You Have No Idea Who Sent That Email: 18 Attacks on Email Sender Authentication

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About Us

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  - HTTP, Email: “CDN forwarding loop”[NDSS16], “Host-of-troubles”[CCS16]

• Vern Paxson: Professor at UC Berkeley
  - Creator of the Bro IDS
  - Co-founder of Corelight, providing network traffic analysis solutions

• Jian Jiang: Senior Director of Engineering at F5 (Shape Security)
  - DNS, Web: “Ghost DNS”[NDSS12], “Cookies lack Integrity”[USENIX15]
How Do You Verify the Email Sender?

Your Single Transaction Alert from Chase

from: Chase <no.reply.alerts@chase.com>
to: whucjj@gmail.com
date: Jun 28, 2020, 8:04 PM
subject: Your Single Transaction Alert from Chase
mailed-by: chase.com
signed-by: chase.com
security: 🔐 Standard encryption (TLS) Learn more
            ➤ Important according to Google magic.
A Case of Our Spoofing Attacks on Gmail (Fixed)
Background: Sender & Authentication
Background: Who’s the Sender?

SMTP envelope

HELO helo.sender.com
MAIL FROM: <s@mfrom.sender.com>
RCPT TO: <bob@email.com>

From: Secure Bank <noreply@bank.com>
To: Bob <bob@email.com>
Subject: Account Alert: Suspicious Purchase

Dear Bob,

We are writing to inform you that…
Background: Email Transmission

The original SMTP has no built-in authentication mechanism
• Anyone can spoof any identity in HELO/MAIL FROM and From
Three Sender-Authentication Protocols

• **Sender Policy Framework (SPF, RFC 7208)**
  - verifying the IP address of the sending domain

• **DomainKeys Identified Mail (DKIM, RFC 6376)**
  - verifying the email is signed by the sending domain

• **Domain Message Authentication, Reporting and Conformance (DMARC, RFC 7489)**
  - “how to” policy for recipient based on SPF and DKIM
  - “fix” the alignment problem of SPF and DKIM
Sender Policy Framework (SPF)

1. Publish authorized IP lists via DNS

   - a.com TXT 1.2.3.0/24
   - a.com TXT 1.2.3.0/24

2. Query the domain in HELO and MAIL FROM to obtain the IP lists

   - HELO a.com
   - MAIL FROM: <s@a.com>
   - RCPT TO: <bob@b.com>

3. Check if the sender’s IP matches the IP lists
   - If yes, SPF pass
     - 1.2.3.4 matches 1.2.3.0/24

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From: Alice <alice@a.com>
To: Bob <bob@b.com>
Subject: Hello from Alice

Dear Bob,
I’m Alice…
DomainKeys Identified Mail (DKIM)

1. Publish public key via DNS
2. Generate DKIM-Signature with private key and attach it to the message.
3. Query “s._domainkey.d” (any._domainkey.a.com) to obtain public key
4. Validate DKIM signature with the public key
What’s Wrong with SPF/DKIM?

HELO helo.attack.com
MAIL FROM: <s@mfrom.attack.com>
RCPT TO: <bob@b.com>

DKIM-Signature: ...
d=attack.com;
s=2020;...
From: Alice <alice@a.com>
To: Bob <bob@b.com>
Subject: Hello from Alice

Dear Bob,

I’m Alice…

What SPF verifies
What DKIM verifies
What the end-user sees

Neither SPF nor DKIM validate the From header that is displayed to the end-user.
Domain Message Authentication, Reporting and Conformance (DMARC)

3. Receiving services perform **identifier alignment test** to check if the domain in From header matches SPF or DKIM-verified domain.
   - Exactly match (strict) or have the same registered domain* (relaxed, default mode)

4. The email passes DMARC authentication if:
   1) either SPF or DKIM show a positive result, and
   2) the From header domain passes the alignment test.

* Defined in public suffix list, https://publicsuffix.org/
Overview of Email Authentication Flow

What could possibly go wrong?
Bypassing the Authentication
Key Idea of Our Attacks

Inconsistencies between different components could lead to security vulnerabilities.
Key Idea of Our Attacks

Ambiguous input ID1-ID2

Attacker

Inconsistencies between different components could lead to security vulnerabilities.
Exp. 1: Inconsistencies b/w SPF and DMARC

SMTP defines multiple identifiers
• HELO and MAIL FROM

SPF (RFC 7208)
• Check both HELO and MAIL FROM
• If either fails, SPF fails

DMARC (RFC 7489)
• Use MAIL FROM for alignment test.
• If MAIL FROM is empty, use HELO

Ambiguity: SPF uses **HELO**, and DMARC uses **MAIL FROM**
Exp. 1: Inconsistencies b/w SPF and DMARC

Ambiguity: SPF uses HELO, and DMARC uses MAIL FROM

HELO attack.com
MAIL FROM: <any@notexist.bank.com>

From: <sec@bank.com>
To: <victim@victim.com>

Dear Customer,

We are writing to inform you that…

1. SPF cannot verify MAIL FROM, and can only verify HELO
   • the non-existent domain doesn’t have SPF policy, yet not considered as FAIL

2. DMARC uses MAIL FROM
   • because MAIL FROM is not empty

3. SPF **pass**, DMARC **pass**
Exp. 2: Inconsistencies b/w DKIM and DNS

Ambiguity: What DKIM uses differs from what DNS queries

HELO attack.com
MAIL FROM: <any@attack.com>

DKIM-Signature: ...;d=bank.com;
s=attack.com.\x00.any;...
From: <sec@bank.com>
To: <victim@victim.com>

Dear Customer,

We are writing to inform you that...

1. Attacker signs the message with his private key and sends the message

2. When receiving the message, DKIM uses ‘attack.com.\x00.any._domainkey.bank.com’ to obtain the public key

3. But DNS takes \x00 as a terminator, and obtains public key from attack.com

4. DKIM pass, DMARC pass
Exp. 3: Authentication Results Injection

Ambiguity: Exploiting how SPF/DKIM forwards results to DMARC

RFC 8601 define Authentication-Results header for communicating results between SPF/DKIM and DMARC:

```
Authentication-Results: example.com; spf=pass
    smtp.mailfrom=sender@sender.com; dkim=pass
    reason="signature ok" header.d=sender.com;
```

DMARC extracts “smtp.mailfrom” and “header.d” to check alignment with From header.
Exp. 3a: DKIM Authentication Results Injection

HELO attack.com
MAIL FROM: <any@attack.com>

From: <sec@bank.com>
To: <victim@victim.com>

Dear Customer,

We are writing to inform you that

1. Attacker signs the message with their private key
2. DKIM verifies the message with the attacker’s public key from ‘selector._domainkey.bank.com(.attack.com’ and generates:

   Authentication-results: bank.com;
   dkim=pass (1024-bit key)
   header.d=bank.com(.attack.com)

   Comments

3. DMARC parses the content after the “(“ as a comment, and uses bank.com to check alignment with From header

4. DKIM pass, DMARC pass
Exp. 3b: SPF Authentication Results Injection

HELO attack.com
MAIL FROM: <any@bank.com.(attack.com>
From: <sec@bank.com>
To: <victim@victim.com>

Dear Customer,

We are writing to inform you that...

- SPF verifies bank.com.(attack.com)
- DMARC uses bank.com to check alignment with From header
- SPF pass, DMARC pass

Attacker can also use single (‘) and double (“) quotes to replace “(“.
Exp. 4a: Multiple From Headers

Ambiguity: What receiving server verifies differ from what MUA displays

RFC 5322: Messages with multiple From should be rejected

In practice: 19/29 accept (15 use first, 3 use last, 1 show both)
Exp. 4b: Multiple From Headers with Space

Three types of variants:
1) _From: a@a.com ; 2) From_: a@a.com; 3) From\n\n_: a@a.com

From
: <any@attack.com>
From: <admin@bank.com>
To: <victim@victim.com>
Dear Customer,…

From
: <any@attack.com>
From: <admin@bank.com>
To: <victim@victim.com>
Dear Customer,…

Attacker Server

Receiving Services

Mail User Agent

DMARC verifies attack.com

MUA display bank.com
Exp. 4c: Multiple From Headers with Normalization

From: <any@attack.com>
From: <admin@bank.com>
To: <victim@victim.com>
Dear Customer,…

From: <any@attack.com>
From: <admin@bank.com>
To: <victim@victim.com>
Dear Customer,…

DMARC verifies attack.com
MUA display bank.com
Exp. 5: From/Sender Ambiguity

• 7/19 MUAs display Sender or Resent-From header value when From header is absent

```
From : <any@attack.com>
Sender: <admin@bank.com>
To: <victim@victim.com>

Dear Customer,…
```

```
From : <any@attack.com>
Sender: <admin@bank.com>
To: <victim@victim.com>

Dear Customer,…
```

Attacker Server ────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────

Receiving Services

DMARC verifies attack.com

Mail User Agent

MUA display bank.com

Victim
Email Parsing Process

Email Message

From: Secure Bank <admin@bank.com>
To: <victim@victim.com>
Dear Customer,…

From Header

From: Secure Bank <admin@bank.com>

Email Address

admin@bank.com
## Complex From Header Syntax

<table>
<thead>
<tr>
<th>Display Name</th>
<th>Comments</th>
<th>Route portion</th>
<th>Real address</th>
</tr>
</thead>
<tbody>
<tr>
<td>From: Secure (<a href="mailto:b@b.com">b@b.com</a>) Bank &lt;@c.com, @d.com: <a href="mailto:a@a.com">a@a.com</a> (<a href="mailto:e@e.com">e@e.com</a>) &gt; (<a href="mailto:f@f.com">f@f.com</a>)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A quick example of valid (!) From header

- **Multiple address lists.** [RFC 5322]
- **Encoding**: defined to support no-ascii character. [RFC 2047]
  - From: bob <b@b.com> is equal to
  - From: =?utf-8?B?Ym9i?=<b@b.com> in Base64 encoding
- **Quoted-pair**: use ‘\’ to escape special characters like ‘( ‘. [RFC 5322]
Exp. 6a: Exploiting Differences in Feature Support

From: `<any@attack.com>, <admin@legitimate.com>`

Mail server                      Email client

From: `<@attack.com, @any.com: admin@legitimate.com>`

Mail server                      Email client

From: `bs64(<admin@legitimate.com>), <any@attack.com>`

Email client                      Mail server
Exp. 6b: Exploiting Parsing Inconsistencies

From: <admin@legitimate.com>, <any@attack.com>

Email client

Mail server

From: admin@legitimate.com, <any@attack.com>

Email client

Mail server

From: <any@attack.com> admin@legitimate.com

Mail server

Email client
How Prevalent are UI-mismatch Vulnerabilities?

• We tested 10 popular email providers and 19 email clients

• 43 out of 82 different combinations that could be exploited

• What we found only constitutes a subset of the problem

Read our paper for more details
Exp. 7: Spoofing via an Email Service Account

Ambiguity: What sending server validates differ from what MUA displays

- Attackers with an email service account - attacker@gmail.com tries to spoof admin@gmail.com

- Sending services should ensure that the From header matches authenticated username
  - But From header validation is error-prone because of complex syntax
- We found 7 out of 8 email providers are vulnerable
Attackers with an email service account
- Create deceptive content in body, To, and Subject, but not From header

RCPT TO: <attacker@gmail.com>

Dear Customer,
We are writing to inform you that…
Exp. 8: Combing Replay and Multiple-From Ambiguity (2/2)

② Attacker replay the messages with an extra From header.

Ambiguity: What DKIM verifies differs from what MUA displays
- DKIM components verify the last header
- MUAs show the first header

RCPT TO: <victim@victim.com>

DKIM-Signature: ...; s=selector; d=gmail.com;...
From: <admin@gmail.com>
From: <attacker@gmail.com>
To: <victim@victim.com>

Dear Customer,
We are writing to inform you that…
Thinking on Defense

• **Better parsing and protocol spec**
  • “Be liberal strict in what you accept”
  • make protocol implementation-friendly
    • simple, well-typed/structured messages, reduce/avoid multiple party processing

• **Better UI**
  • UI needs more explicit security indicators

• **For end-users**
  • Don’t blindly trust the email sender displayed in email client
  • Use end-to-end authentication such as PGP
    • PGP may also have parsing ambiguities, but hopefully better than those in SPF/DKIM/DMARC.
New tool - espoofeer

We will make this tool publicly available at

https://github.com/chenjj/espoofeer
Thank you!

See more demo videos at here, full paper at here.