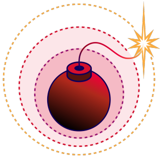
Blast-RADIUS

Breaking Enterprise Network Authentication

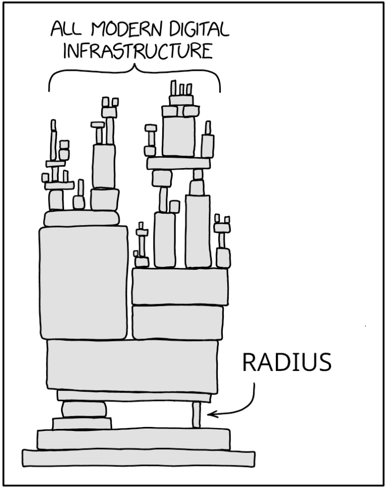
Sharon Goldberg[1], **Miro Haller**[2], Nadia Heninger[2], Mike Milano[3], Dan Shumow[4],
Marc Stevens[5], Adam Suhl[2]

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

RealWorldCrypto; March 26, 2025



What is RADIUS? Where is it used?



modified XKCD from [7]

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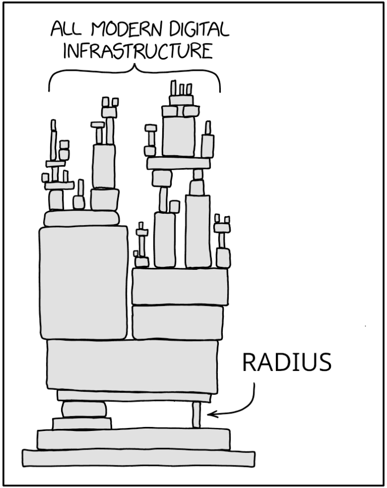

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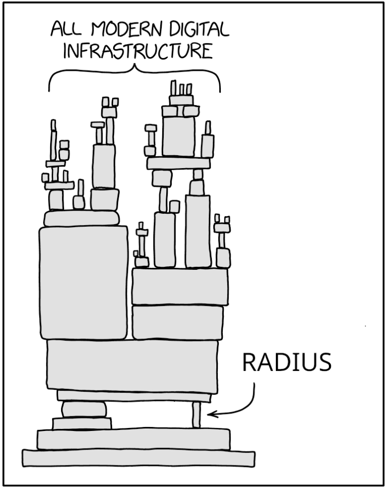

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- *RADIUS:* standard protocol for enterprise network authentication.
- RADIUS is *everywhere*:

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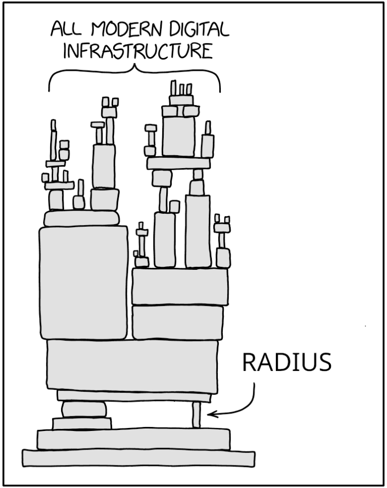

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- Used for backbone routers, non-cable ISP, IoT devices, identity providers (Okta, Duo), 802.1X, enterprise WiFi, eduroam...

Blast-RADIUS on a Single Slide

Blast-RADIUS on a Single Slide

How does RADIUS work?

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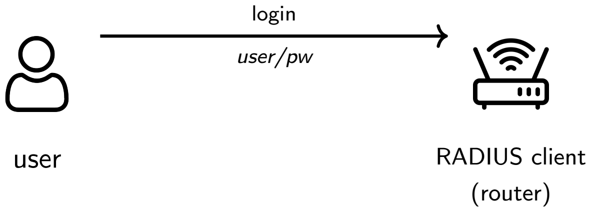

login

user/pw

user

RADIUS client
(router)

icons from [5]

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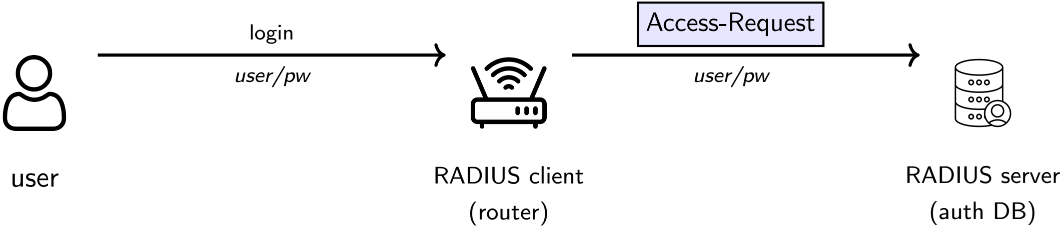

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Access-Request

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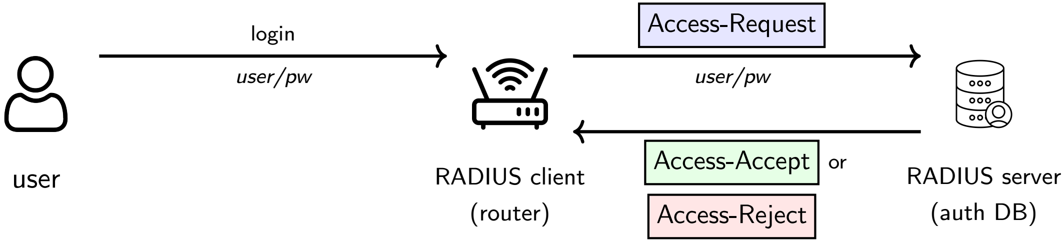

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Access-Accept or

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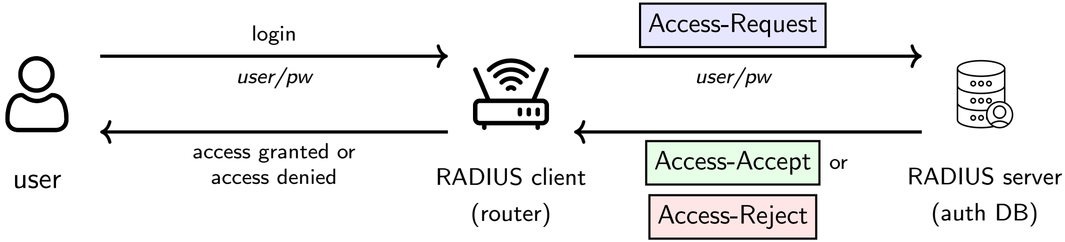

login

user/pw

access granted or access denied

user

Access-Request

user/pw

Access-Accept or

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RADIUS client (router)

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icons from [5]

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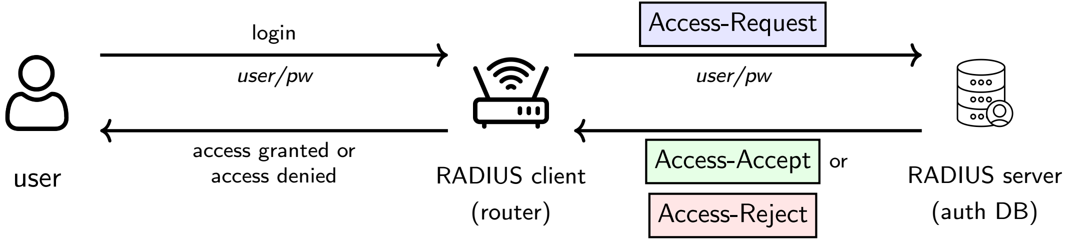

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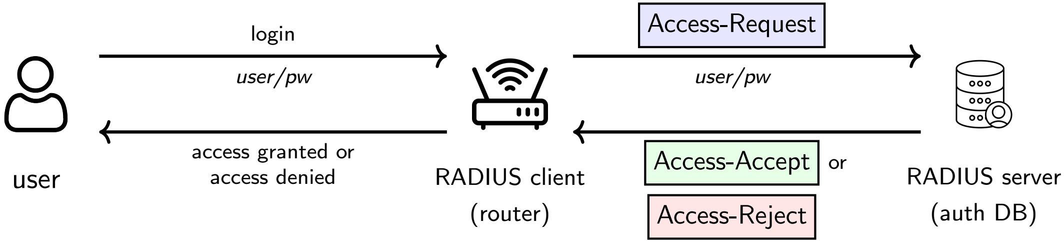

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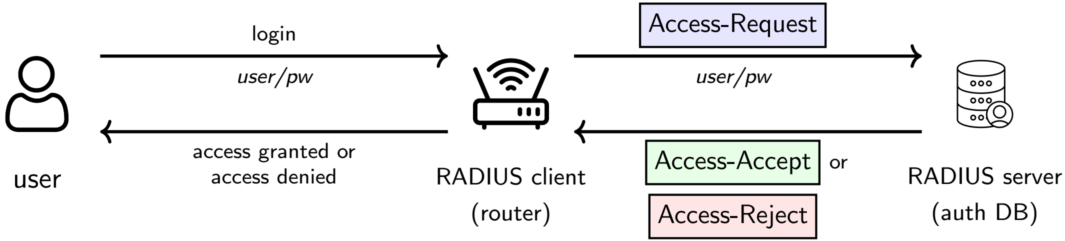

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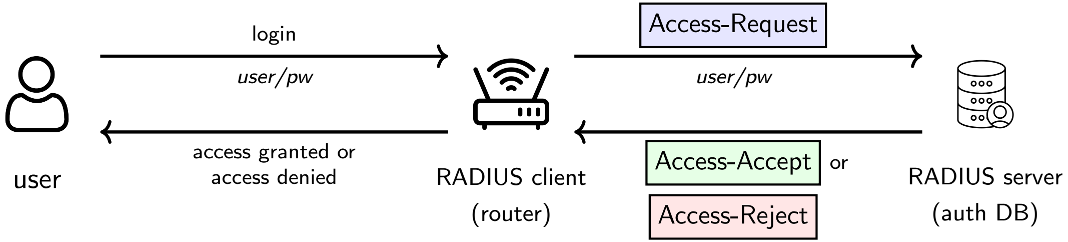

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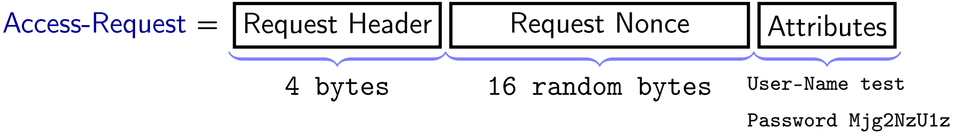
- *Impact:* authenticate as any user; accelerate RADIUS/UDP deprecation.
- *Mitigation:* responsible disclosure with over 90 vendors (incl. Cisco, Microsoft, ...).

icons from [5]

THE RADIUS PROTOCOL

RADIUS Packet Formats



Access-Request = Request Header | Request Nonce | Attributes

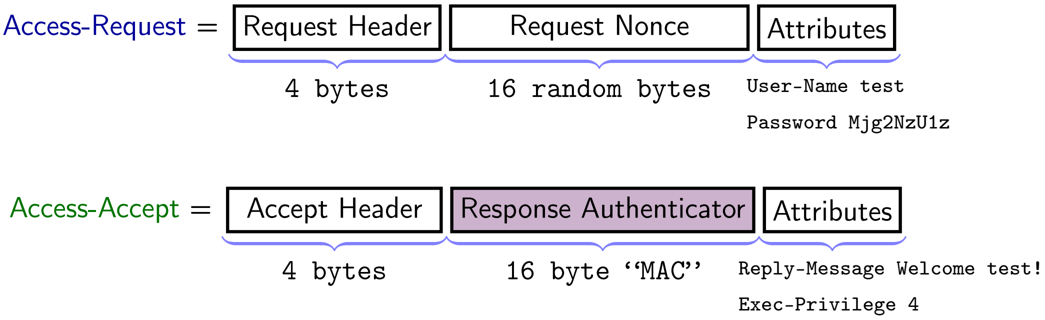
Request Header: `4 bytes`

Request Nonce: `16 random bytes`

Attributes:

```
User-Name test
Password Mjg2NzU1z
```

RADIUS Packet Formats



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Access-Accept = Accept Header | Response Authenticator | Attributes

4 bytes

16 byte ‘‘MAC’’

`Reply-Message Welcome test!`

`Exec-Privilege 4`

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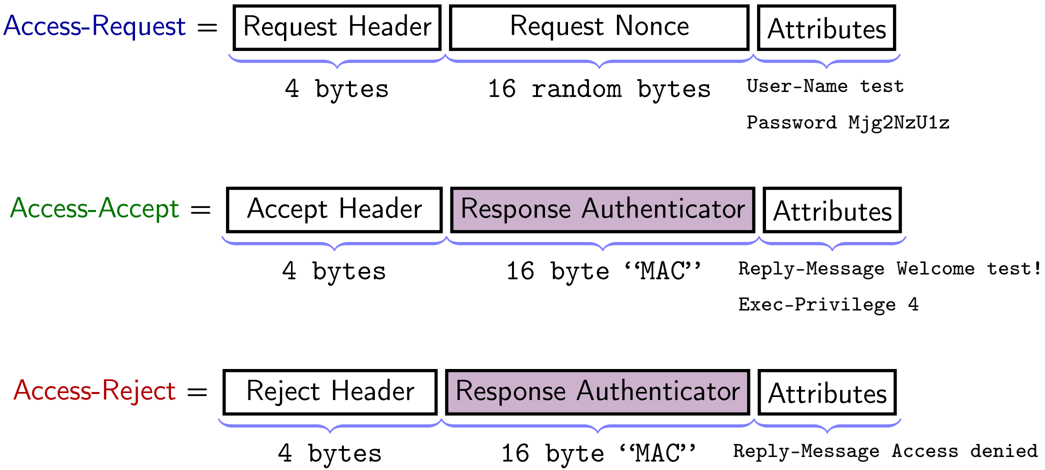

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Access-Accept = Accept Header | Response Authenticator | Attributes

- Accept Header: 4 bytes
- Response Authenticator: 16 byte “MAC”
- Attributes:

```
Reply-Message Welcome test!
Exec-Privilege 4
```

Access-Reject = Reject Header | Response Authenticator | Attributes

- Reject Header: 4 bytes
- Response Authenticator: 16 byte “MAC”
- Attributes:

```
Reply-Message Access denied
```

Response Authenticator

Goal: Prevent forgery of packets (e.g., by MITM attacker).

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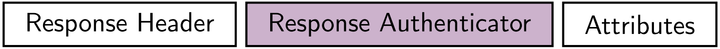
The Response Authenticator from packet



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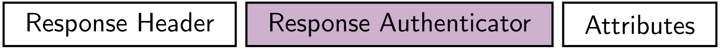

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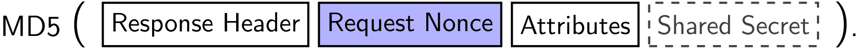

MD5 (Response Header | Request Nonce | Attributes | Shared Secret).

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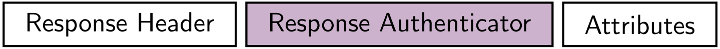
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Attributes

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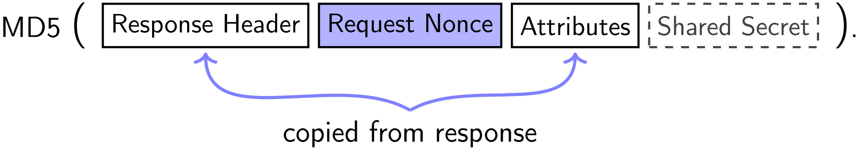
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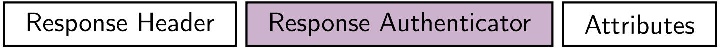

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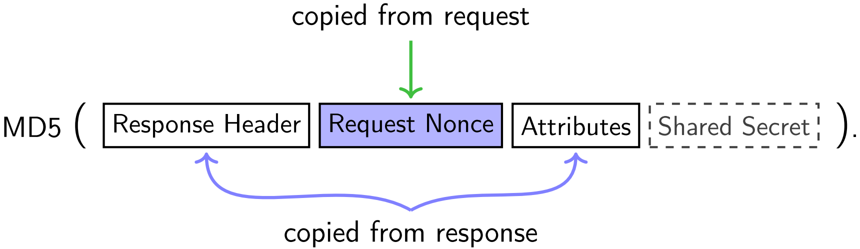

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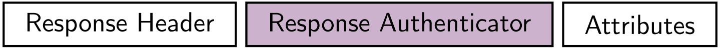

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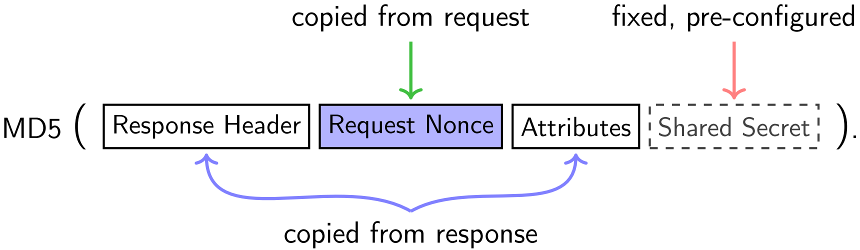

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fixed, pre-configured

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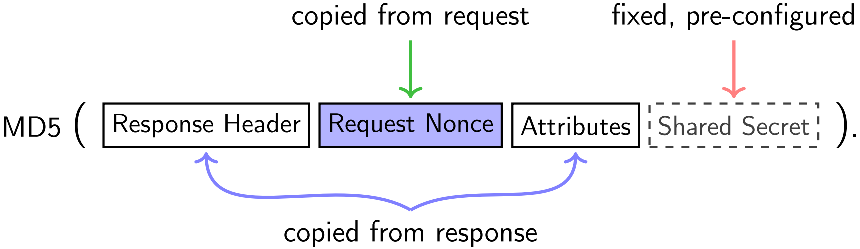

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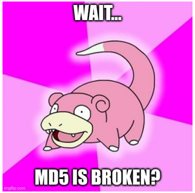

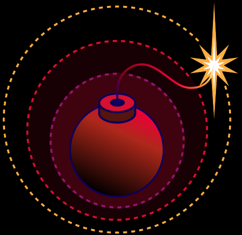

THE BLAST-RADIUS ATTACK

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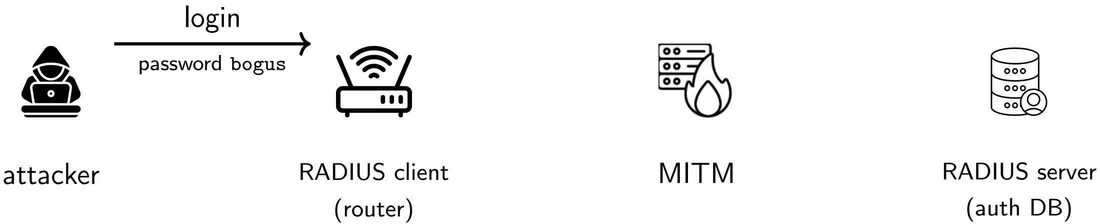

login

password bogus

attacker

RADIUS client
(router)

MITM

RADIUS server
(auth DB)

icons from [5]

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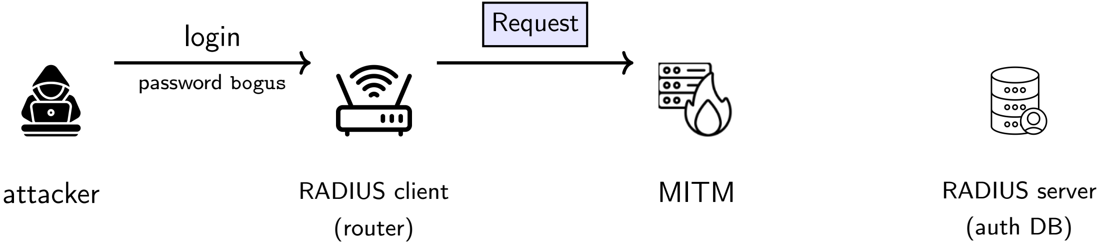

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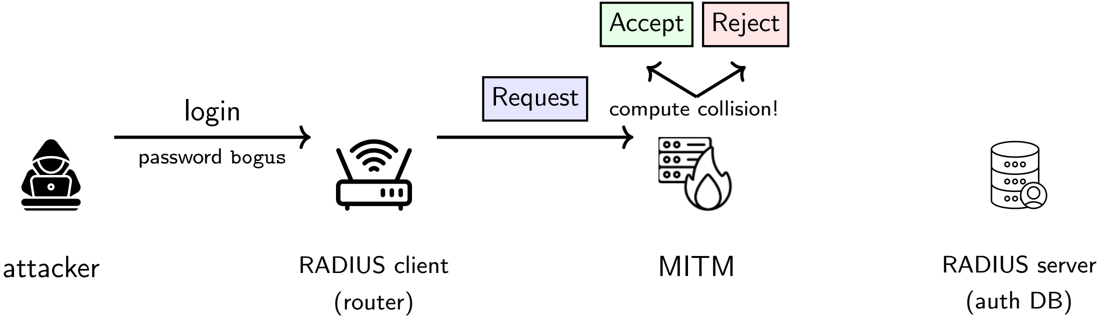

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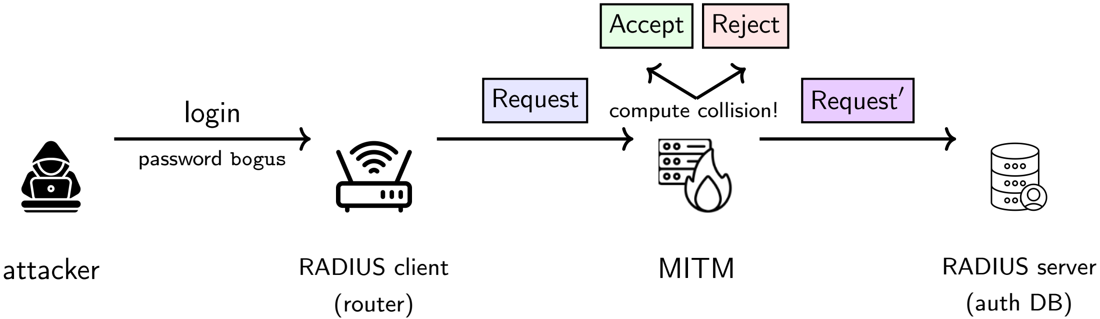

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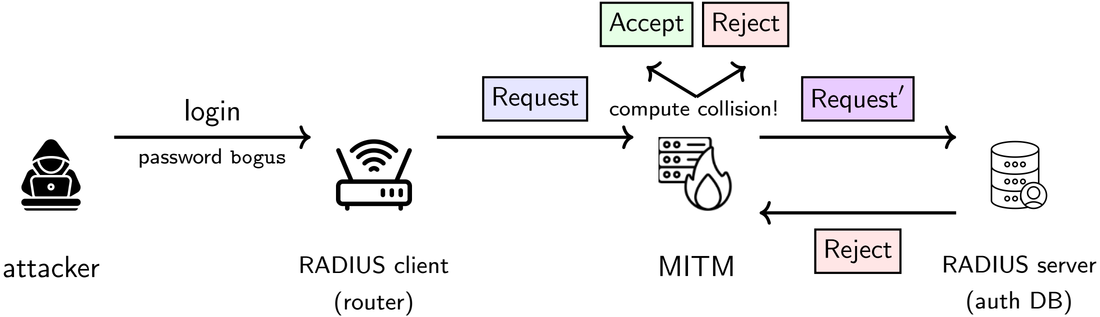

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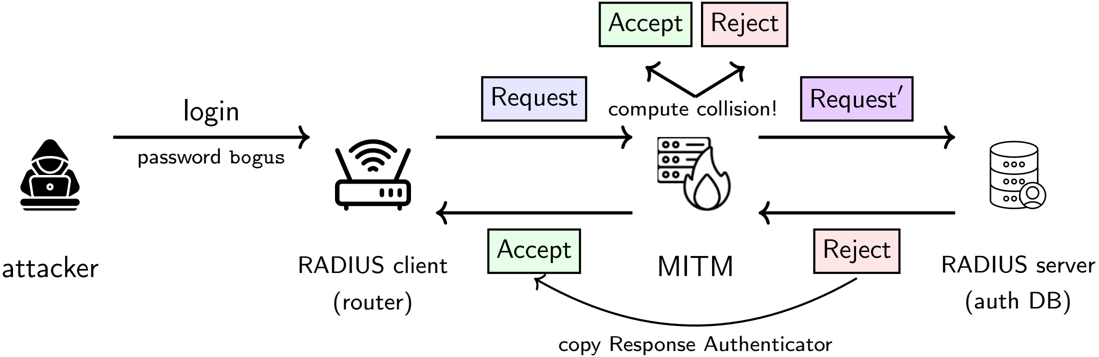

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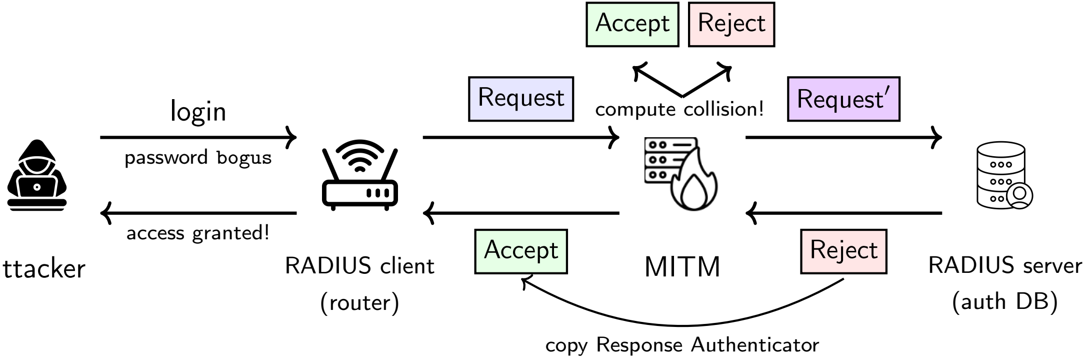

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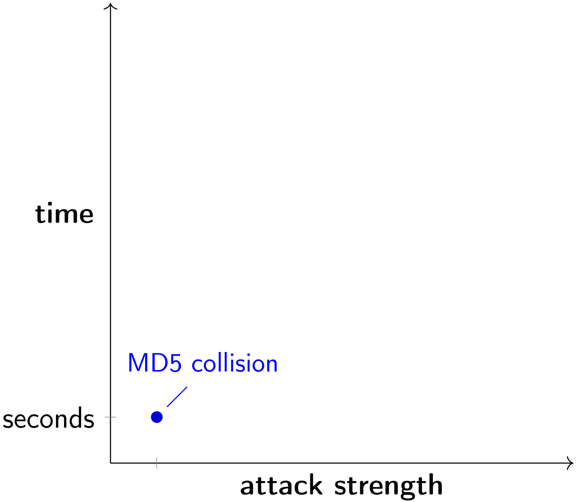
Recap of MD5 Collisions



2004: MD5 collision [14]

Produce unstructured strings G_1, G_2 such that

$$\mathrm{MD5}(G_1) = \mathrm{MD5}(G_2).$$

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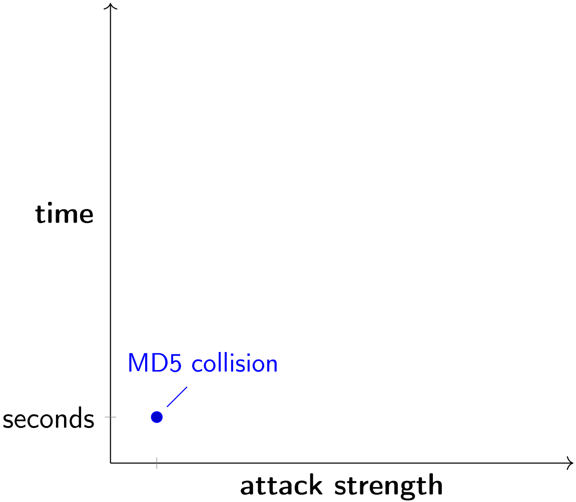

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MD5 IS NOT COLLISION-RESISTANT
BUT IT'S STILL OK IN PRACTICE, RIGHT?
imgflip.com

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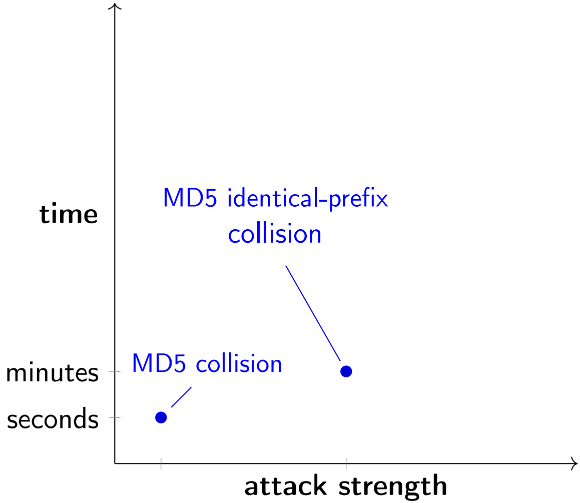

2004: Identical-prefix collision [14]

Given prefix P, produce G_1, G_2 such that

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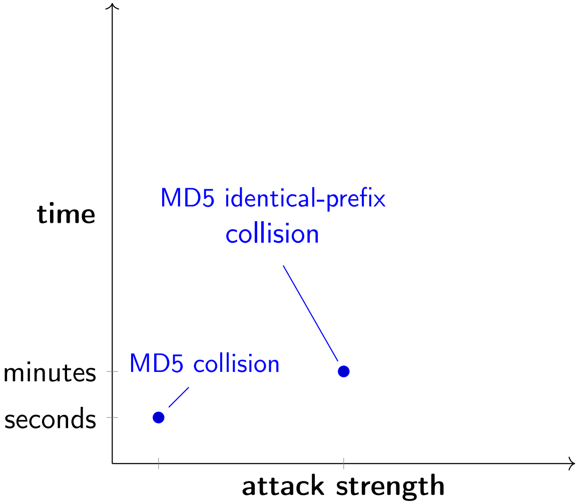

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famous non-MD5 example of an identical-prefix collision [10]

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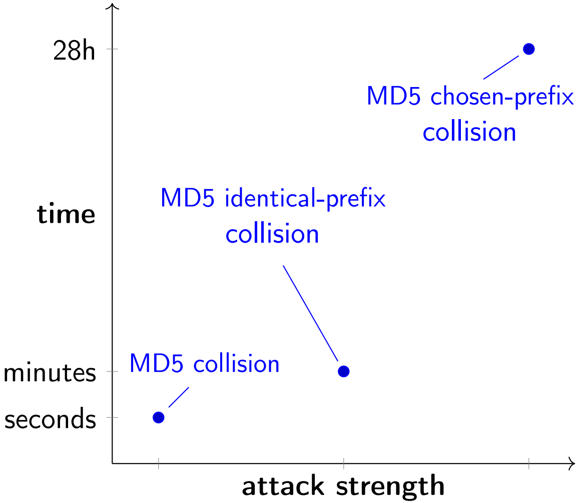

2007: MD5 chosen-prefix collision [11]

Given prefixes P_1, P_2, produce G_1, G_2 such that

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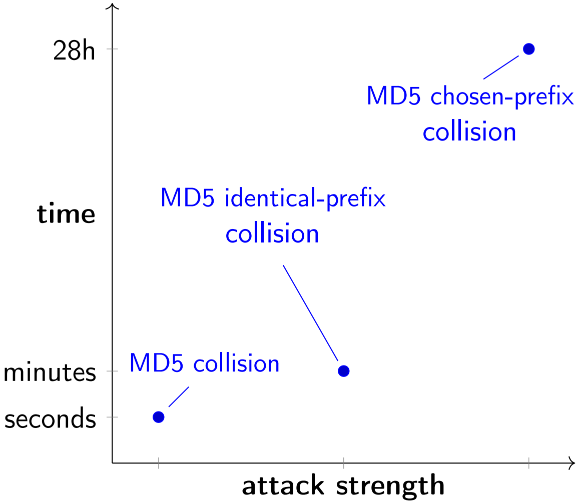
Recap of MD5 Collisions



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215 PS3 for Rogue TLS CA cert [12]

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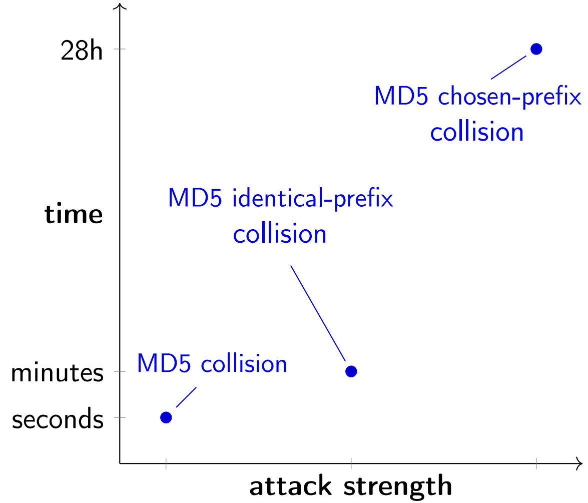

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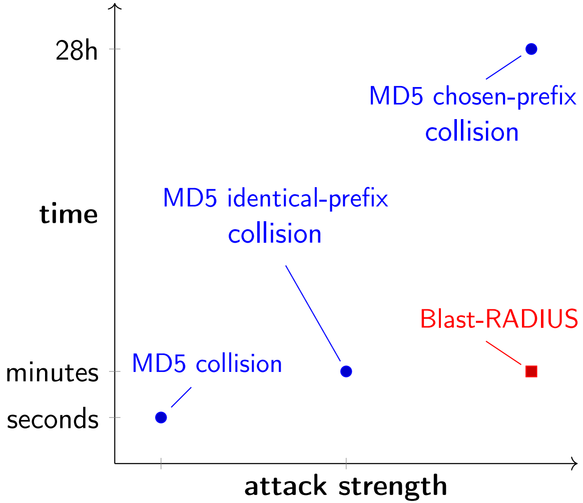
Due to Merkle-Damgård structure of MD5, can append identical suffix S:

$$\mathrm{MD5}(P_1||G_1||S) = \mathrm{MD5}(P_2||G_2||S).$$

Recap of MD5 Collisions



2024: Blast-RADIUS

A chosen-prefix collision:*
Given prefixes P_1, P_2, produce G_1, G_2 such that (for any suffix S)

$$\mathrm{MD5}(P_1 || G_1 || S) = \mathrm{MD5}(P_2 || G_2 || S).$$

*But faster and with some additional conditions!

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

Attack: MD5 collision to forge Access-Accept with same Response Authenticator as Access-Reject (without knowledge of the shared secret).

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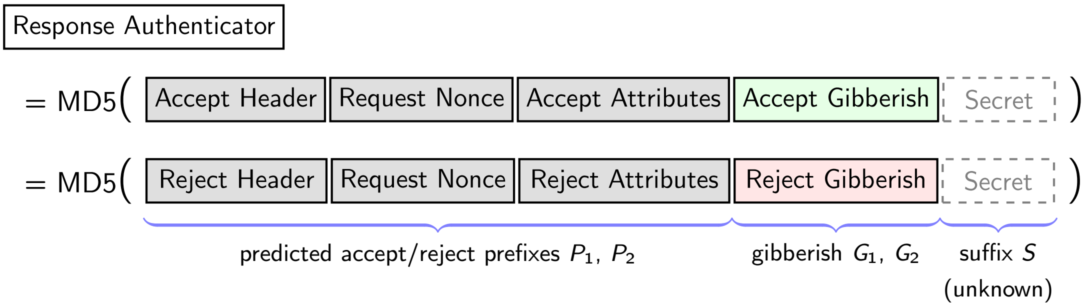
MD5 chosen-prefix collision $\mathrm{MD5}(P_1||G_1||S) = \mathrm{MD5}(P_2||G_2||S)$ applied to RADIUS:



Response Authenticator

= MD5(Accept Header | Request Nonce | Accept Attributes | Accept Gibberish | Secret)

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

predicted accept/reject prefixes P_1, P_2

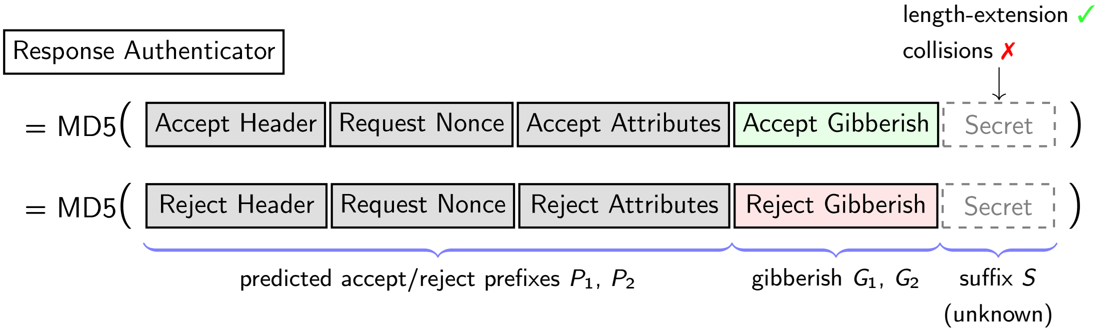
gibberish G_1, G_2

suffix S (unknown)

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

Attack: MD5 collision to forge Access-Accept with same Response Authenticator as Access-Reject (without knowledge of the shared secret).

MD5 chosen-prefix collision $\mathrm{MD5}(P_1||G_1||S) = \mathrm{MD5}(P_2||G_2||S)$ applied to RADIUS:



length-extension ✓

collisions ✗

Response Authenticator

= MD5(Accept Header | Request Nonce | Accept Attributes | Accept Gibberish | Secret)

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

predicted accept/reject prefixes P_1, P_2

gibberish G_1, G_2

suffix S (unknown)

Easy, all done?

"While MD5 has been broken, it is a testament to the design of RADIUS that there have been (as yet) no attacks on RADIUS Authenticator signatures which are stronger than brute-force."

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

Challenge 1: Inject MD5 Reject Gibberish In Protocol

Problem: Server must include $\boxed{\text{Reject Gibberish}}$ in Response Authenticator computation for Access-Reject.

$$\text{MD5}\Big(\ \boxed{\text{Reject Header}}\boxed{\text{Request Nonce}}\boxed{\text{Reject Gibberish}}\boxed{\text{Shared Secret}}\ \Big)$$

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Solution: 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.*
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> *(RFC 2058, emphasis added)*

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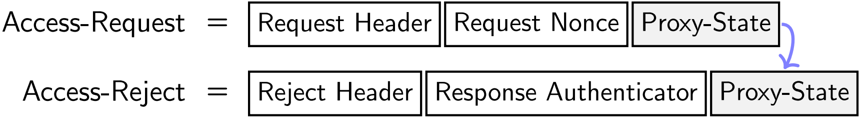

Access-Request = Request Header | Request Nonce | Proxy-State

Access-Reject = Reject Header | Response Authenticator | Proxy-State

Challenge 2: Fitting Gibberish Into Protocol Attributes

Problem: Hiding Reject Gibberish in single Proxy-State attribute is too slow.

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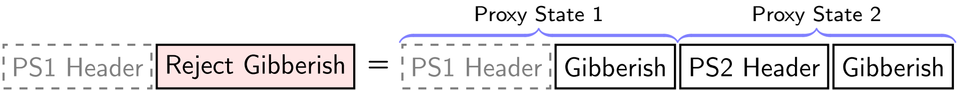
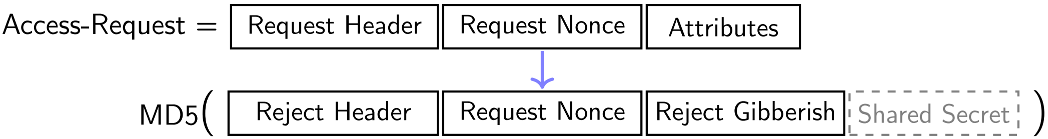
Solution: Spread longer gibberish across multiple Proxy-State attributes by modifying collision algorithm to embed Proxy-State header.



(PS1 Header is part of the MD5 prefix not the gibberish.)

Challenge 3: Fast Collision Computation



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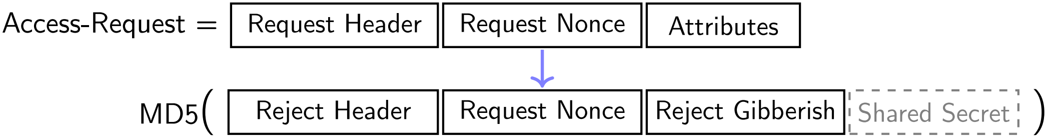

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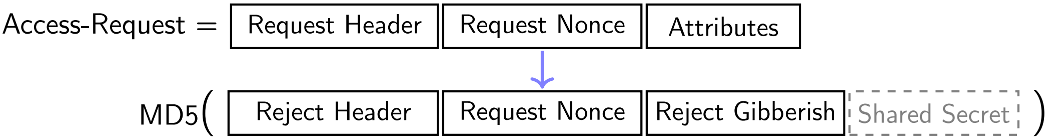

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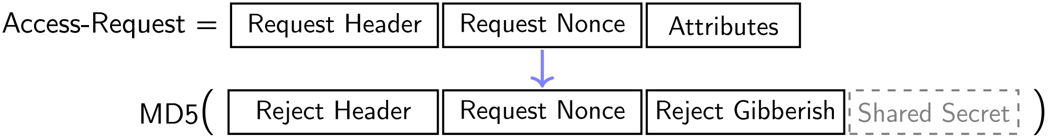

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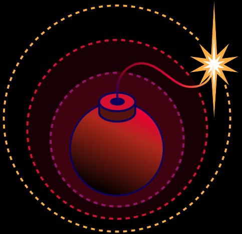
Can you go faster? Yes, attack parallelizes well, hardware implementation.



IMPACT & MITIGATION

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Affected authentication modes:

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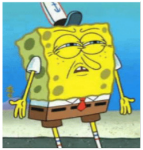
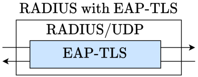
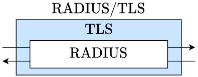




RADIUS with EAP-TLS

RADIUS/UDP

EAP-TLS



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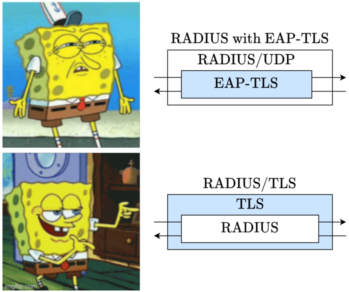

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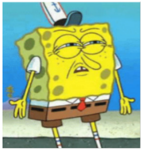

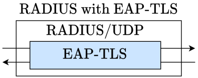

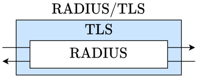

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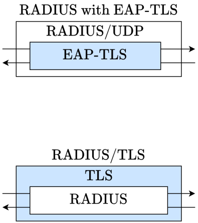
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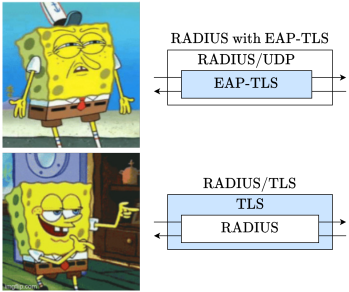

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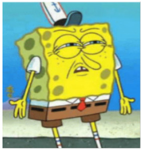
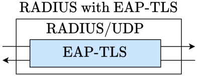
- RADIUS/UDP traffic over VLAN/IPSEC: useful for lateral movement.





RADIUS with EAP-TLS

RADIUS/UDP

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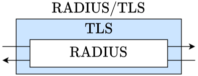

RADIUS/TLS

TLS

RADIUS

Mitigations

Massive disclosure with 90+ vendors.

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Long-term:

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Mitigations Trouble

Many equipment vendors have upgraded [2], but some challenges remain:

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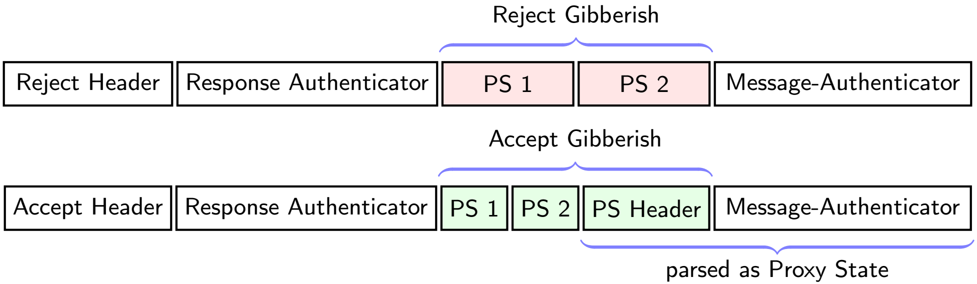
Many equipment vendors have upgraded [2], but some challenges remain:

- Juniper vs. Cisco: incompatible Message-Authenticator placement.
- Correct behavior: put as first attribute for sending, mandate presence for receiving.
- Incorrect placement may be vulnerable to **Message-Authenticator hiding attack**:



Blast-RADIUS Attack

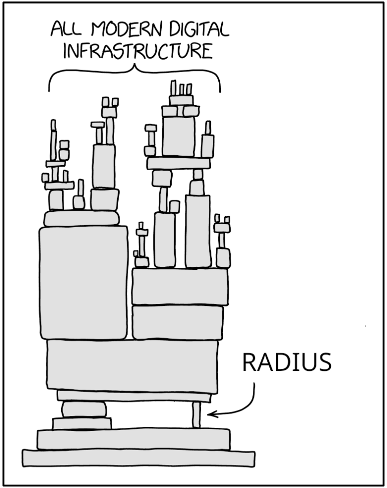
Attack summary: MD5 collision attack on RADIUS authentication by MITM adversary.

`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.

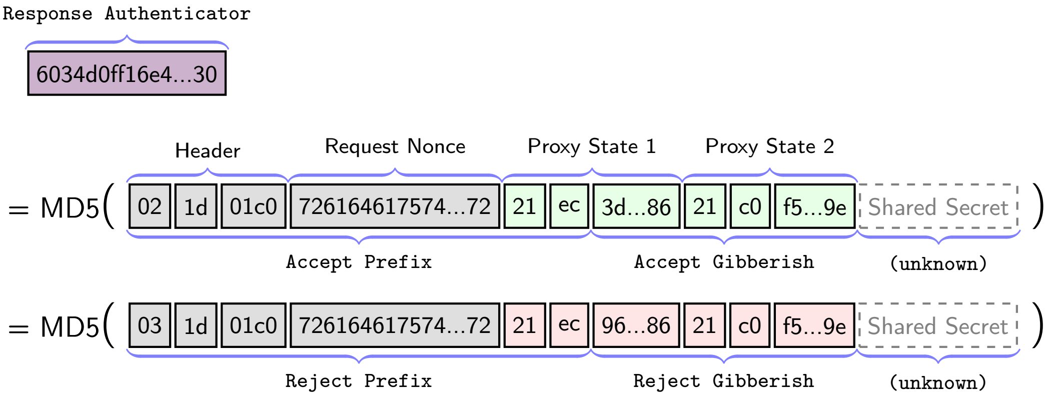


XKCD modified from [7]

BONUS MATERIAL

Blast-RADIUS: Example

As concrete example, putting everything together, we get the following collision.



Response Authenticator

6034d0ff16e4…30

Header

Request Nonce

Proxy State 1

Proxy State 2

= MD5(02 | 1d | 01c0 | 726164617574…72 | 21 | ec | 3d…86 | 21 | c0 | f5…9e | Shared Secret)

Accept Prefix

Accept Gibberish

(unknown)

= MD5(03 | 1d | 01c0 | 726164617574…72 | 21 | ec | 96…86 | 21 | c0 | f5…9e | Shared Secret)

Reject Prefix

Reject Gibberish

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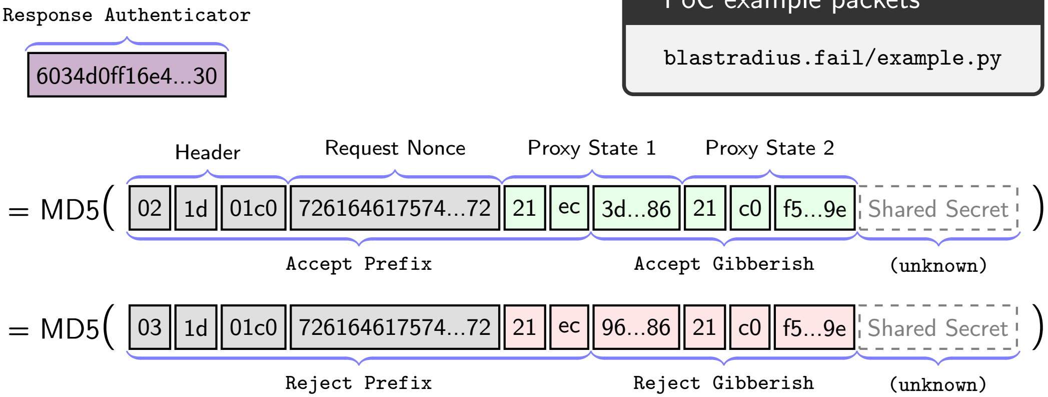
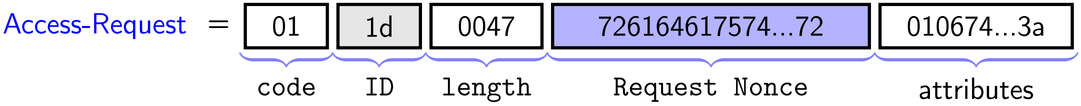


PoC example packets

`blastradius.fail/example.py`

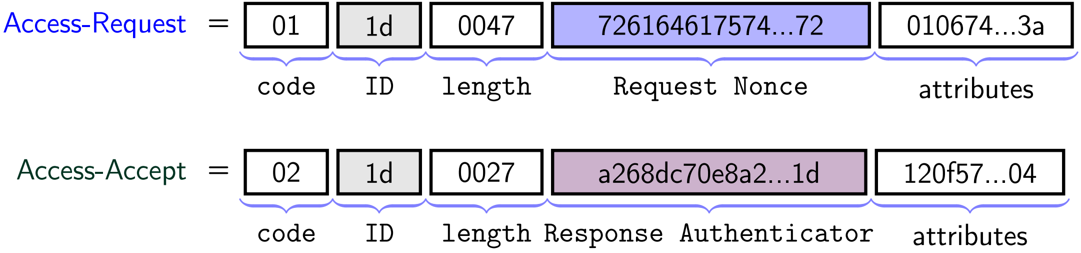
End-to-End Example Attack (1/4)



Access-Request = 01 1d 0047 726164617574...72 010674...3a

code ID length Request Nonce attributes

End-to-End Example Attack (1/4)



Access-Request = 01 | 1d | 0047 | 726164617574...72 | 010674...3a

code | ID | length | Request Nonce | attributes

Access-Accept = 02 | 1d | 0027 | a268dc70e8a2...1d | 120f57...04

code | ID | length | Response Authenticator | attributes

End-to-End Example Attack (1/4)

Access-Request	=	01	1d	0047	726164617574...72	010674...3a
		code	ID	length	Request Nonce	attributes
Access-Accept	=	02	1d	0027	a268dc70e8a2...1d	120f57...04
		code	ID	length	Response Authenticator	attributes
Access-Reject	=	03	1d	0024	357bf27e8c0a...e5	121041...2e
		code	ID	length	Response Authenticator	attributes

End-to-End Example Attack (2/4)

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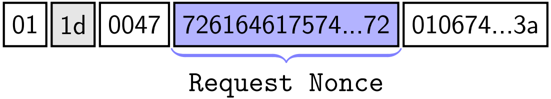

01	1d	0047	726164617574...72	010674...3a

Request Nonce

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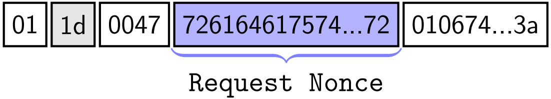

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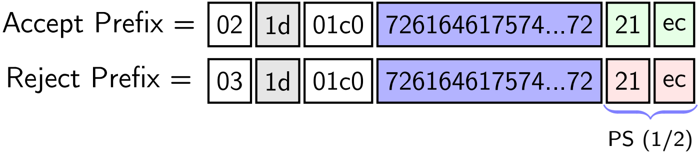

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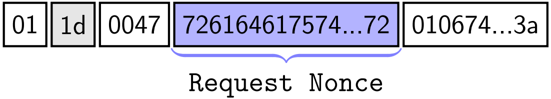

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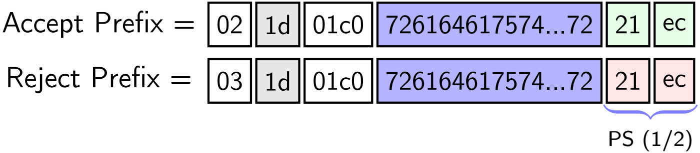
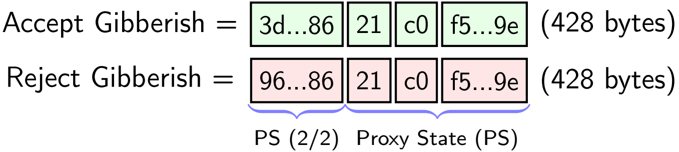


Accept Prefix = 02 | 1d | 01c0 | 726164617574...72 | 21 | ec

Reject Prefix = 03 | 1d | 01c0 | 726164617574...72 | 21 | ec

PS (1/2)

to compute the MD5 chosen-prefix collision gibberish.



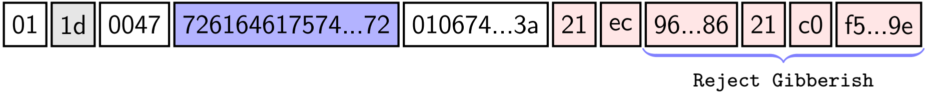
Accept Gibberish = 3d...86 | 21 | c0 | f5...9e (428 bytes)

Reject Gibberish = 96...86 | 21 | c0 | f5...9e (428 bytes)

PS (2/2) Proxy State (PS)

End-to-End Example Attack (3/4)

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



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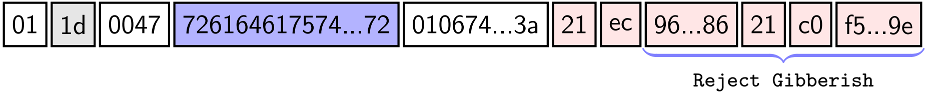
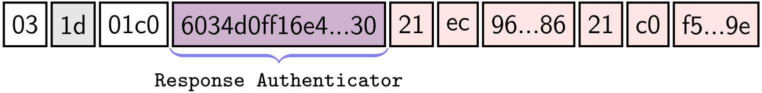


01	1d	0047	726164617574...72	010674...3a	21	ec	96...86	21	c0	f5...9e

`Reject Gibberish`

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



03	1d	01c0	6034d0ff16e4...30	21	ec	96...86	21	c0	f5...9e

`Response Authenticator`

End-to-End Example Attack (3/4)

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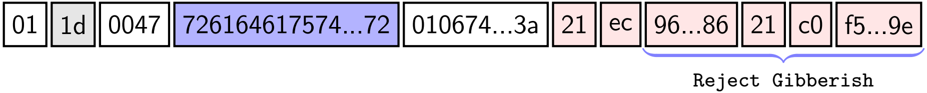

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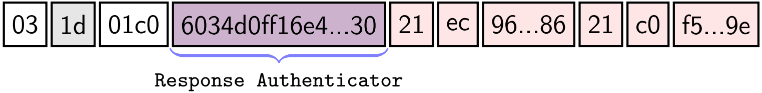
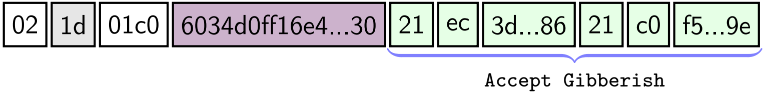


03	1d	01c0	6034d0ff16e4...30	21	ec	96...86	21	c0	f5...9e

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



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End-to-End Example Attack (4/4)

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

End-to-End Example Attack (4/4)

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

$$\overbrace{\boxed{\text{6034d0ff16e4...30}}}^{\texttt{Response Authenticator}}$$

$$= \mathrm{MD5}\Big(\underbrace{\boxed{02}\,\boxed{1d}\,\boxed{01c0}\,\boxed{726164617574...72}\,\boxed{21}\,\boxed{ec}}_{\texttt{Accept Prefix}}\,\underbrace{\boxed{3d...86}\,\boxed{21}\,\boxed{c0}\,\boxed{f5...9e}}_{\texttt{Accept Gibberish}}\,\underbrace{\boxed{\text{Shared Secret}}}_{\texttt{(unknown)}}\Big)$$

$$= \mathrm{MD5}\Big(\underbrace{\boxed{03}\,\boxed{1d}\,\boxed{01c0}\,\boxed{726164617574...72}\,\boxed{21}\,\boxed{ec}}_{\texttt{Reject Prefix}}\,\underbrace{\boxed{96...86}\,\boxed{21}\,\boxed{c0}\,\boxed{f5...9e}}_{\texttt{Reject Gibberish}}\,\underbrace{\boxed{\text{Shared Secret}}}_{\texttt{(unknown)}}\Big)$$

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⟹ Confirms no Message-Authenticator used, Proxy-State accepted in Access-Accept.

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EAP: It's Complicated.

- TLS in EAP-TLS does not protect RADIUS packets.
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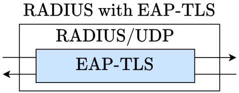

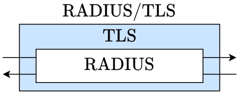

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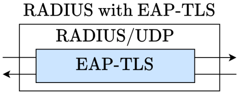
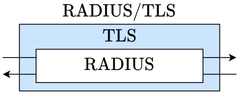


RADIUS with EAP-TLS

RADIUS/UDP

EAP-TLS



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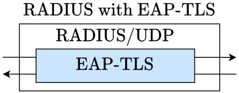

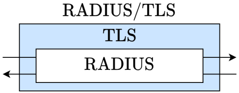

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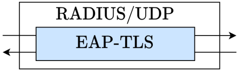
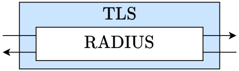
- In eduroam and 802.1X, key is negotiated inside EAP session $\implies$ would require further attacks.

RADIUS with EAP-TLS



RADIUS/TLS

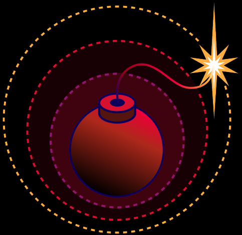


Attack Extensions

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

$$\text{AcceptPrefix} = \boxed{02}\,\boxed{1d}\,\boxed{01c0}\,\boxed{726164617574...72}\,\underbrace{\boxed{1a0b000007db1d04}}_{\substack{\text{Attribute:} \\ \texttt{Exec-Privilege 04}}}\,\boxed{21}\,\boxed{ec}$$

- Proxy-State attributes are *not* the only way to inject the `RejectGibberish`.
  - Any reflected user input could work, e.g. 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.



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