RADIUS/UDP Considered Harmful

The Blast-RADIUS Attack

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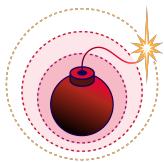
[1]Cloudflare, [2]UC San Diego, [3]BastionZero, [4]Microsoft Research, [5]Centrum Wiskunde & Informatica

August 18, 2024



Attack Summary

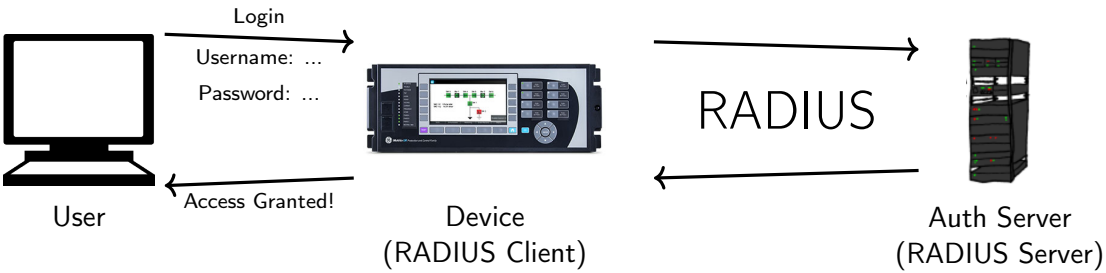
MitM network attacker can forge arbitrary RADIUS responses (for non-EAP authentication modes)

e.g., can log into victim device with bogus credentials

This is a **protocol vulnerability**: RADIUS hard codes weak authentication based on MD5

What is RADIUS?

- RADIUS is the de facto standard lightweight protocol for authentication, authorization, and accounting (AAA) for networked devices.
- Log into X but handle auth on server Y



What uses RADIUS?

> *RADIUS is in wide-spread use, and is supported by essentially every switch, router, access point, and VPN concentrator product sold in the past twenty-five years.*
>
> *(Alan DeKok, lead developer of FreeRADIUS, [DeK24])*

- Backbone routers
- VPNs
- ISP infrastructure (DSL/FTTH)
- IoT devices
- Identity Providers and MFA (Okta, Duo)
- Not vulnerable to this attack: 802.1X, enterprise WiFi, eduroam

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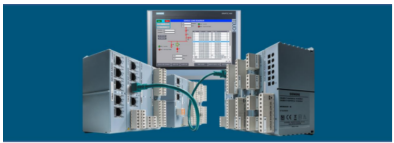

ENERGY AUTOMATION PRODUCTS

SICAM A8000

Substation Automation for Industry and Infrastructure

siemens.com/sicam-a8000

Fulfillment of high cyber security requirements according to BDEW whitepaper, NERC CIP and IEC62351 with support for RADIUS, Syslog, IPSec and TLS

- Power grid equipment
- Industrial control systems

RADIUS still uses 90s-era cryptography

- MD5 was broken 20 years ago
- But backward compatibility is hard
- Perceived lack of urgency to deprecate

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> *("Deprecating Insecure Practices in RADIUS" IETF draft, 2023)*

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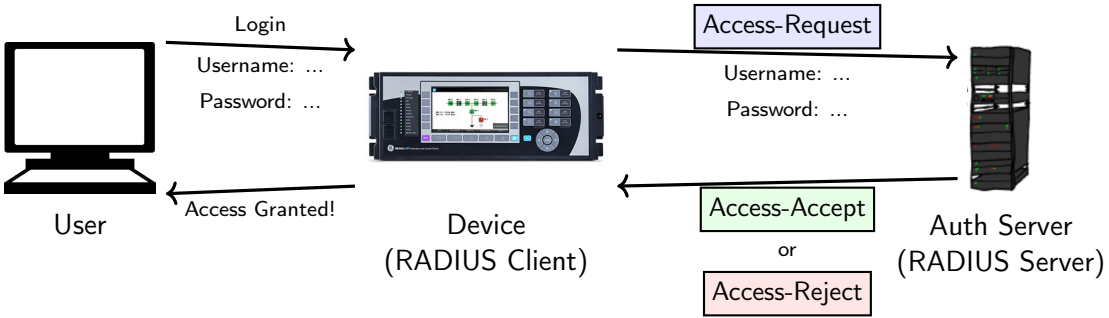
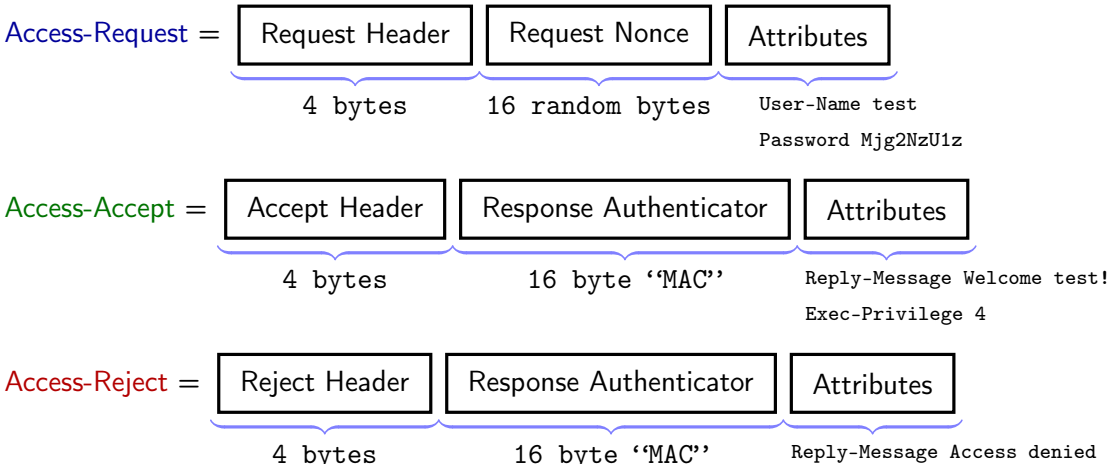
..until now!

How does RADIUS work?



- RADIUS requests and responses are often sent over UDP.
- Client and server share fixed shared secret for authenticating responses and obfuscating passwords.

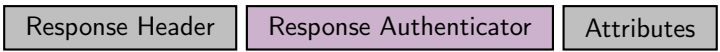
Packet Formats



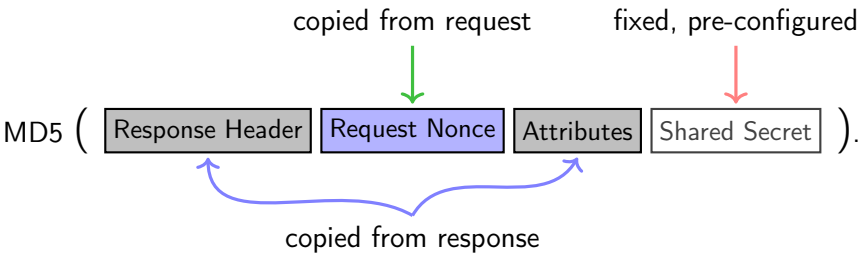
Response Authenticator

Goal: Prevent forgery of packets, e.g., by machine-in-the-middle attacker.

The Response Authenticator from packet



is computed as



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- $\mathrm{MAC}_S(M) = \mathrm{MD5}(S \| M \| S)$? Yes?* (sandwich/envelope MAC)

*assuming proper padding

Blast-RADIUS: Turning Access-Reject Into Access-Accept

- MitM attacker wants to forge an Access-Accept
  - Don't know shared secret, so can't compute Response Authenticator

- Attack: create an MD5 collision such that Access-Accept and Access-Reject will produce the same Response Authenticator (simplified):

$$\text{MD5}(\text{Access-Accept}) = \text{MD5}(\text{Access-Reject})$$

$$\text{implies}$$

$$\text{MD5}(\text{Access-Accept} \mid\mid \text{Secret}) = \text{MD5}(\text{Access-Reject} \mid\mid \text{Secret}).$$

- Trick server into sending the Access-Reject

Blast-RADIUS Attack Overview

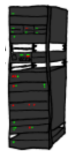
Attacker

login

password bogus

Victim Device

MitM



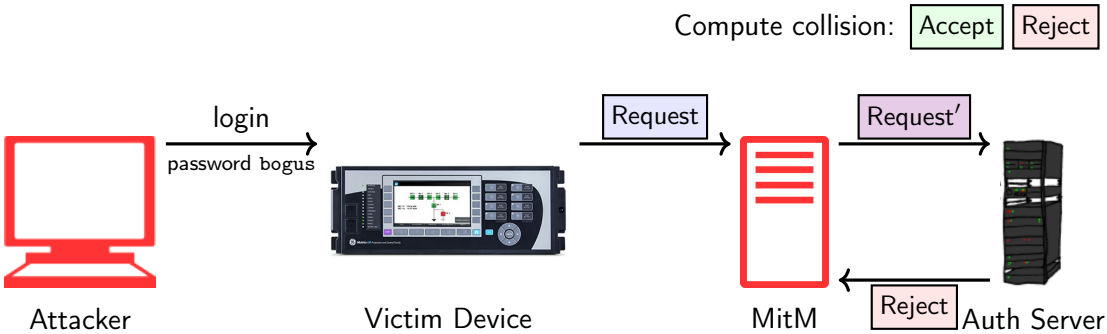
Auth Server

Blast-RADIUS Attack Overview

Blast-RADIUS Attack Overview

Compute collision: Accept Reject

Blast-RADIUS Attack Overview



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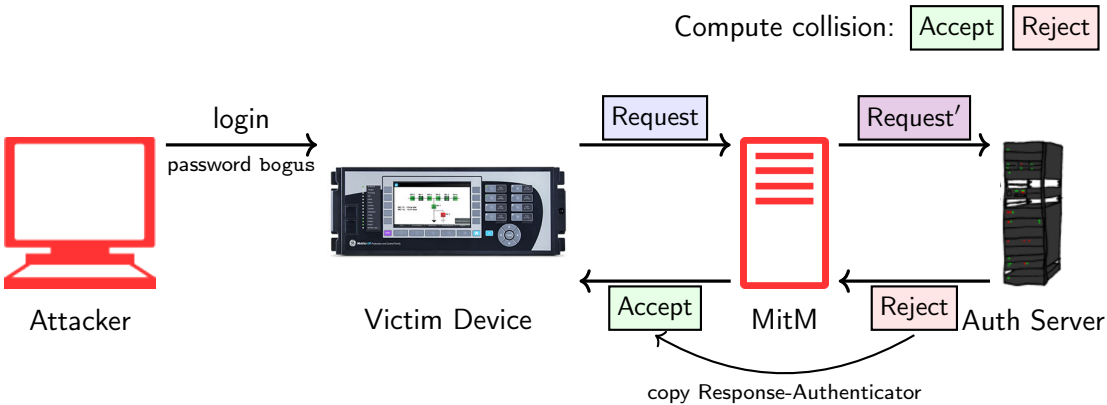

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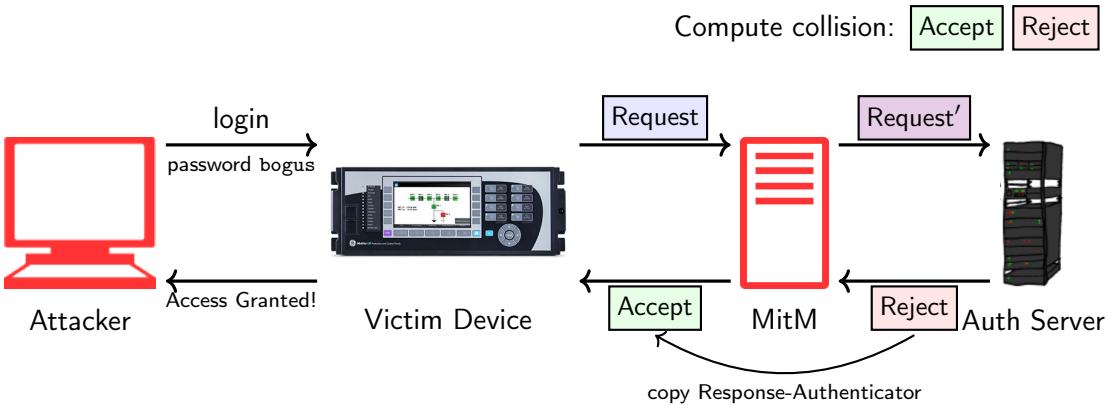
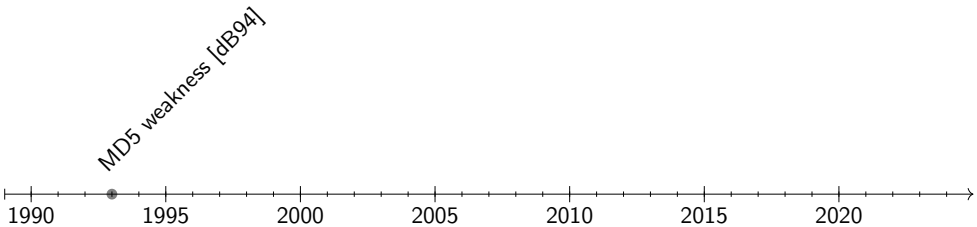


MD5 Collision Attack History



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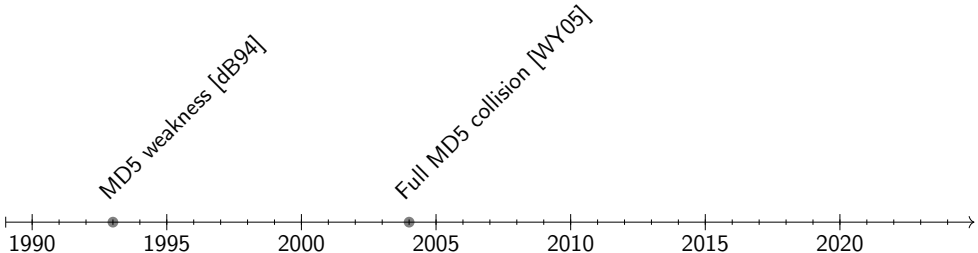

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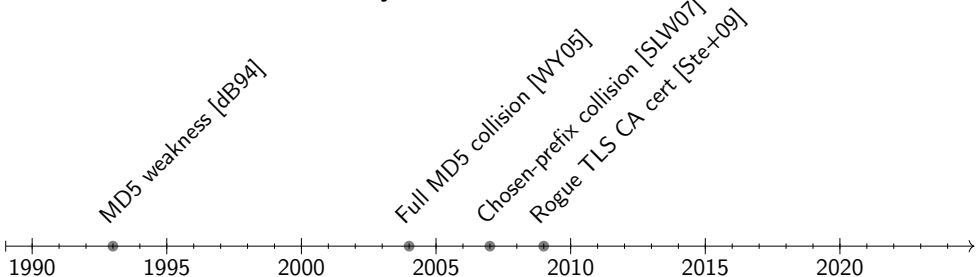

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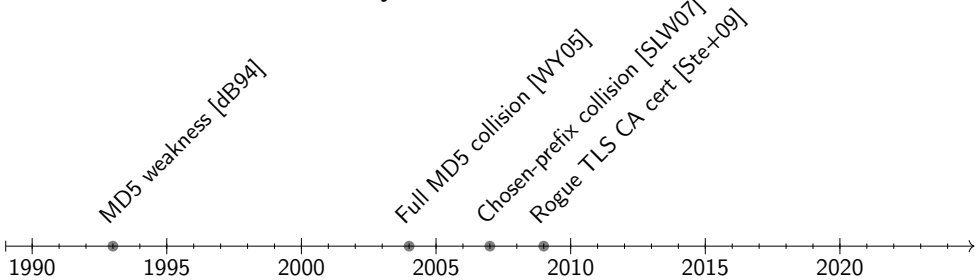

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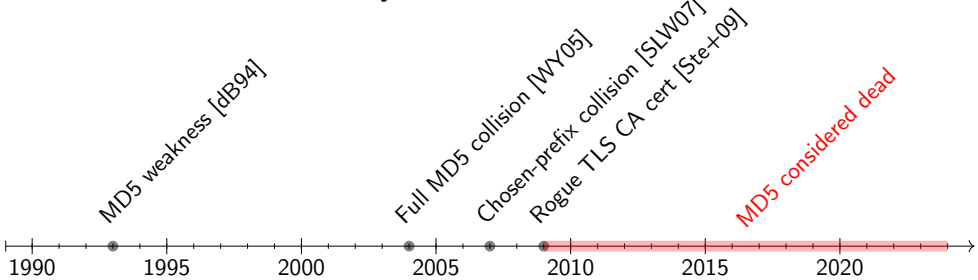

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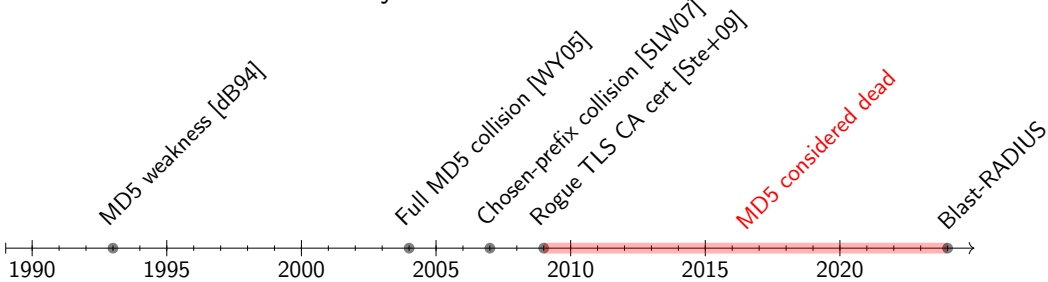

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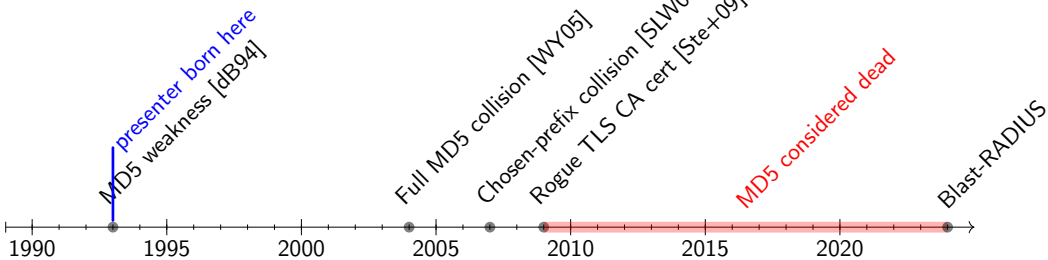

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MD5 Collision for RADIUS Response Authenticator

Given prefixes P_1, P_2, generated collision gibberish G_1, G_2, and suffix S:

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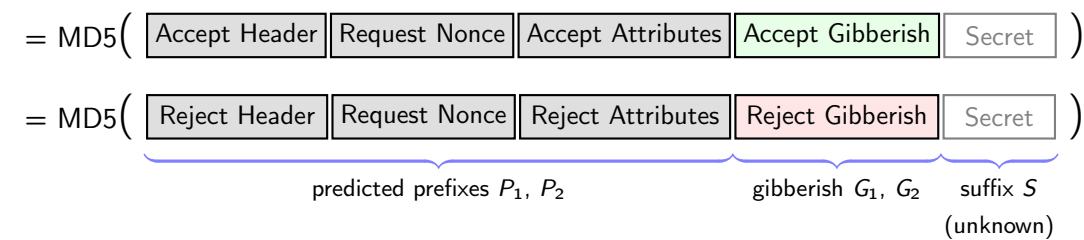
Applied to RADIUS:

Response Authenticator



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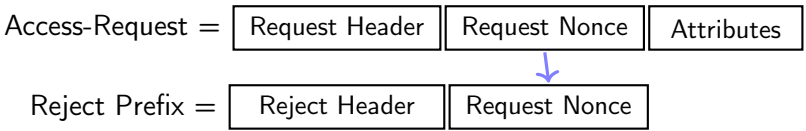

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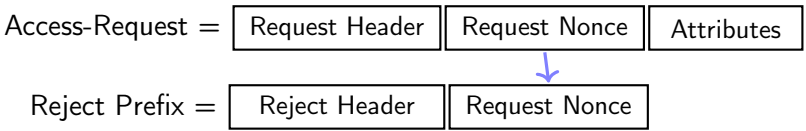

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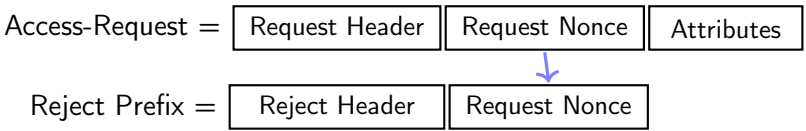

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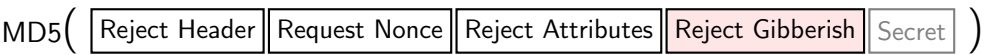
- Collision time depends on collision length and type:
  - $\mathrm{MD5}(G_1) = \mathrm{MD5}(G_2)$ and $\mathrm{MD5}(P||G_1) = \mathrm{MD5}(P||G_2)$ takes seconds.
  - Chosen-prefix collision of [Ste+09]: 204-byte G_1 and G_2 in 28h on 215 PS3.
  - We optimized our 428-byte collision from days to $\leq$ 5m on 47 servers.

Challenge 2: RejectGibberish Injection

- Server needs to include `Reject Gibberish` in Response Authenticator:



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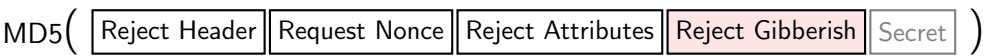

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- The Proxy-State attribute:

  This Attribute is available to be sent by a proxy server to another server when forwarding an Access-Request and ***MUST be returned unmodified*** *in the Access-Accept, Access-Reject or Access-Challenge.*

  (RFC 2058, emphasis added)

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MD5(| Reject Header | Request Nonce | Reject Attributes | Reject Gibberish | Secret |)

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Access-Request =

Request Header	Request Nonce	Attributes	Proxy-State Header	Reject Gibberish

Aside: MD5 Collision Internals ([SLW07])

Track "Intermediate Hash Value" *IHV* (4 words)
dIHV = difference in IHV between pair of messages.
dIHV = 0 means collision.

Phase 1: Birthday

Find gibberish blocks $G_1^{(0)}$, $G_2^{(0)}$ that put *dIHV* into a nice subspace

Phase 2: Near-collision

Repeatedly find gibberish blocks $G_1^{(i+1)}$, $G_2^{(i+1)}$ that keep *dIHV* in the subspace and reduce its hamming weight
Eventually *dIHV* = 0

Tradeoff: number of near-collision blocks vs difficulty of finding each near-collision block

Challenge 3: Gibberish Length

Maximum length of Proxy-State is 253 bytes.
Gibberish that short would take too long to compute (we want $\approx$ 400 bytes)

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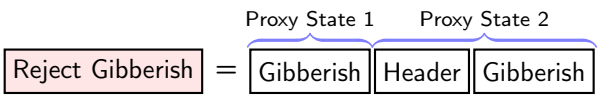
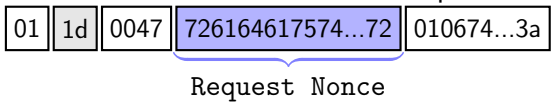
Maximum length of Proxy-State is 253 bytes.
Gibberish that short would take too long to compute (we want ≈ 400 bytes)
Solution: Embed extra Proxy-State header(s) inside gibberish



Blast-RADIUS Attack Example (1/3)

1. Attacker triggers Access-Request.
2. MITM attacker observes Access-Request.



3. MITM attacker predicts the following prefixes

AcceptPrefix = 02 | 1d | 01c0 | 726164617574...72

RejectPrefix = 03 | 1d | 01c0 | 726164617574...72

to compute the MD5 chosen-prefix collision gibberish.

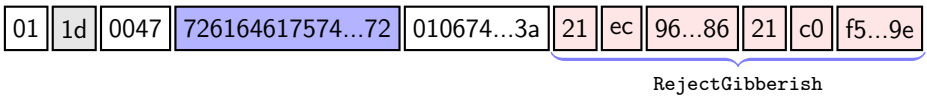
AcceptGibberish = 21 | ec | 3d...86 | 21 | c0 | f5...9e (428 bytes)

RejectGibberish = 21 | ec | 96...86 | 21 | c0 | f5...9e (428 bytes)

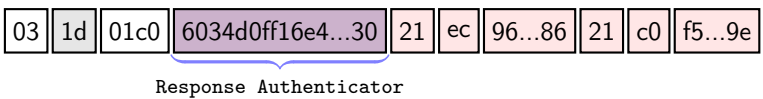
Proxy State Proxy State

Blast-RADIUS Attack Example (2/3)

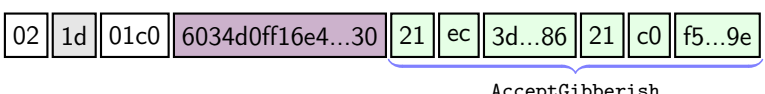
4. MITM sends Access-Request with appended `RejectGibberish` to server.



5. MITM intercepts Access-Reject, learning the Response Authenticator.

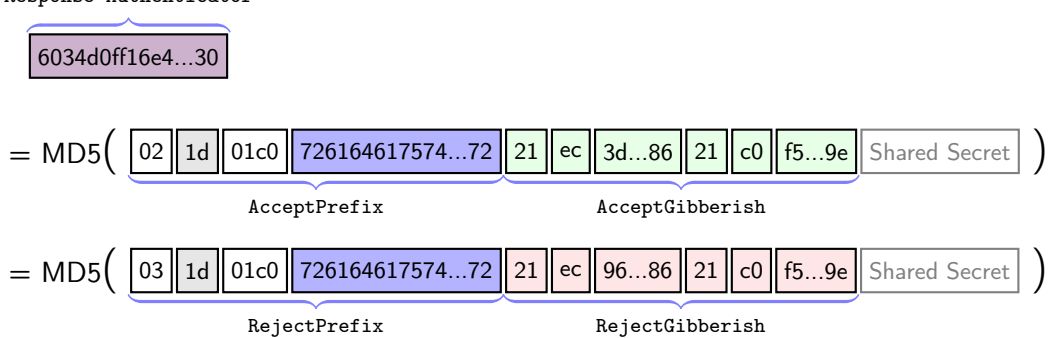


6. MITM puts Response Authenticator in Access-Accept packet with appended `AcceptGibberish`.



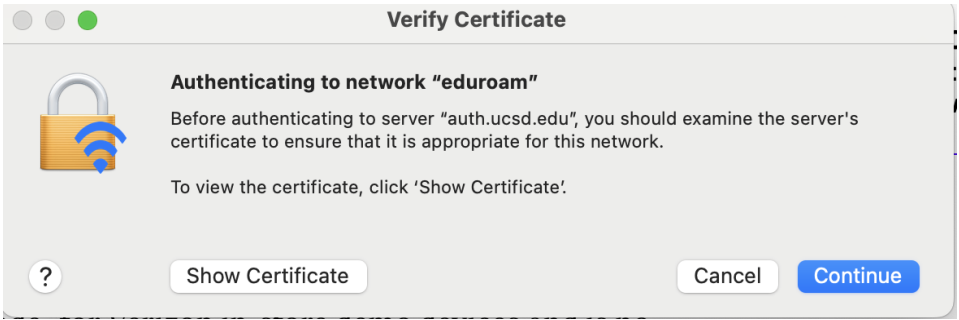
Blast-RADIUS Attack Example (3/3)

7. Access-Accept and Access-Reject produce the same Response Authenticator, and, hence, pass the RADIUS client authentication check.



What about EAP-TLS?

- Extensible Authentication Protocol supports authentication modes beyond simple password
- e.g., EAP-TLS and EAP-TTLS are two such modes



What about EAP-TLS?

- TLS does not wrap RADIUS: RADIUS wraps EAP wraps TLS
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- TLS does not wrap RADIUS: RADIUS wraps EAP wraps TLS
- Access-Accept packet is still sent over UDP!
- BUT, any packet with an `EAP-Message` requires a separate `Message-Authenticator` attribute, which uses HMAC-MD5:

  > *A RADIUS client receiving an Access-Accept, Access-Reject or Access-Challenge with a Message-Authenticator attribute present MUST calculate the correct value of the Message-Authenticator and silently discard the packet if it does not match the value sent.*
  >
  > *(RFC 3579)*

Impact

Affected modes:

- PAP, CHAP, MS-CHAP are vulnerable
- EAP modes likely not vulnerable (require Message-Authenticator)

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Timing:

- RADIUS client timeouts $\leq$ 1m, our PoCs take $\approx$ 5m.
- Optimizations feasible: parallelizes well, hardware implementation.

Mitigations

- Massive disclosure with 90+ vendors.
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- Message-Authenticator attribute uses HMAC-MD5 not vulnerable to MD5 collisions.
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Short-term:

- Message-Authenticator attribute uses HMAC-MD5 not vulnerable to MD5 collisions.
- All requests and responses should include and verify Message-Authenticator.

Long-term:

- Encapsulate all RADIUS traffic in (D)TLS tunnel.
- Current IETF draft is being standardized [RW24].

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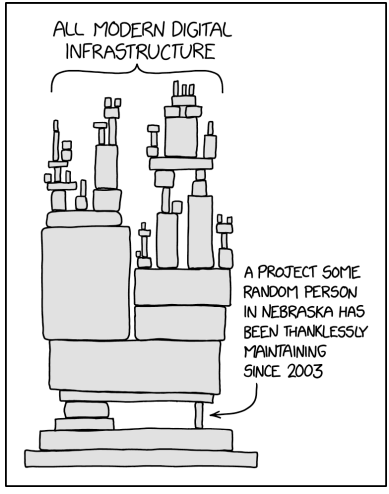
Blast-RADIUS attack

Attack summary: MD5 collision attack on RADIUS authentication by MitM adversary.

`https://blastradius.fail`

RADIUS/UDP Considered Harmful
Sharon Goldberg, Miro Haller, Nadia Heninger, Mike Milano, Dan Shumow, Marc Stevens, and Adam Suhl.
USENIX Security, August 2024.



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[DeK24] Alan DeKok. *RADIUS and MD5 Collision Attacks*. https://networkradius.com/assets/pdf/radius_and_md5_collisions.pdf. 2024.

[RW24] Jan-Frederik Rieckers and Stefan Winter. *(Datagram) Transport Layer Security ((D)TLS Encryption for RADIUS*. Internet-Draft draft-ietf-radext-radiusdtls-bis-02. Work in Progress. Internet Engineering Task Force, July 2024. 38 pp. URL: https://datatracker.ietf.org/doc/draft-ietf-radext-radiusdtls-bis/02/.

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[Ste+09] Marc Stevens et al. "Short Chosen-Prefix Collisions for MD5 and the Creation of a Rogue CA Certificate". In: *CRYPTO*. Vol. 5677. Lecture Notes in Computer Science. Springer, 2009, pp. 55–69.

[TKSA14] Henrik Thejl, Nagaraja K S, and Karl-Georg Aspacher. "A method for user management and a power plant control system thereof for a power plant system". Pat. 2765466. Siemens Gamesa Renewable Energy A/S. Jan. 24, 2014. URL: `https://data.epo.org/publication-server/rest/v1.0/publication-dates/20190904/patents/EP2765466NWB1/document.pdf`.

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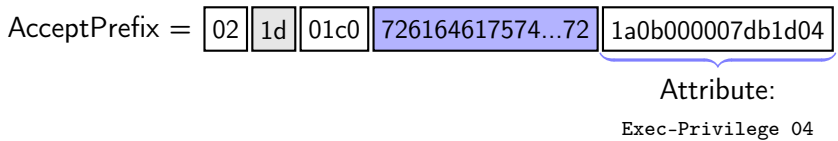
Backup Slides

Attack Extensions

- Adversary can add arbitrary attributes in prefix for Access-Accept.



- Proxy-State attributes are *not* the only way to inject the `RejectGibberish`.
  - Any reflected user input could work, e.g. the User-Name or Vendor-Specific attributes.
    - In Access-Request:
      `User-Name: 0PZjN-_ayr83S-nc6q...Mt85`
    - In Access-Reject:
      `Reply-Message: Login for 0PZjN-_ayr83S-nc6q...Mt85 failed!`
  - The client does not need to support or parse these attributes.