CSE508 Network Security

Stony Brook University

2021-04-20

Email

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Email Overview

MUA: Mail User Agent

Thunderbird, webmail, Pine, …

MSA: Mail Submission Agent

SMTP (port 587)

Often same as initial MTA

MTA: Mail Transfer Agent

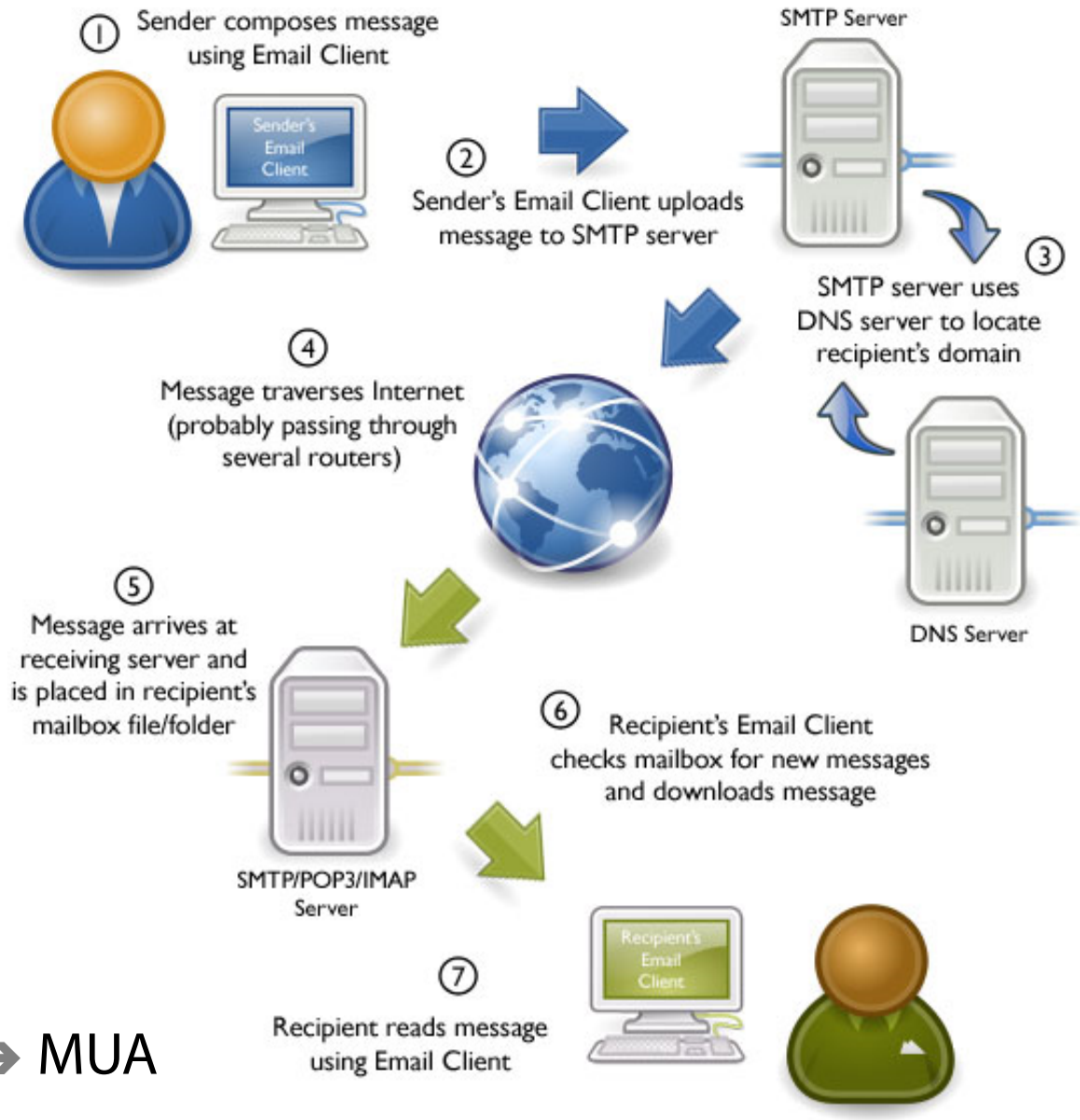
SMTP (port 25)

MDA: Mail Delivery Agent

IMAP (port 143), POP3 (port 110), local,

Typical flow:

MUA ➔ MSA ➔ MTA ➔ … ➔ MTA ➔ MDA ➔ MUA



SMTP Transport Example

```
S: 220 smtp.example.com ESMTP Postfix
C: HELO relay.example.org
S: 250 Hello relay.example.org, I am glad to meet you
C: MAIL FROM:<bob@example.org>
S: 250 Ok
C: RCPT TO:<alice@example.com>
S: 250 Ok
C: RCPT TO:<theboss@example.com>
S: 250 Ok
C: DATA
S: 354 End data with <CR><LF>.<CR><LF>
C: From: "Bob Example" <bob@example.org>
C: To: "Alice Example" <alice@example.com>
C: Cc: theboss@example.com
C: Date: Tue, 15 January 2008 16:02:43 -0500
C: Subject: Test message
C:
C: Hello Alice.
C: This is a test message with 5 header fields and 4 lines in the message body.
C: Your friend,
C: Bob
C: .
S: 250 Ok: queued as 12345
C: QUIT
S: 221 Bye
```

Email/Messaging Security and Privacy Goals

Protect message content

Verify communicating parties' identities

Fight spam

(subject of future lecture)

Fight phishing

(subject of future lecture)

Hide communication patterns

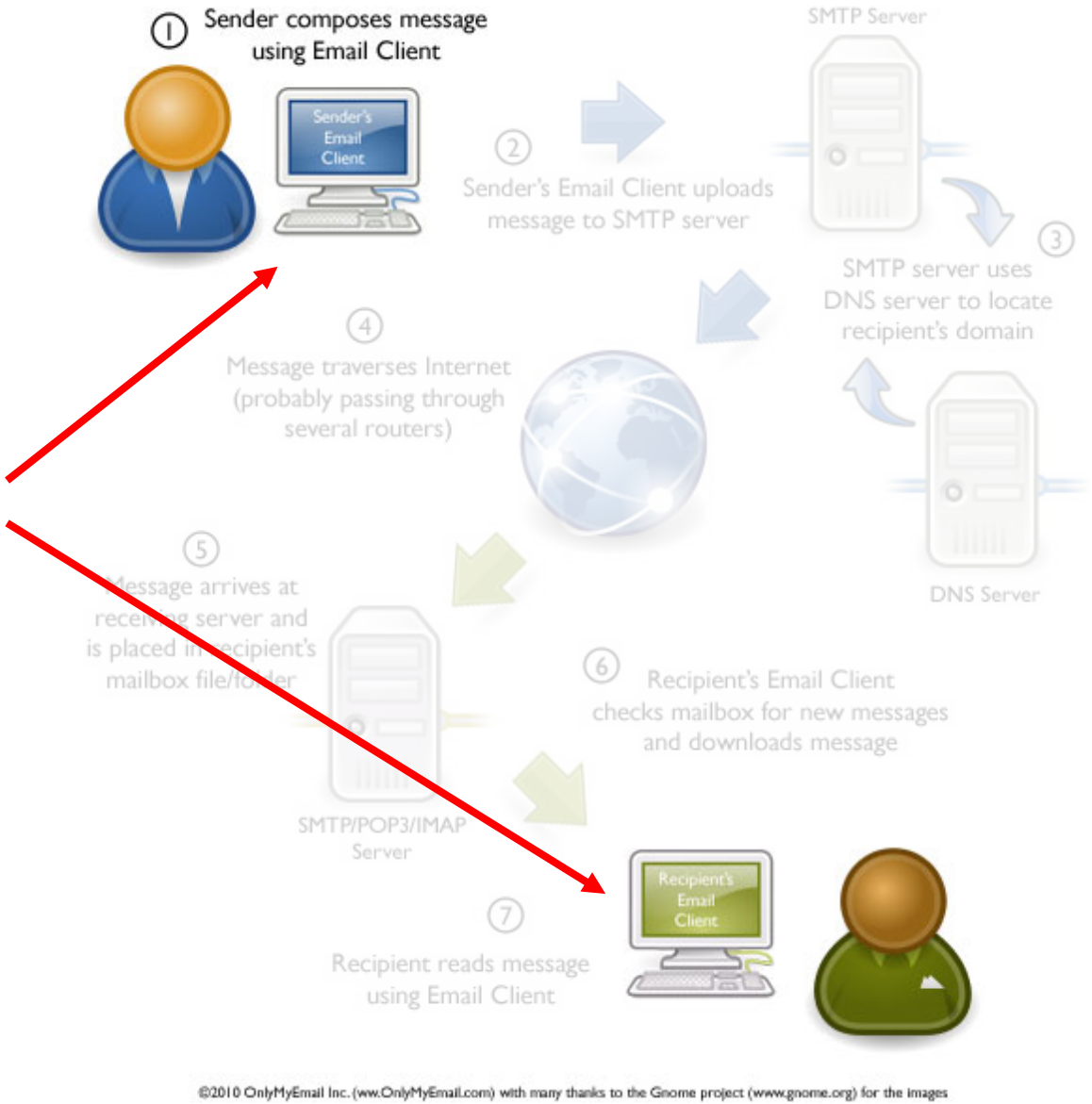
(subject of future lecture)

Who can read my email?

Adversaries with local or remote access to my devices

Intruders, spouse, administrator, …

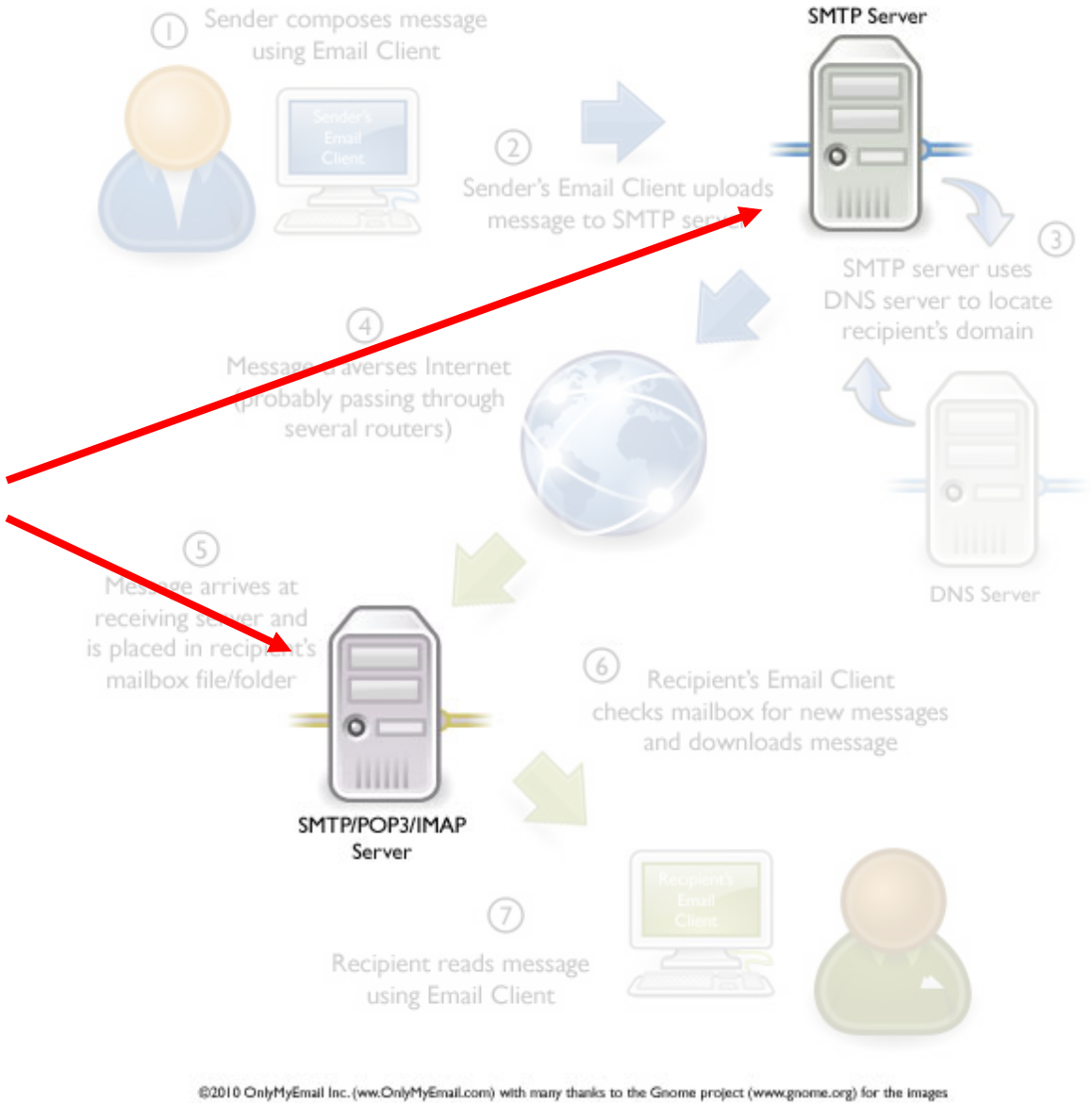
Malware, stolen credentials, physical access, …



Who can read my email?

Adversaries with local or remote access to MTAs and other intermediary servers

Intruders, administrators, other insiders, LEAs, …

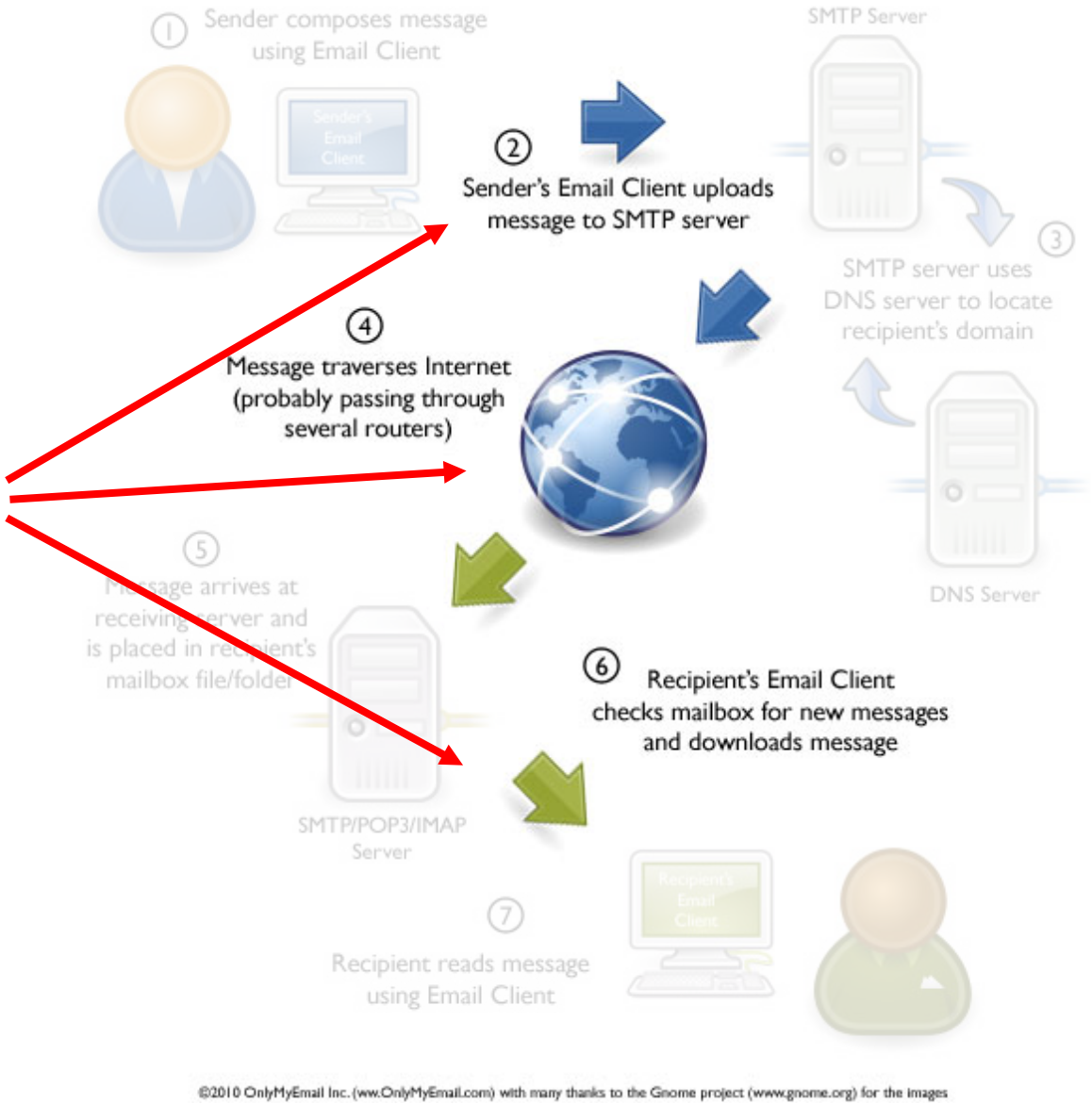


Who can read my email?

Adversaries with access to any intermediate network

Intruders, administrators, other insiders, LEAs, …

Passive eavesdropping, MitM, DNS poisoning, …



Confidentiality Threats Recap:

Stored messages

Compromised system (either local user machine or remote email server)
Malware, intruder, insider, stolen/lost device, …

Compromised authentication
Password theft, phone unlock, …

Messages in transit

Eavesdropping and interception

Displayed messages

Screendump, reflections, shoulder surfing, …

Securing Email Transit

These days encryption is mandatory for client-to-server email transmission and retrieval

MUA ➔ MSA: STARTTLS (port 587/25), SMTPS (port 465)

MDA ➔ MUA: POP3S (port 995), IMAPS (port 993)

```
mikepo@capcom:~> nc smtp.gmail.com 25
220 mx.google.com ESMTP i185sm2356739qhc.49 - gsmtp
HELO foo.example.com
250 mx.google.com at your service
MAIL FROM:<mikepo@example.com>
530 5.7.0 Must issue a STARTTLS command first.
```

MTA ➔ MTA relaying: *a different story…*

STARTTLS: Opportunistic Encryption

Legacy MTAs may not support TLS

- Fail-open design is necessary

MTAs do their best to deliver messages

- A recipient MTA may present a self-signed cert (common in antispam/AV systems)
- There is no PKI for email…

MitM is trivially easy

- STARTTLS command is sent over a plaintext channel (!)
- Analogous to SSL stripping, but in this case the client has no indication that downgrade has happened
- Just assumes that the receiving MTA does not support TLS

Message interception is still possible

- Better than nothing: bulk passive eavesdropping not possible

I want to STARTTLS

```
mikepo@capcom:~> nc aspmx.l.google.com 25
220 mx.google.com ESMTP h126si17458667qhh.29 - gsmtp
EHLO foo.example.com
250-mx.google.com at your service, [128.59.23.41]
250-SIZE 157286400
250-8BITMIME
250-STARTTLS
250-ENHANCEDSTATUSCODES
250-PIPELINING
250-CHUNKING
250 SMTPUTF8
STARTTLS
220 2.0.0 Ready to start TLS
<TLS Handshake>
```

I want to STARTTLS

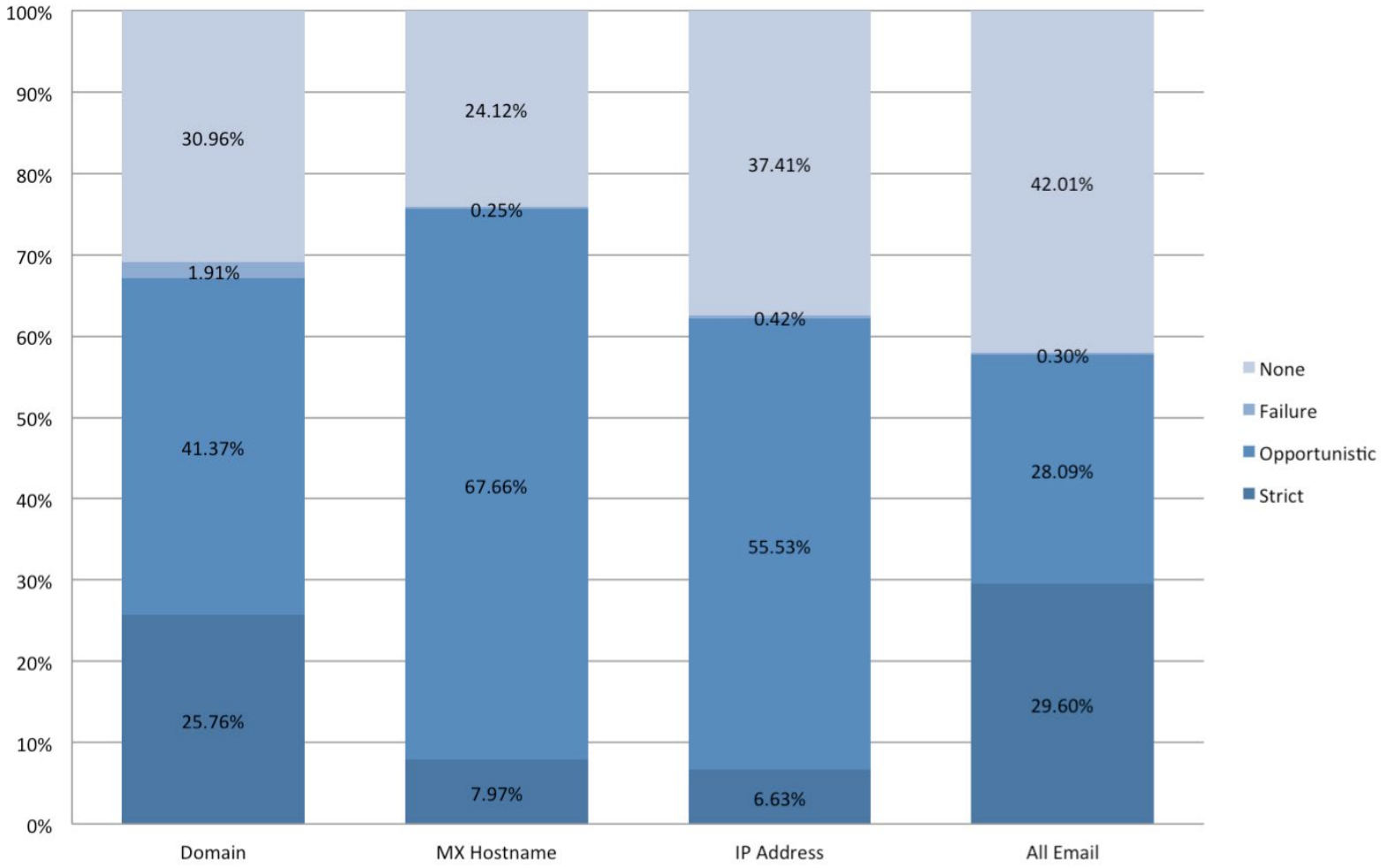
```
mikepo@capcom:~> nc aspmx.l.google.com 25
220 mx.google.com ESMTP h126si17458667qhh.29 - gsmtp
EHLO foo.example.com
250-mx.google.com at your service, [128.59.23.41]
250-SIZE 157286400
250-8BITMIME
250-STARTTLS
250-ENHANCEDSTATUSCODES
250-PIPELINING
250-CHUNKING
250 SMTPUTF8
STARTTLS
220 2.0.0 Ready to start TLS
<TLS Handshake>
```

Can be stripped off by a MitM attacker

Facebook STARTTLS Study: May 2014

~60% of all messages sent via encrypted connection

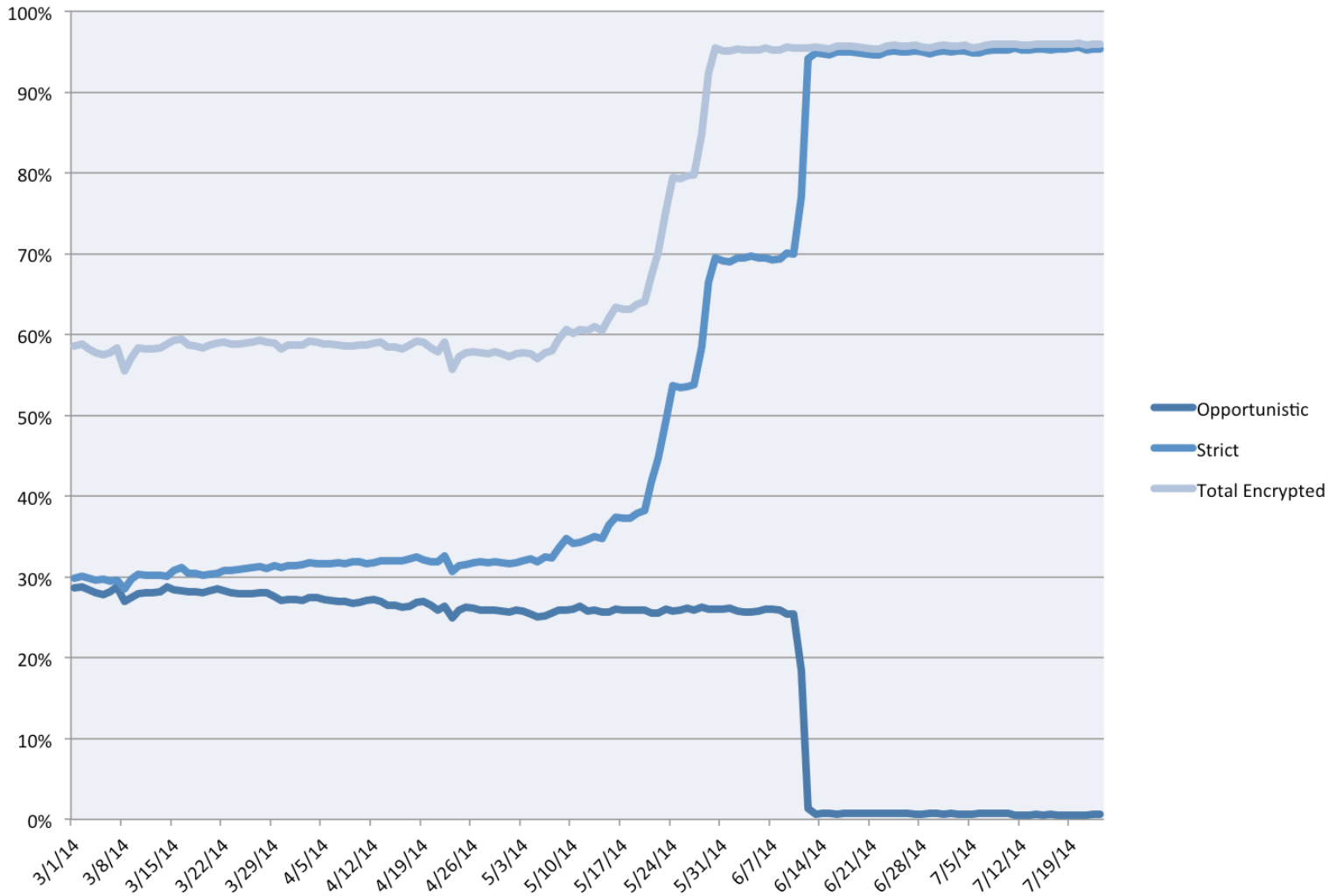
Only ~30% pass strict validation (mostly due to self-signed certs)



Facebook STARTTLS Study: August 2014

~95% of outgoing messages encrypted with PFS and strict certificate validation

Mostly due to changes by big recipient networks (Microsoft, Yahoo)



Safer email – Transparenc

https://www.google.com/transparencyreport/saferemail/

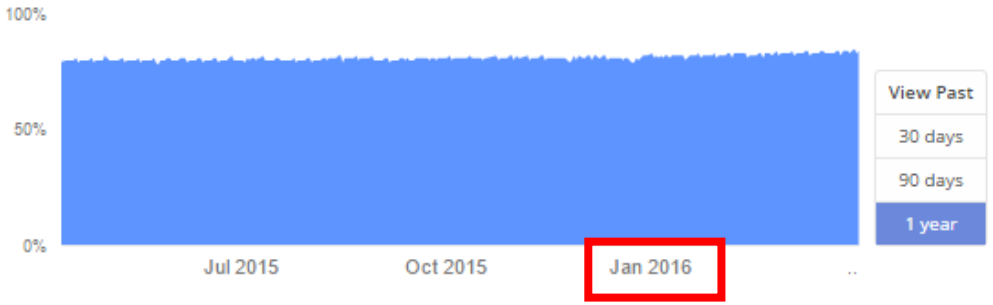
How much email was encrypted in transit?

Generally speaking, use of encryption in transit increases over time, as more providers enable and maintain their support. Factors such as varying volumes of email may explain other fluctuations.

Outbound

84%

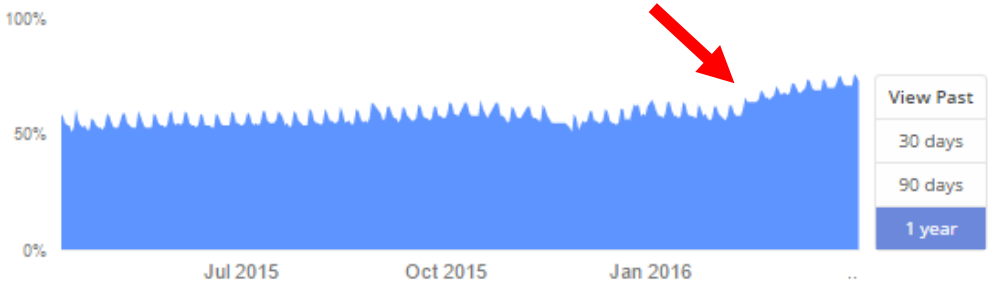
Messages from Gmail to other providers.



Inbound

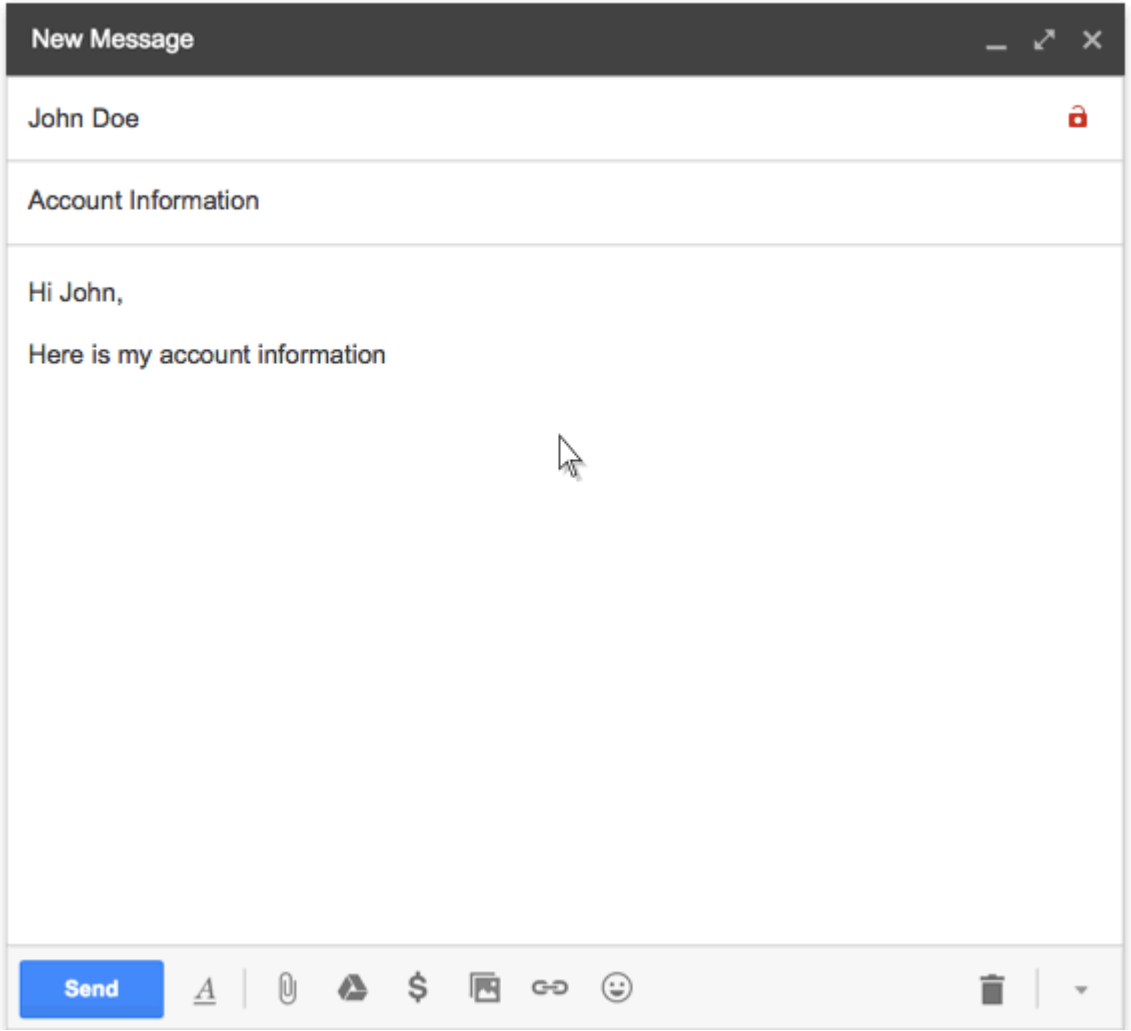
73%

Messages from other providers to Gmail.



Download data

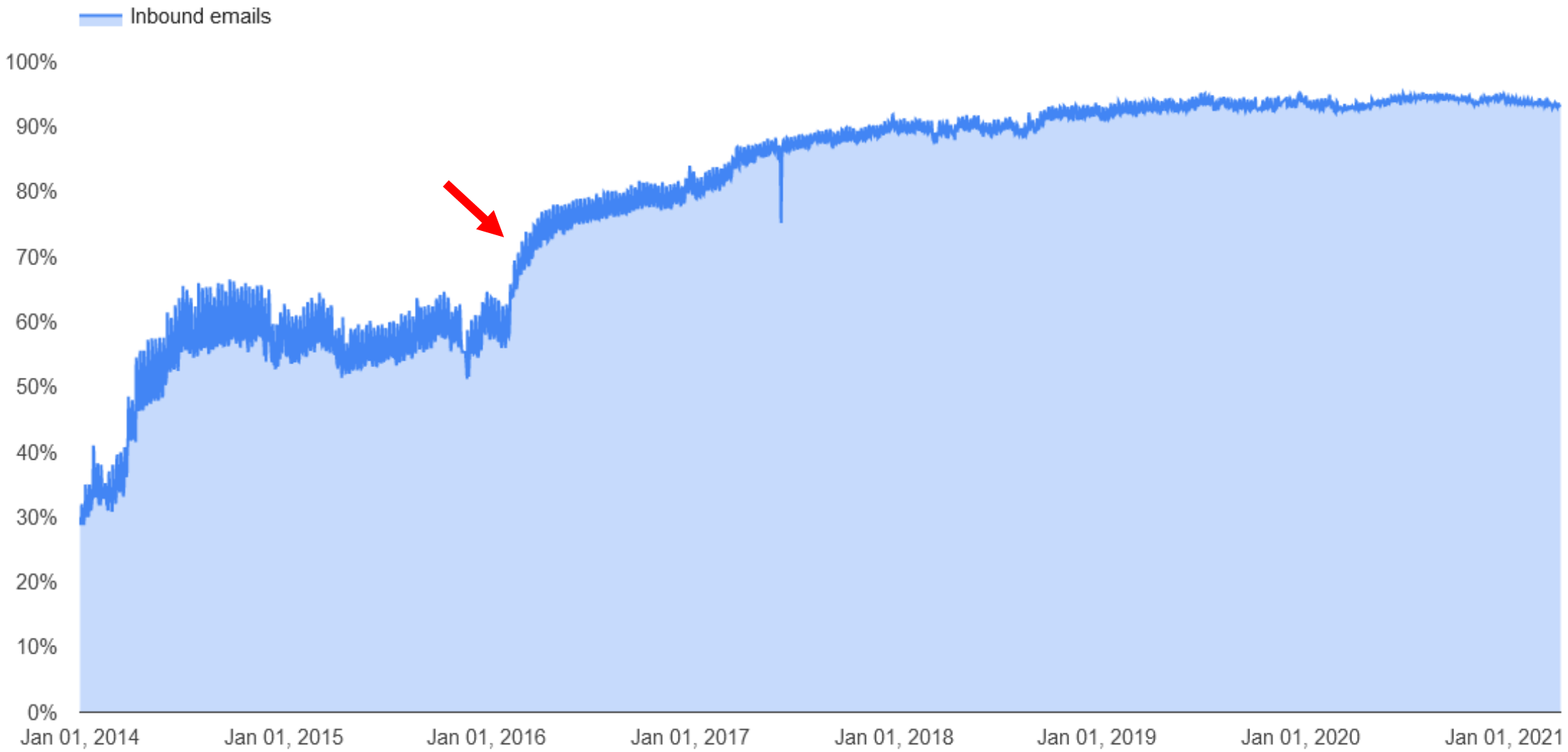
A tiny GUI change prompted many networks to deploy STARTTLS



Email encryption in transit – Go

https://transparencyreport.google.com/safer-email/overview?hl=en&encrypt_in=start:1388534400000;end:1618876799999;series:inbo

Start 12/31/2013 End 4/19/2021



Google, Yahoo SMTP ema

www.telecomasia.net/content/google-yahoo-smtp-email-severs-hit-thailand

telecomasia.net

LOG IN | SIGN UP

SEARCH HERE...

BANDWIDTH & ACCESS | APPS & CONTENT | OPERATOR SERVICES | BILLING & IT | DEVICE & OS | FUTURE TV

Google, Yahoo SMTP email severs hit in Thailand

Staff writer | September 12, 2014 | telecomasia.net

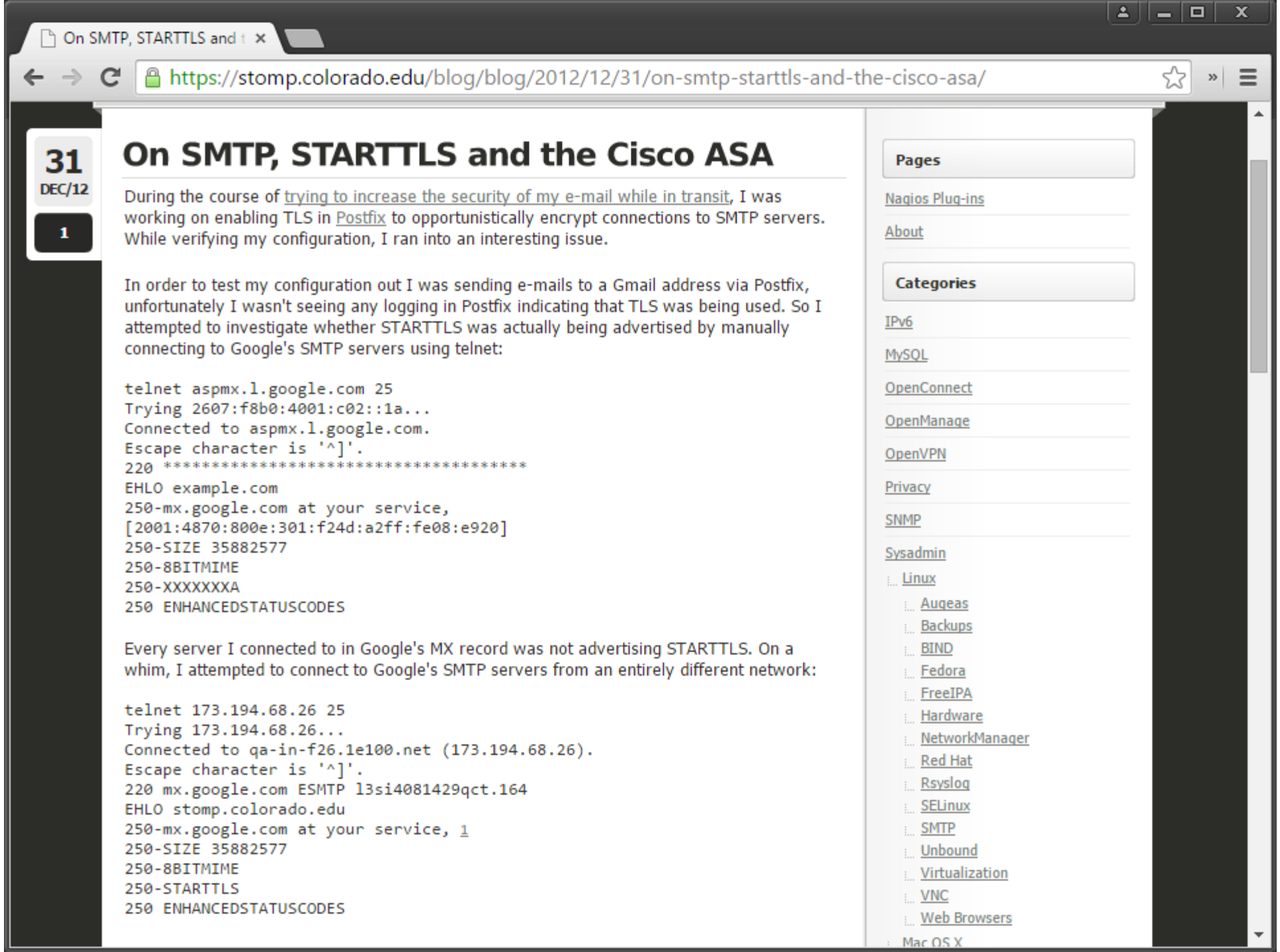
Internet users in Thailand have been hit by a massive man-in-the-middle attack aimed grabbing email login credentials from fake SMTP servers.

The attack has been verified on Google's and Yahoo's email servers and on two of the country's largest fixed-line ISPs, though preliminary analysis suggest that all SMTP servers are targeted.

The STRIPTLS attack as it has become known works by inserting a man-in-the-middle at the ISPs. This is done via a transparent proxy.

LATEST NEWS

- Big data to push TV future
- Irdeto, Alibaba firm up pira China
- CJ Hellovision launches Ult
- Pay TV revenues surge in e markets
- Broadcom unveils chipset f China
- TV remains prime screen in homes
- Global ad spend seen rising
- Indosat narrows losses for


On SMTP, STARTTLS and t
https://stomp.colorado.edu/blog/blog/2012/12/31/on-smtp-starttls-and-the-cisco-asa/
31
DEC/12
1
On SMTP, STARTTLS and the Cisco ASA
During the course of trying to increase the security of my e-mail while in transit, I was working on enabling TLS in Postfix to opportunistically encrypt connections to SMTP servers. While verifying my configuration, I ran into an interesting issue.
In order to test my configuration out I was sending e-mails to a Gmail address via Postfix, unfortunately I wasn't seeing any logging in Postfix indicating that TLS was being used. So I attempted to investigate whether STARTTLS was actually being advertised by manually connecting to Google's SMTP servers using telnet:
telnet aspmx.l.google.com 25
Trying 2607:f8b0:4001:c02::1a...
Connected to aspmx.l.google.com.
Escape character is '^]'.
220 ***********************************
EHLO example.com
250-mx.google.com at your service,
[2001:4870:800e:301:f24d:a2ff:fe08:e920]
250-SIZE 35882577
250-8BITMIME
250-XXXXXXXA
250 ENHANCEDSTATUSCODES
Every server I connected to in Google's MX record was not advertising STARTTLS. On a whim, I attempted to connect to Google's SMTP servers from an entirely different network:
telnet 173.194.68.26 25
Trying 173.194.68.26...
Connected to qa-in-f26.1e100.net (173.194.68.26).
Escape character is '^]'.
220 mx.google.com ESMTP l3si4081429qct.164
EHLO stomp.colorado.edu
250-mx.google.com at your service, 1
250-SIZE 35882577
250-8BITMIME
250-STARTTLS
250 ENHANCEDSTATUSCODES
Pages
Nagios Plug-ins
About
Categories
IPv6
MySQL
OpenConnect
OpenManage
OpenVPN
Privacy
SNMP
Sysadmin
Linux
Augeas
Backups
BIND
Fedora
FreeIPA
Hardware
NetworkManager
Red Hat
Rsyslog
SELinux
SMTP
Unbound
Virtualization
VNC
Web Browsers
Mac OS X

DNS Hijacking

STARTTLS stripping is not the only way to intercept email

DNS MX record poisoning: spoofed MX response

- Compromised name server, MotS DNS poisoning, …
- Messages are diverted through the attacker's mail server

DANE (DNS-based Authentication of Named Entities)

- Allow X.509 certs to be bound to DNS names through DNSSEC
- Trust anchor assertions: domain operator can securely convey information about which certificate authority should be trusted

MTA-STS (MTA Strict Transport Security – RFC 8461)

- Allows recipient domains to tell senders whether they support TLS, how MTAs should validate certificates, and what to do if TLS negotiation fails
- Client-side policy cache provides TOFU-like protection

Gmail making email more secure with MTA-STS standard

April 10, 2019

Posted by Nicolas Lidzborski, Senior Staff Software Engineer, Google Cloud and Nicolas Kardas, Senior Product Manager, Google Cloud

We're excited to announce that Gmail will become the first major email provider to follow the new SMTP MTA Strict Transport Security (MTA-STS) RFC 8461 and SMTP TLS Reporting RFC 8460 internet standards. Those new email security standards are the result of three years of collaboration within IETF, with contributions from Google and other large email providers.

SMTP alone is vulnerable to man-in-the-middle attacks

Like all mail providers, Gmail uses Simple Mail Transfer Protocol (SMTP) to send and receive mail messages. SMTP alone only provides best-effort security with opportunistic encryption, and many SMTP servers do not prevent certain types of malicious attacks intercepting email traffic in transit.

End-to-End Email Encryption

Two major standards: **PGP** and **S/MIME** (similar, but incompatible)

- Both rely on public key cryptography
- Both support signing and/or encryption
- Main difference: *how certificates are signed*

Typical workflow

- Encrypt message with a random symmetric key
- Encrypt symmetric key with the public key(s) of recipient(s)
- Digitally sign a hash of the message

Metadata still in the clear (!)

- Email headers, appended "Received:" records, subject line

Pretty Good Privacy

De facto standard for encrypted email

PGP (Phil Zimmermann) ➔ OpenPGP (RFC 4880)

- Gnu Privacy Guard (GPG): GPL implementation

Authentication

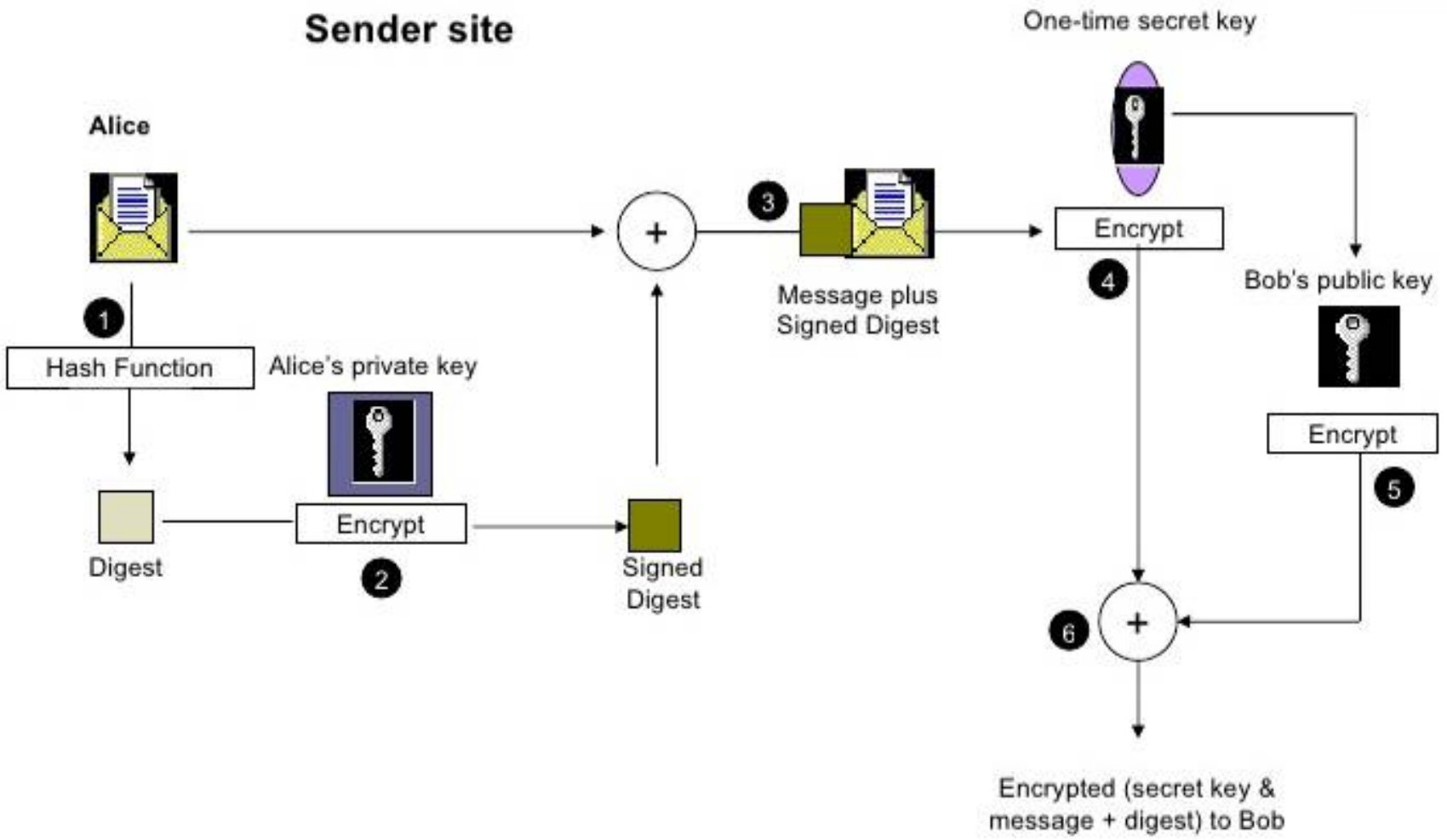
- Senders attach their digital signature to the message
- Receivers verify the signature using public-key cryptography

Confidentiality

- Symmetric key encryption
- Random session key generated for each message
- Session key is encrypted with recipient's public key

Both are typically used on the same message

PGP Encryption



http://www.slideshare.net/rvenkatesh25/network-security-primer

PGP Signed Message Example

```
From: alice@wonderland.com
Date: Mon, 16 Nov 1998 19:03:30 -0600
Subject: Message signed with PGP
MIME-Version: 1.0
Content-Type: text/plain; charset=US-ASCII
Content-Transfer-Encoding: 7bit
Content-Description: "cc:Mail Note Part"

-----BEGIN PGP SIGNED MESSAGE-----

Bob,

This is a message signed with PGP, so you can see how much overhead PGP
signatues introduce.  Compare this with a similar message signed with S/MIME.

Alice

-----BEGIN PGP SIGNATURE-----
Version: PGP for Personal Privacy 5.0
Charset: noconv

iQCVAwUBM+oTwFcsAarXHFeRAQEsJgP/X3noON57U/6XVygOFjSY5lTpvAduPZ8M
aIFalUkCNuLLGxmtsbwRiDWLtCeWG3k+7zXDfx4YxuUcofGJn0QaTlk8b3nxADL0
O/EIvC/k8zJ6aGaPLB7rTIizamGOt5n6/08rPwwVkRB03tmT8UNMAUCgoM02d6HX
rKvnc2aBPFI=
=mUaH
-----END PGP SIGNATURE-----
```

PGP Additional Features

Compression

- Sign ➔ Compress ➔ Encrypt
- Compression after encryption is pointless (no redundancy)
- Signature does not depend on the compression algorithm

Email Compatibility

- Ciphertext contains arbitrary 8-bit octects
- Some email systems may interpret some of them as control commands
- Solution: base64 encoding (33% space overhead)

Segmentation

- Transparent message segmentation and reassembly for very large messages
- Segments mailed separately

Encrypted Email: Two Main Challenges

Public key authenticity

Assurance that a public key is correct and belongs to the person or entity claimed

- Ensure it has not been tampered with or replaced by an attacker

Public key discovery

How can we find the public key of a person/entity?

- Especially the very first time we need to contact them

PGP: Web of Trust

- Decentralized trust model
  - In contrast to the centralized hierarchical model of PKI
  - Users create their own certificates
- Users validate other users' certificates, forming a "web of trust"
  - No trusted authorities: trust is established through friends
  - Adjustable "skepticism" parameters: number of fully and partially trusted endorsers required to trust a new certificate (1 and 3 for GnuPG)
  - Key signing parties
- Main problems
  - Privacy issues: social graph metadata
  - Bootstrapping: new users are not readily trusted by others
  - When opinions vary, "stronger set" wins: impersonation through collusion/compromised keys
  - Scalability: WoT for the whole world?

https://xkcd.com/364/

Finding Public Keys

Public PGP key servers

- pgp.mit.edu
- keyserver.pgp.com

Cache certificates from received emails

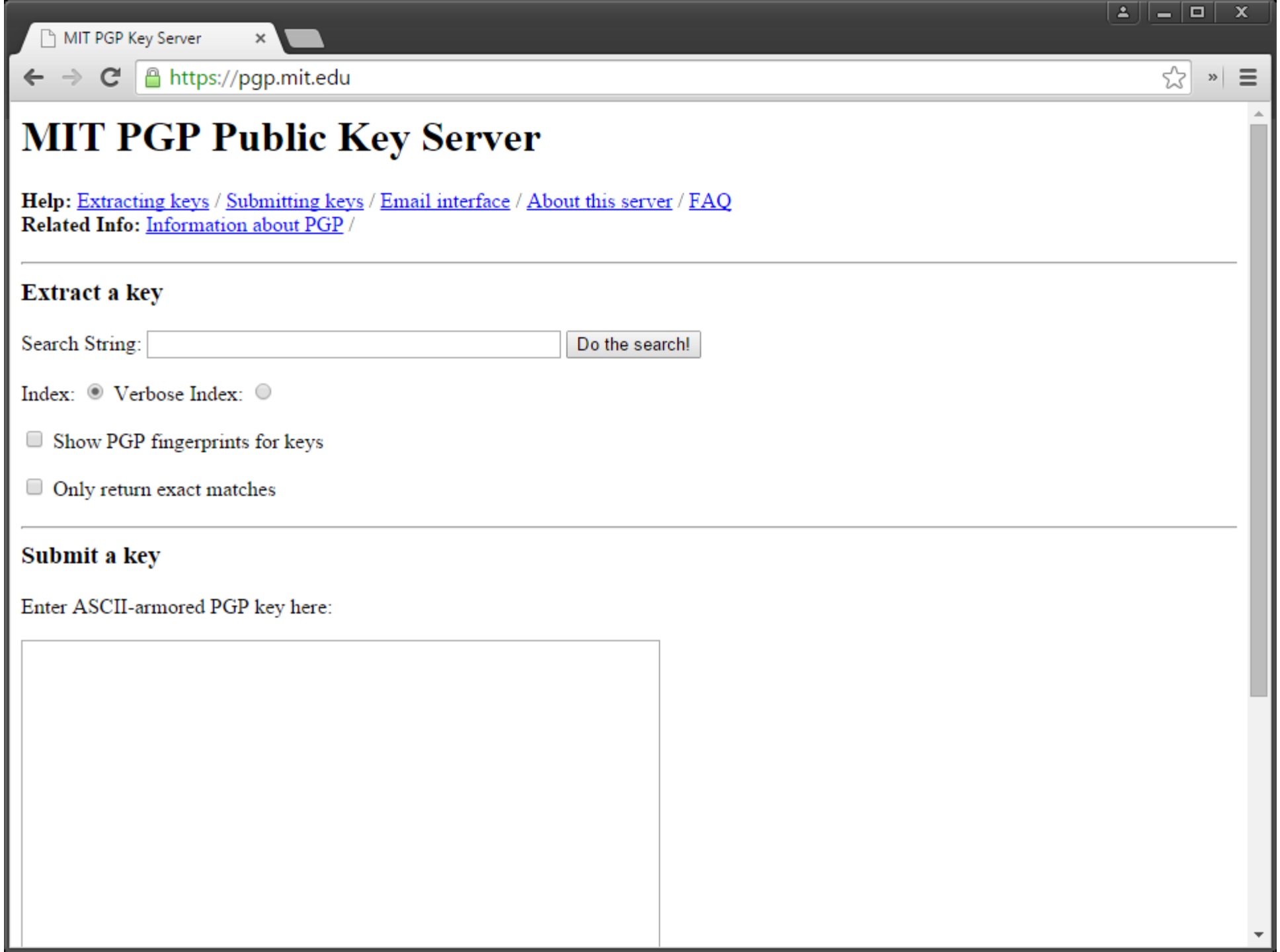
Integration with user management systems (LDAP)

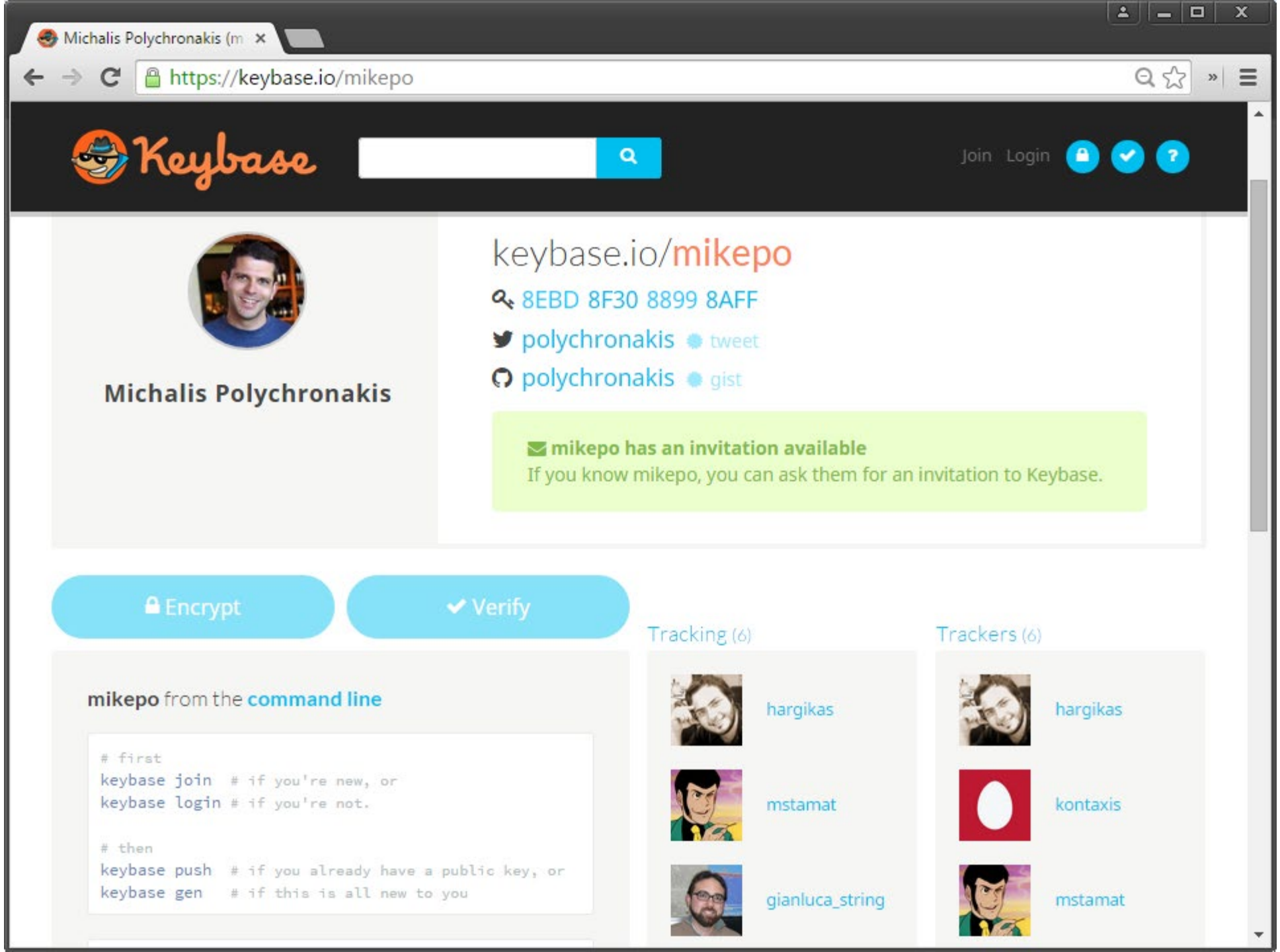
Ad-hoc approaches

- List public key on home page
- Print on business card
- Exchange through another medium on a case-by-case basis

Association with social profiles/identities

- keybase.io


MIT PGP Key Server
https://pgp.mit.edu
MIT PGP Public Key Server
Help: Extracting keys / Submitting keys / Email interface / About this server / FAQ
Related Info: Information about PGP /
Extract a key
Search String:
Do the search!
Index: Verbose Index:
Show PGP fingerprints for keys
Only return exact matches
Submit a key
Enter ASCII-armored PGP key here:


Michalis Polychronakis (m
https://keybase.io/mikepo
Keybase
Join Login
Michalis Polychronakis
keybase.io/mikepo
8EBD 8F30 8899 8AFF
polychronakis tweet
polychronakis gist
mikepo has an invitation available
If you know mikepo, you can ask them for an invitation to Keybase.
Encrypt
Verify
mikepo from the command line
first
keybase join # if you're new, or
keybase login # if you're not.
then
keybase push # if you already have a public key, or
keybase gen # if this is all new to you
Tracking (6)
hargikas
mstamat
gianluca_string
Trackers (6)
hargikas
kontaxis
mstamat

Biggest Issue: Usability

Non-trivial setup

- PGP: user is responsible for everything

Key management

Key revocation

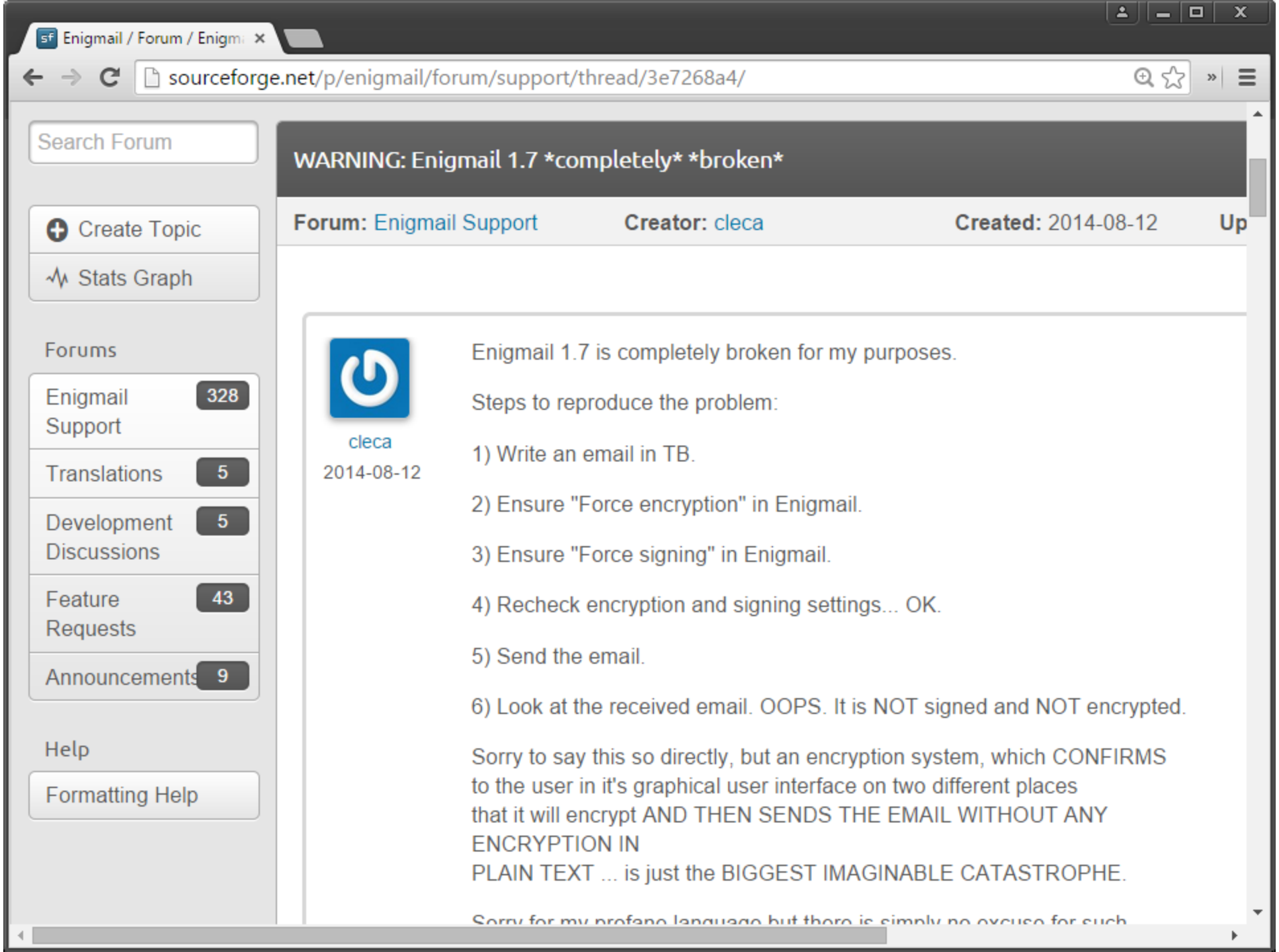
Public key fingerprints

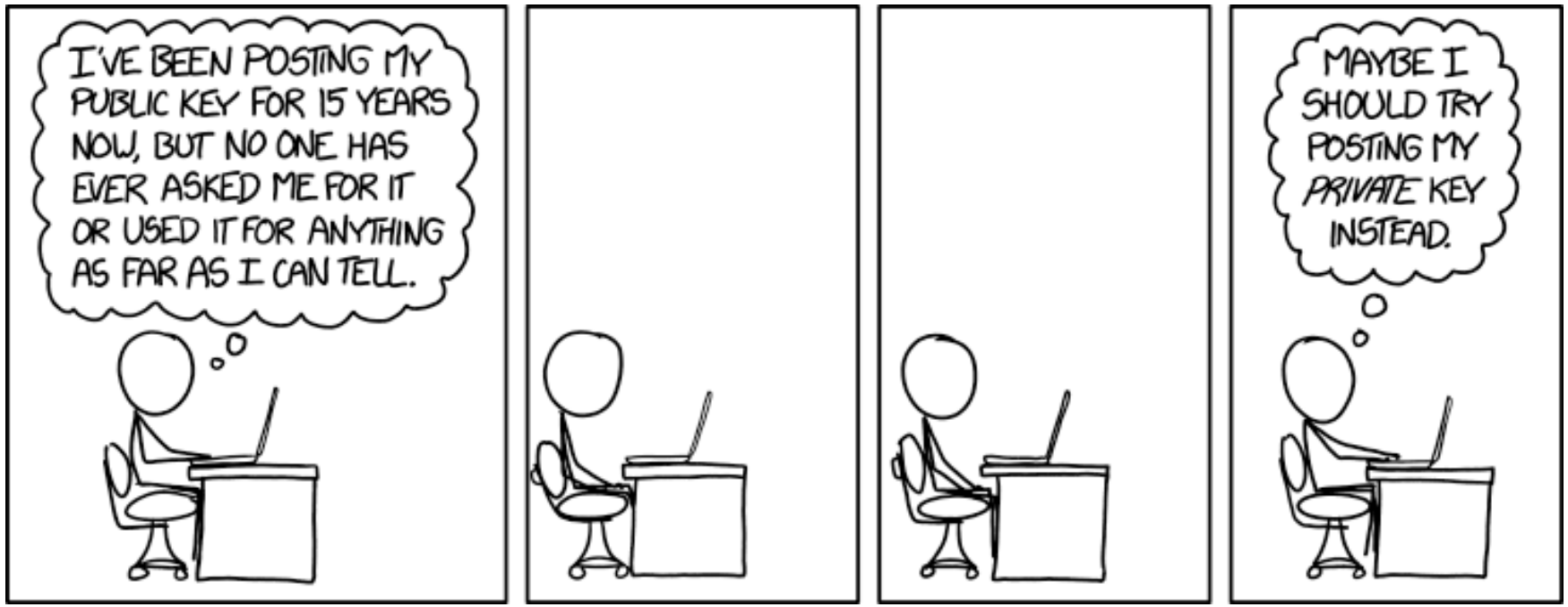
Poor mail client integration

- Can lead to catastrophic failures: e.g., Enigmail+Thunderbird silent encryption failure

(Let alone key discovery and trustworthiness issues)

https://xkcd.com/1181/


Enigmail / Forum / Enigm
sourceforge.net/p/enigmail/forum/support/thread/3e7268a4/
Search Forum
Create Topic
Stats Graph
Forums
Enigmail Support 328
Translations 5
Development Discussions 5
Feature Requests 43
Announcements 9
Help
Formatting Help
WARNING: Enigmail 1.7 *completely* *broken*
Forum: Enigmail Support
Creator: cleca
Created: 2014-08-12
Up
cleca
2014-08-12
Enigmail 1.7 is completely broken for my purposes.
Steps to reproduce the problem:
1) Write an email in TB.
2) Ensure "Force encryption" in Enigmail.
3) Ensure "Force signing" in Enigmail.
4) Recheck encryption and signing settings... OK.
5) Send the email.
6) Look at the received email. OOPS. It is NOT signed and NOT encrypted.
Sorry to say this so directly, but an encryption system, which CONFIRMS
to the user in it's graphical user interface on two different places
that it will encrypt AND THEN SENDS THE EMAIL WITHOUT ANY
ENCRYPTION IN
PLAIN TEXT ... is just the BIGGEST IMAGINABLE CATASTROPHE.



https://xkcd.com/1553/


Runa A. Sandvik on Twitte
Twitter, Inc. [US] https://twitter.com/runasand/status/573613717004247040
Search Twitter
Have an account? Log in
Runa A. Sandvik
@runasand
Follow
Swedish media org @Aftonbladet publishes its GPG private key for a second time (first time was in 2012):
Anders Nilsson @nilssonanders
Sweden's biggest newspaper #Aftonbladet includes their private key in guide to PGP mail them (via @_zulln) bit.ly/1FfHAOI
RETWEETS
42
FAVORITES
15
2:39 PM - 5 Mar 2015

Adobe Product Security Incident Response Team (PSIRT) Blog

Working to help protect customers from vulnerabilities in Adobe software. Contact us at PSIRT(at)adobe(dot)com.

PSIRT PGP Key (0x33E9E596)

```
-----BEGIN PGP PUBLIC KEY BLOCK-----
Version: Mailvelope v1.8.0
Comment: https://www.mailvelope.com

xsFNBFm/2KMBEADbwToJM3BCVE1OeC22HgVEqNEDppXzuD2dgfKuy0M4tx2L
De7GkPjo6AOsw4yi8bakLiidpw5B0J/AR1VtIjIDEmS0F9MRZIcV0UKyA5qV
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AwIJEIbAD8Kvh3YWBBUIAgoDFgIBAhkBAhsDAh4BAADk2A//f+6PFzg4VmLI
PzsTZPoqPR/lXlZ7RIYbQosHvsFwyW0WWX1uI1sEeD5Qo7HQt6NNMAOW51Js
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6+kMuQyG4swmxsZhljlqGMHcs0c/BuI3W+n5w+xLM7N5jjCTjNXR+tGmstdm
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```

CATEGORIES

- Alert
- Security Bulletins and Advisories
- Uncategorized

ARCHIVES

- September 2017
- August 2017
- July 2017
- June 2017
- May 2017
- April 2017
- March 2017
- February 2017
- January 2017
- December 2016
- November 2016
- October 2016
- September 2016
- August 2016
- July 2016
- June 2016
- May 2016
- April 2016
- March 2016
- February 2016
- January 2016
- December 2015

```
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ZlRwd77Vmfc=
=QOc7
-----END PGP PUBLIC KEY BLOCK-----

-----BEGIN PGP PRIVATE KEY BLOCK-----
Version: Mailvelope v1.8.0
Comment: https://www.mailvelope.com

xcaGBFm/2KMBEADbwToJM3BCVE1OeC22HgVEqNEDppXzuD2dgfKuy0M4tx2L
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```

S/MIME

Based on standard X.509 certificates

- Analogous operation to TLS: trusted CA sign certificates
- Traditional PKI

Uses MIME to include cryptographic information in the message

- Multipurpose Internet Mail Extensions: extends the format of email messages to support binary attachments, and text in non-ASCII character sets

Works well within corporations

- Certificate distribution through the existing Active Directory infrastructure

Built-in support in most modern email clients

- Seamless interoperability between them

S/MIME Signed Message Example

```
From: alice@wonderland.com
Date: Mon, 16 Nov 1998 19:03:08 -0600
Subject: Message signed with S/MIME
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary="simple boundary"


--simple boundary
Content-Type: text/plain; charset=US-ASCII
Content-Transfer-Encoding: 7bit
Content-Description: "cc:Mail Note Part"

Bob,

This is a message signed with S/MIME, so you can see how much overhead S/MIME
signatures introduce.  Compare this with a similar message signed with PGP.

Alice


--simple boundary
Content-Type: application/octet-stream; name="smime.p7s"
Content-Transfer-Encoding: base64
Content-Disposition: attachment; filename="smime.p7s"

MIIQQwYJKoZIhvcNAQcCoIIQNDCCEDACAQExCzAJBgUrDgMCGgUAMAsGCSqGSIb3DQEHAaCCDnww
ggnGMIIJL6ADAgECAhBQQRR9a+DX0FHXfQOVHQhPMA0GCSqGSIb3DQEBBAUAMGIxETAPBgNVBAcT
CEludGVybmV0MRcwFQYDVQQKEw5WZXJpU2lnbiwgSW5jLjE0MDIGA1UECxMrVmVyaVNpZ24gQ2xh
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MgYDVQQLEytWZXJpU2lnbiBDbGFzcyAxIENBIC0gSW5kaXZpZHVhbCBTdWJzY3JpYmVyMUYwRAYD
```

End-to-End vs. Cloud-to-Cloud

IMAP: one of the oldest "cloud" services!

- Keep messages on the server
- Conveniently access them from multiple devices

Useful cloud-based email features

- Powerful search, collaborative SPAM filtering, …
- Need access to the **plaintext (!)** Gmail cannot index or filter encrypted messages

Tradeoff: privacy vs. convenience

- Active research on searchable encryption

Encrypted Webmail?

Several recent efforts have focused on transparently combining the convenience of webmail with PGP encryption

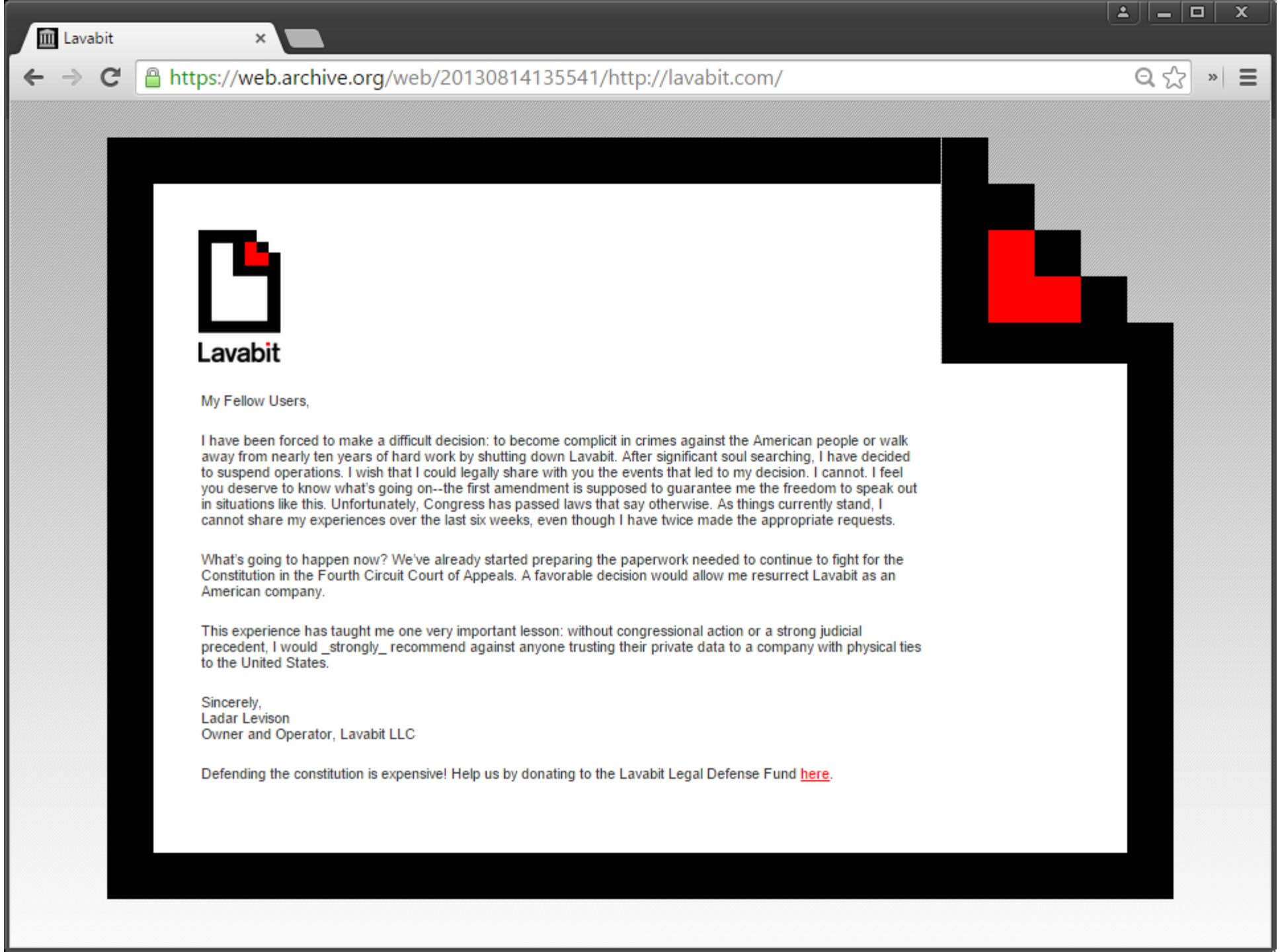
- Is this really possible in a *secure* way?

JavaScript crypto is not a good idea

- Secure JS code delivery?
- Secure key storage?
- Secure runtime (it's a *web browser*!)?

Google end-to-end: implement cryptographic functionality as part of a browser extension

- More control, but still not trivial
- After initial excitement, it seems the effort has been abandoned


Lavabit
https://web.archive.org/web/20130814135541/http://lavabit.com/
Lavabit
My Fellow Users,
I have been forced to make a difficult decision: to become complicit in crimes against the American people or walk away from nearly ten years of hard work by shutting down Lavabit. After significant soul searching, I have decided to suspend operations. I wish that I could legally share with you the events that led to my decision. I cannot. I feel you deserve to know what's going on--the first amendment is supposed to guarantee me the freedom to speak out in situations like this. Unfortunately, Congress has passed laws that say otherwise. As things currently stand, I cannot share my experiences over the last six weeks, even though I have twice made the appropriate requests.
What's going to happen now? We've already started preparing the paperwork needed to continue to fight for the Constitution in the Fourth Circuit Court of Appeals. A favorable decision would allow me resurrect Lavabit as an American company.
This experience has taught me one very important lesson: without congressional action or a strong judicial precedent, I would _strongly_ recommend against anyone trusting their private data to a company with physical ties to the United States.
Sincerely,
Ladar Levison
Owner and Operator, Lavabit LLC
Defending the constitution is expensive! Help us by donating to the Lavabit Legal Defense Fund here.

Lavabit: *"so secure that even our administrators can't read your e-mail"*

But they could, if they wanted to…

"Basically we generate public and private keys for the user and then encrypt the private key using a derivative of the plain text password. We then encrypt user messages using their public key before writing them to disk."

"Because we need the plain text password to decrypt a user's private key, we don't support secure password authentication. We decided to support SSL instead (which encrypts everything; not just the password)."

http://highscalability.com/blog/2013/8/13/in-memoriam-lavabit-architecture-creating-a-scalable-email-s.html
https://arstechnica.com/information-technology/2013/11/op-ed-a-critique-of-lavabit/