many self-signed or expired certs, broken chains
- Big providers have correct setups
- Sending mail to ‘small’ domain/provider means risks of MITM
- We know from Foster *et al.* that mail servers do not verify certs in outgoing connections

Initiator

- Plain-text login pervasive
- CRAM not used much (and no implementations for SCRAM?)

Scans are intrusive

Scans are intrusive

Actually, that is so wrong. We do

`nmap 0.0.0.0/0 | grep | sort -u | wc -l`

Scans are intrusive

Let's show them what insights **only** scans can give.

Our example will be Internet routing!

The fragility of Internet routing

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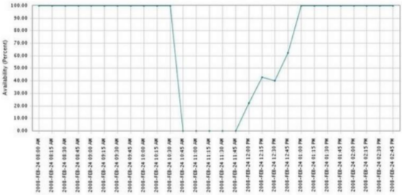
CNET › Tech Culture › How Pakistan knocked YouTube offline (and how to make sure it never happens again)

How Pakistan knocked YouTube offline (and how to make sure it never happens again)

YouTube becoming unreachable isn't the first time that Internet addresses were hijacked. But if it spurs interest in better security, it may be the last.

by Declan McCullagh @declanm / February 25, 2008 2:30 PM PST / Updated: February 25, 2008 4:28 PM PST

0 / more +



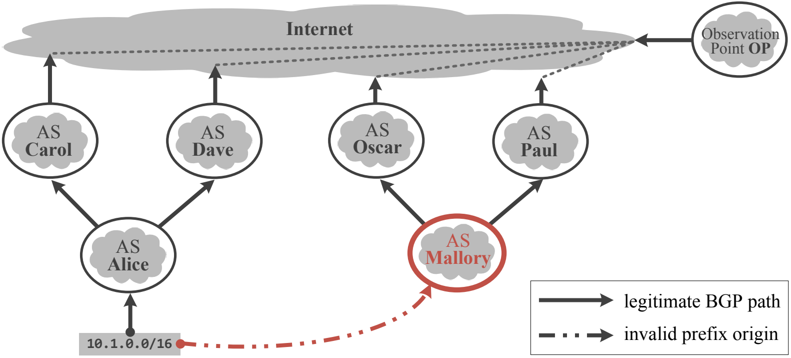
This graph that network-monitoring firm Keynote Systems provided to us shows the worldwide availability of YouTube.com dropping dramatically from 100 percent to 0 percent for over an hour. It didn't recover completely until two hours had elapsed.

Keynote Systems

THIS WEEK'S MUST READS /

1. How Pakistan knocked YouTube offline (and how to make sure it never happens again)
   Tech Culture
2. Google's Android Wear software will let you leave your phone at home (if there's Wi-Fi)
   Mobile
3. In Adobe's new Lightroom, multiple photos can now meld into one
   Photography
4. Yahoo's new search pact with Microsoft includes opt-out clause
   Internet
5. Microsoft rolling out 34 unscheduled patches for Windows today
   Operating Systems

Origin Relocation Attacks



Monitoring Internet routing

Attack detection systems for BGP exist

- But they mostly address other kinds of attacks
- Or they have enormous false-positive rates

So we built HEAP

- A filter chain to link to attack detection system
- A powerful system to rule out false positives
- The goal is to cut down the number of reported events to a more manageable size

Reason with external data

Idea: rule out benign events, investigate rest

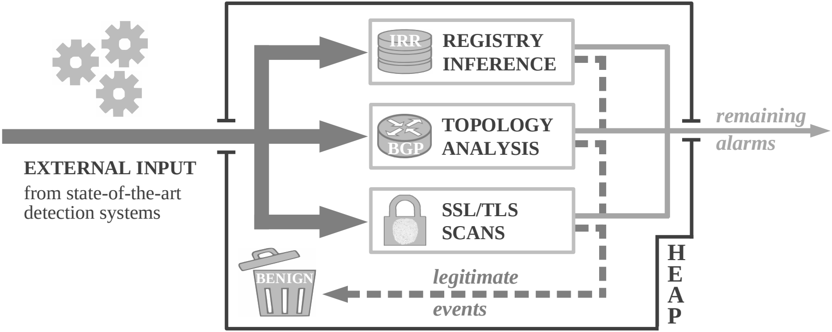


Figure: Hijacking Event Analysis Program (figure courtesy J. Schlamp)

Data source: SSL/TLS scans

IPv4-wide scans

- Create ground truth
  - Identify *beacon hosts* with *unique* keys
  - Filter out all hosts which were in suspicious prefix at scan-time
- With this ground truth:
  - During suspicious event, scan hosts in affected prefixes
  - If key is still the same: not an attack
  - Attacker unlikely to compromise both host(s) and BGP

How to evaluate

Lack of input sources

- Most attack detectors do not focus on subprefix attacks
- Or they are discontinued
- We thus had to build our own, very coarse, ‘detector’
- Essentially, we just counted every subprefix (subMOAS) events as an ‘attack’
- Gross overestimate of real attacks, but it creates a worst case for our evaluation setup
- We discounted events of less than 2 hrs duration

Evaluation results

	total	in %
All subMOAS events	**14,050**	**100.0%**
IRR analysis	5,699	40.56%
topology reasoning	2,328	16.57%
SSL/TLS scans	2,639	18.78%
Legitimate events (cum.)	**7,998**	**56.93%**

I.e. we can rule out more than half of **all** events in our super-coarse detector.

Case study: IP space of Top 1M (Alexa)

Assumption: this is valuable IP space

	total	in %
All subMOAS events	**849**	**100.0%**
IRR analysis	294	34.63%
topology reasoning	146	17.20%
SSL/TLS scans	576	67.85%
Legitimate events (cum.)	**689**	**81.15%**

One conclusion: run a Web server in your prefix, and you increase chances we can monitor your IP space.

Conclusion

A good step forward

- We can rule out 57% of **all** events shorter than 2 hrs
- For important IP spaces, this rises to 80%
- We can show commercial detectors have at least 10% false positives

We offer two conclusions

- IRR data is immensely useful—we wish operators would enter it into the DB more often
- Scans are very useful, too—and ‘opt-in’ to HEAP is as simple as setting up a small Web server with unique key

Summary

Security measurements point out weaknesses in email

- Connections between big providers are already (reasonably) secure
- The risk lies with mail from/to remaining providers
- Authentication mechanisms (initiator) are very poor
- (PS: The Web's security is a mess, too)

Scans can be immensely useful to improve security, too

- Monitor Internet routing and filter alarms

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Questions?

email: `ralph.holz@sydney.edu.au`

Recommendations

A few things we can do

- Warnings in user agents that mail will be sent in plain
  $\rightarrow$ Google has implemented this now
- Flag-day for encryption (as for XMPP)
- Combine setup with automatic use of, *e.g.*, Let's Encrypt
- Ship safe defaults
- Follow guides, *e.g.*, `bettercrypto.org`
- More in the paper

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On XMPP

Majority of certs for XMPP are self-signed.

- Inspection of Common Names shows: proprietary use
  - Content Distribution Network (`incapsula.com`)
  - Apple Push
  - Samsung Push
  - Unified Communication solutions

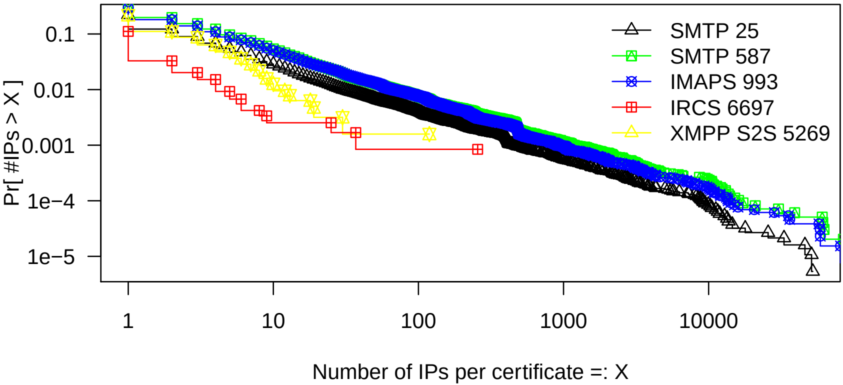
Oddity of scans

The Internet has background noise.

- Independent of port you scan, about 0.07-0.1% of IPs reply with SYN/ACK, but do not carry out a handshake
- Confirmed with authors of `zmap`
- Important to keep in mind when investigating protocols with smaller deployments, where SSL/TLS does not seem to succeed very often

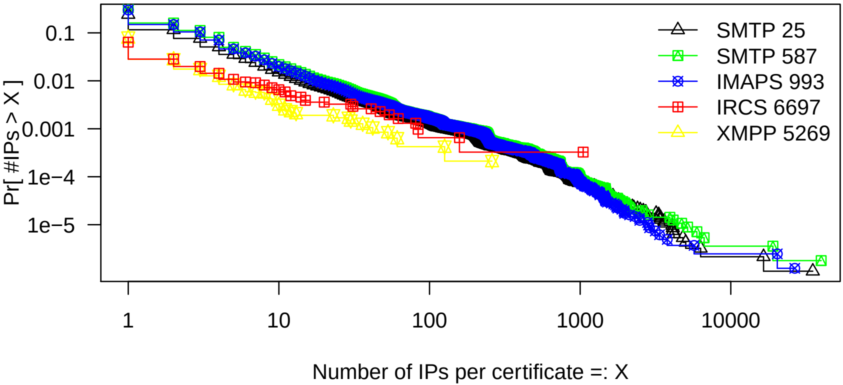
Certificate reuse—valid certs

Much reuse, even among valid certs

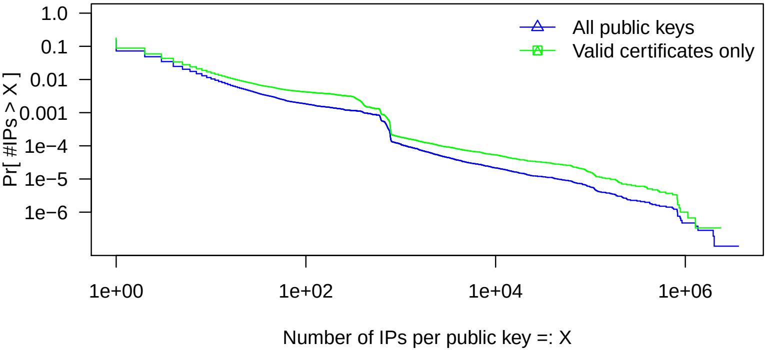


Certificate reuse—self-signed

Many default certs from default configurations



Key reuse across *all* protocols



Oddity in IMAPS...

Common name	Occurrences
*.securesites.com	88k
*.sslcert35.com	31k
localhost/emailAddress=webaster@localhost	27k
localhost/emailAddress=webaster@localhost	21k
*.he.net	19k
www.update.microsoft.com	19k
*.securesites.net	11k
*.cbeyondhosting2.com	11k
*.hostingterra.com	11k
plesk/emailAddress=info@plesk.com	6k

Table: Selected Common Names in IMAPS certificates.

Oddity in IMAPS...

Common name	Occurrences
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localhost/emailAddress=webaster@localhost	27k
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www.update.microsoft.com	19k
*.securesites.net	11k
*.cbeyondhosting2.com	11k
*.hostingterra.com	11k
plesk/emailAddress=info@plesk.com	6k

Table: Selected Common Names in IMAPS certificates.

Mapping to ASes

AS number	Registration information	CIRCL rank
3257	TINET-BACKBONE Tinet SpA, DE	9532
3731	AFNCA-ASN - AFNCA Inc., US	4804
4250	ALENT-ASN-1 - Alentus Corporation, US	9180
4436	AS-GTT-4436 - nLayer Communications, Inc., US	10,730
6762	SEABONE-NET TELECOM ITALIA SPARKLE S.p.A., IT	11,887
11346	CIAS - Critical Issue Inc., US	557
13030	INIT7 Init7 (Switzerland) Ltd., CH	6255
14618	Amazon.com Inc., US	4139
16509	Amazon.com Inc., US	3143
18779	EGIHOSTING - EGIHosting, US	4712
21321	ARETI-AS Areti Internet Ltd.,GB	2828
23352	SERVERCENTRAL - Server Central Network, US	11,135
26642	AFAS - AnchorFree Inc., US	–
41095	IPTP IPTP LTD, NL	6330
54500	18779 - EGIHosting, US	–