Dragonblood: Analyzing the Dragonfly Handshake of WPA3 and EAP-pwd

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ANRW. Montreal, Canada, 22 July 2019.

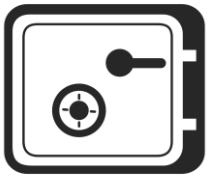
NEW YORK UNIVERSITY

Background: Dragonfly in WPA3

= Password Authenticated Key Exchange (PAKE)

Provide mutual authentication

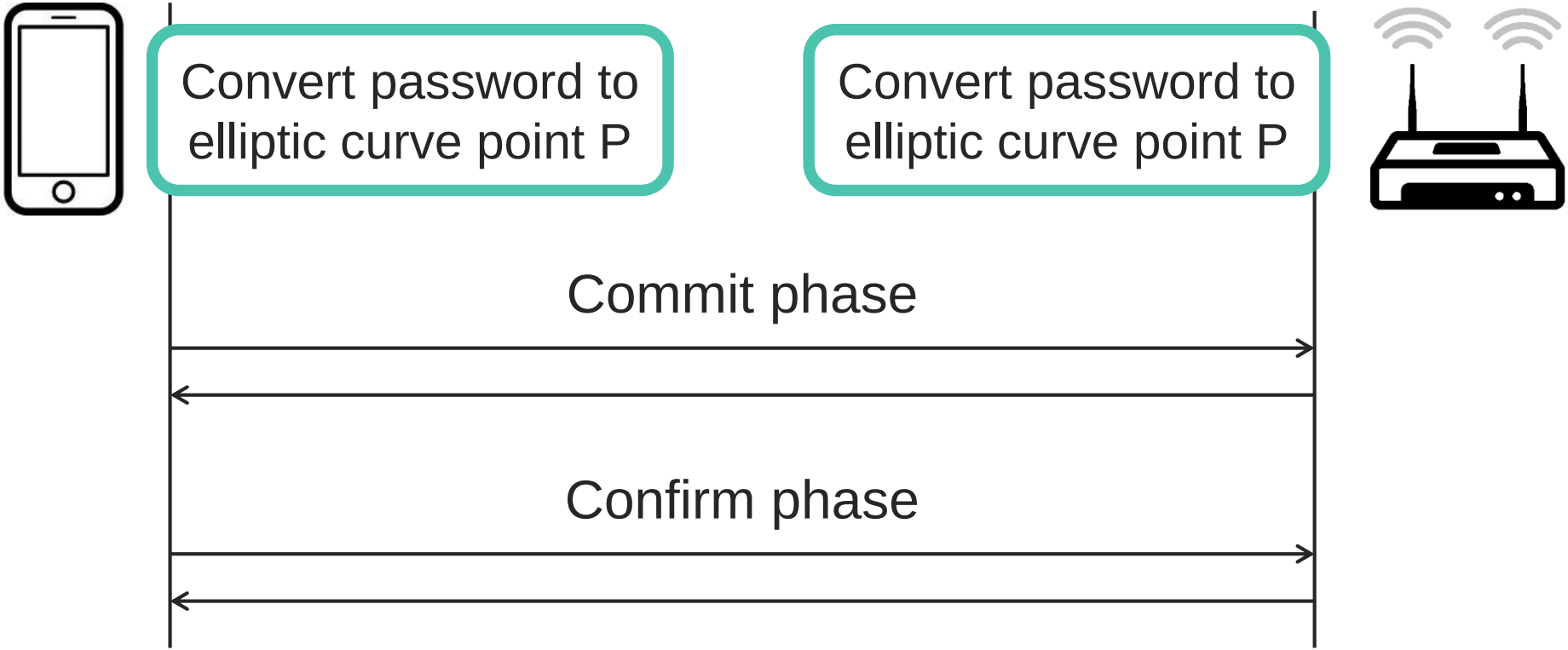
Negotiate session key



Forward secrecy & prevent offline dictionary attacks

Protect against server compromise

Dragonfly


Convert password to elliptic curve point P
Convert password to elliptic curve point P
Commit phase
Confirm phase

With MODP groups: hash-to-group

```
for (counter = 1; counter < 256; counter++)
    value = hash(pw, counter, addr1, addr2)
    if value >= p: continue
    P = value^((p-1)/q)
    if P > 1: return P
```

With MODP groups: hash-to-group

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In practice always true

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Problem: value >= p

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No timing leak countermeasures
despite warnings by IETF & CFRG!

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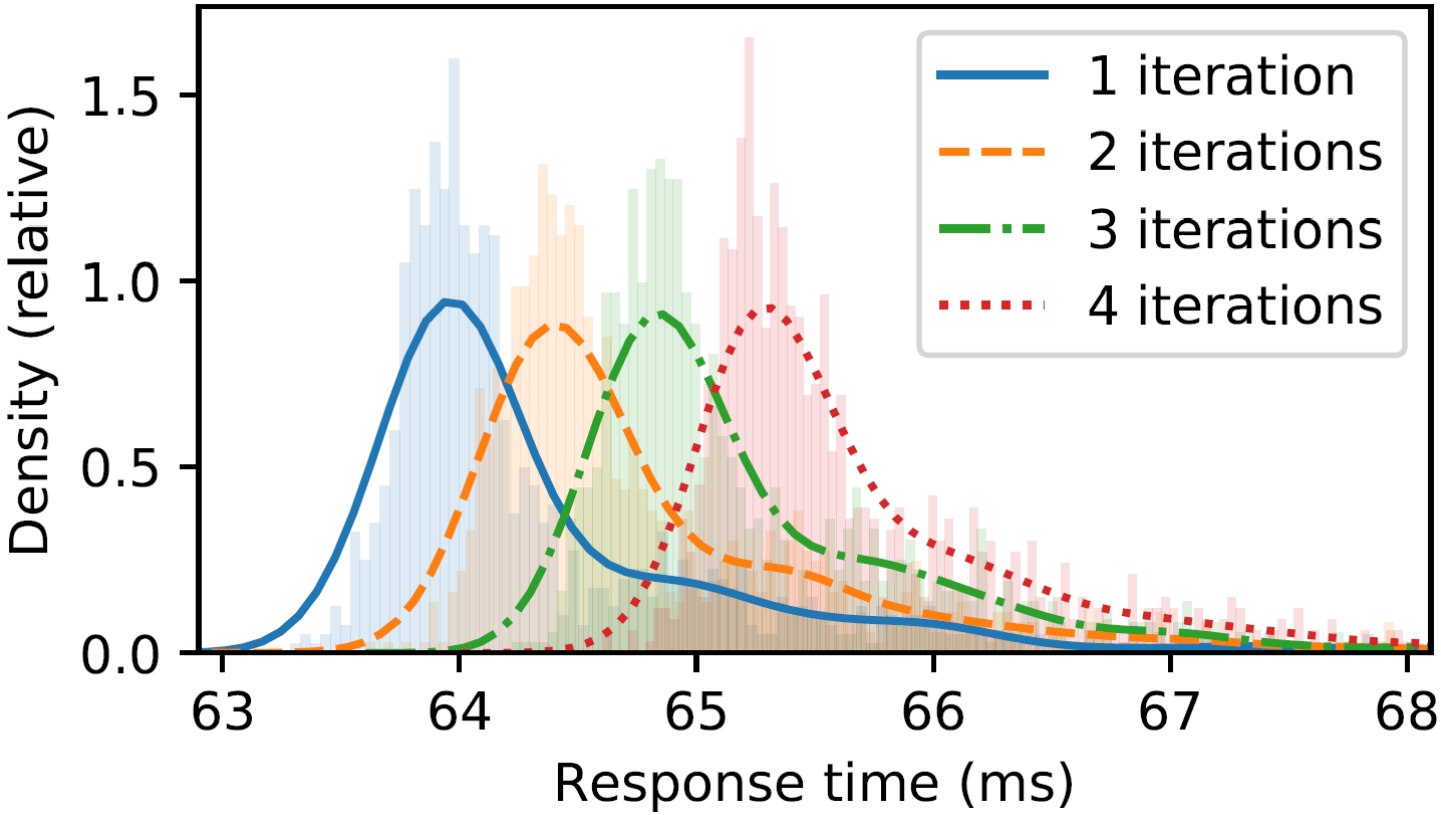
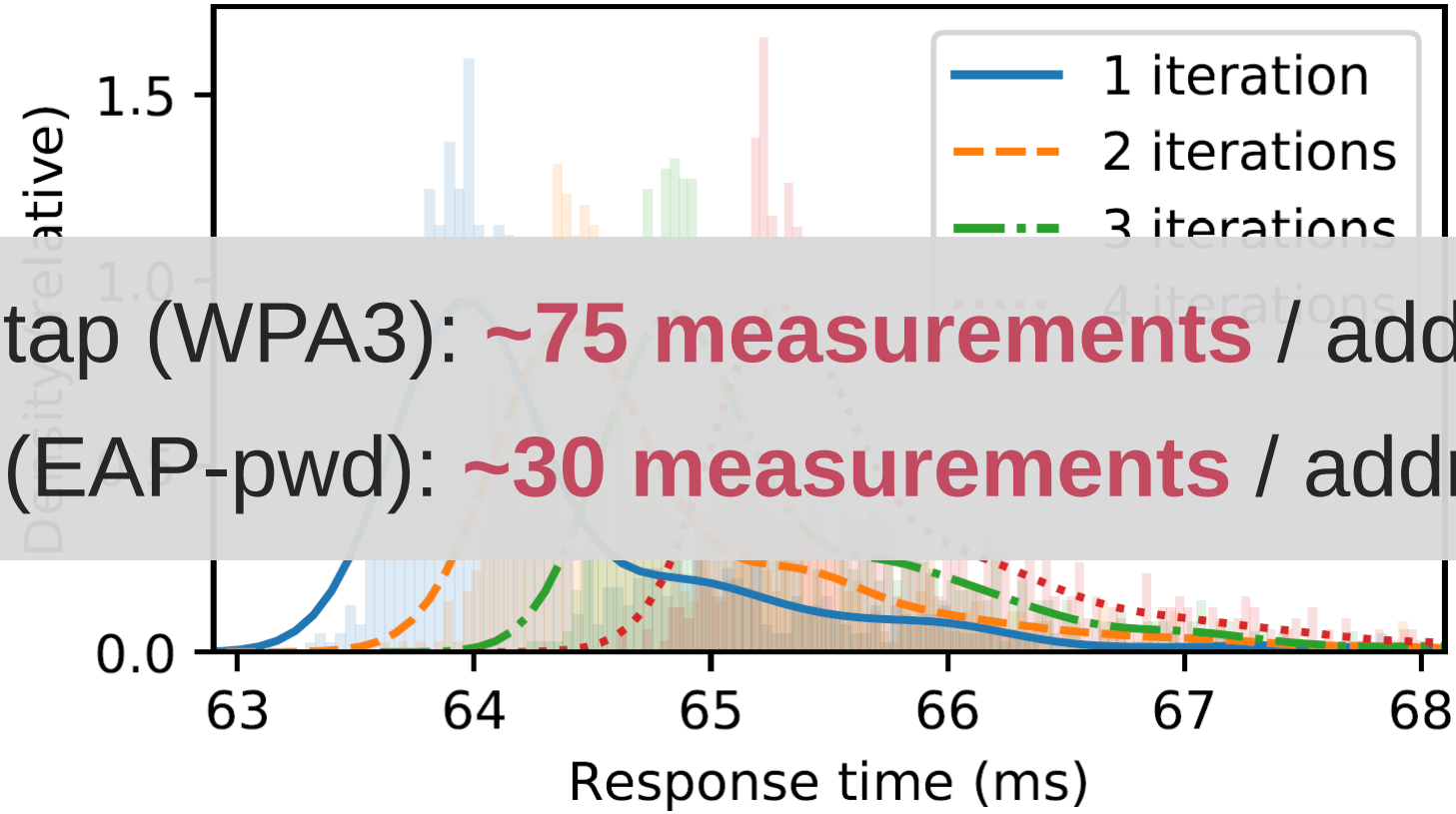
WPA3: **spoof client address** to obtain different executions

No timing leak countermeasures
despite warnings by IETF & CFRG!

Raspberry Pi 1 B+: differences are measurable



Raspberry Pi 1 B+: differences are measurable



Hostap (WPA3): **~75 measurements** / address

iwd (EAP-pwd): **~30 measurements** / address

Leaked information: #iterations needed

Client address	addrA
Measured	

Leaked information: #iterations needed

Client address	addrA
Measured	
Password 1	
Password 2	
Password 3	

Leaked information: #iterations needed

Client address	addrA
Measured	
~~Password 1~~	
Password 2	
Password 3	

Leaked information: #iterations needed

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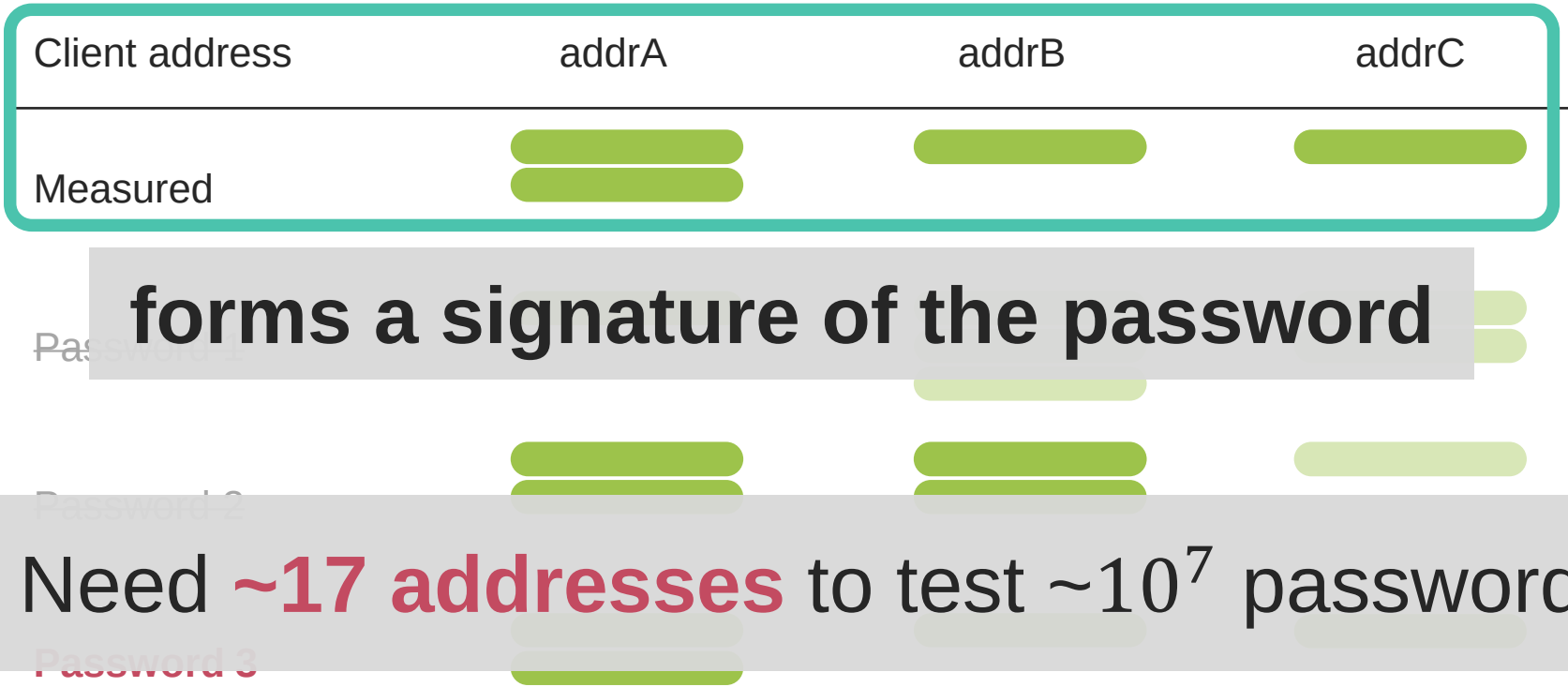

Need **~17 addresses** to test ~10^7 passwords

What about elliptic curves?

Hash-to-group with elliptic curves also affected?

- By default Dragonfly uses NIST curves
- **Timing leaks for NIST curves are mitigated**

Dragonfly also supports Brainpool curves

- After our initial disclosure, the Wi-Fi Alliace private created guidelines that mention these are secure to use
- Bad news: **Brainpool curves in Dragonfly are insecure**

Hash-to-curve

```
for (counter = 1; counter < k or not x; counter++)
    value = hash(pw, counter, addr1, addr2)
    if value >= p: continue
    y_sqr = value^3 + a * value + b
    if is_quadratic_residue(y_sqr) and not x:
        x = value
        pw = random()
y = sqrt(x^3 + a * x + b)
return (x, y)
```

Hash-to-curve

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for (counter = 1; counter < k or not x; counter++)
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Problem: no solution for y

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Problem: different passwords have different execution time

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→ Always execute at least k iterations

Hash-to-curve

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In case quadratic test is not constant time

Hash-to-curve

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return (x, y)
```

Problem: value >= p

Hash-to-curve

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for (counter = 1; counter < 2^len; counter++)
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    if value >= p: continue
    y_sqr = value^3 + a * value + b
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May be true for Brainpool curves!

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Quadratic test may be skipped

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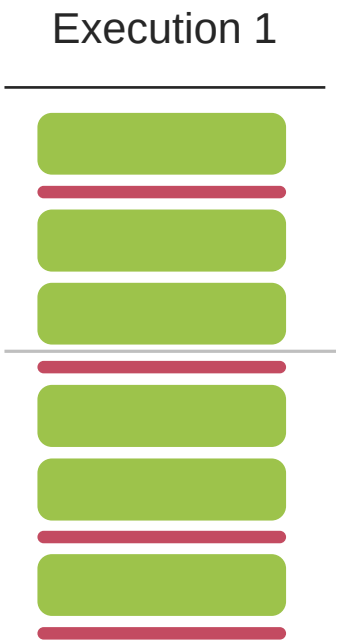
A random #(extra iterations) have a too big hash output

Influence of extra iterations



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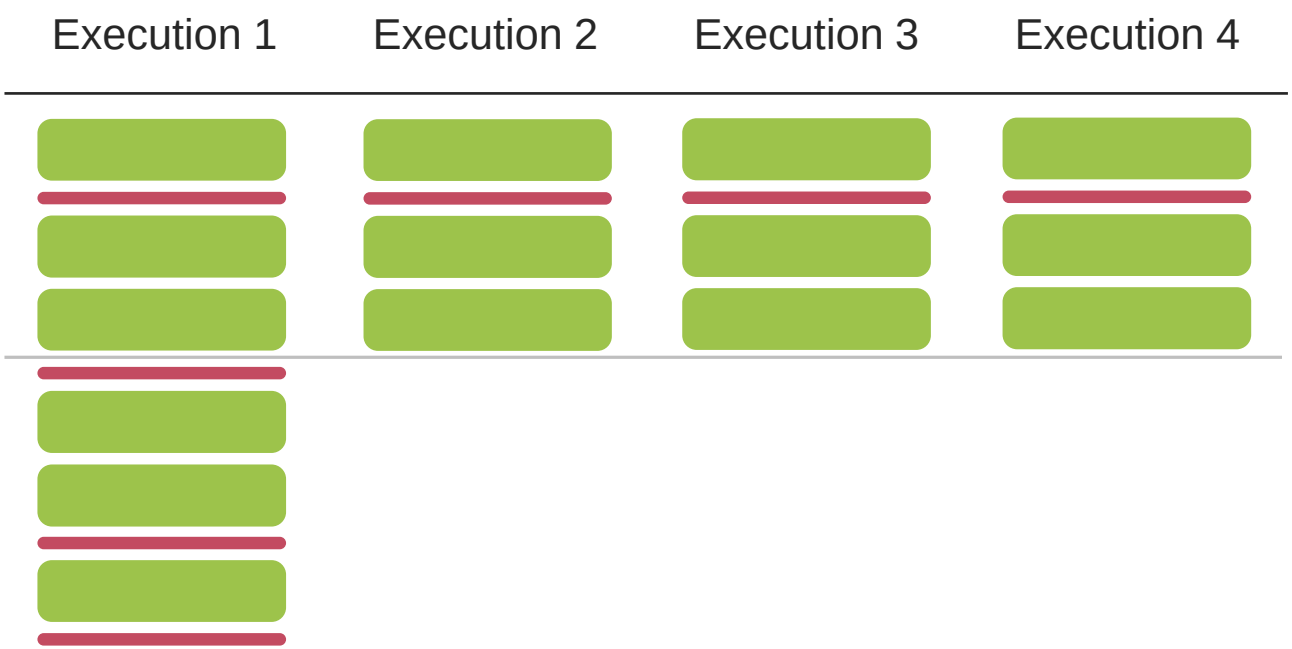

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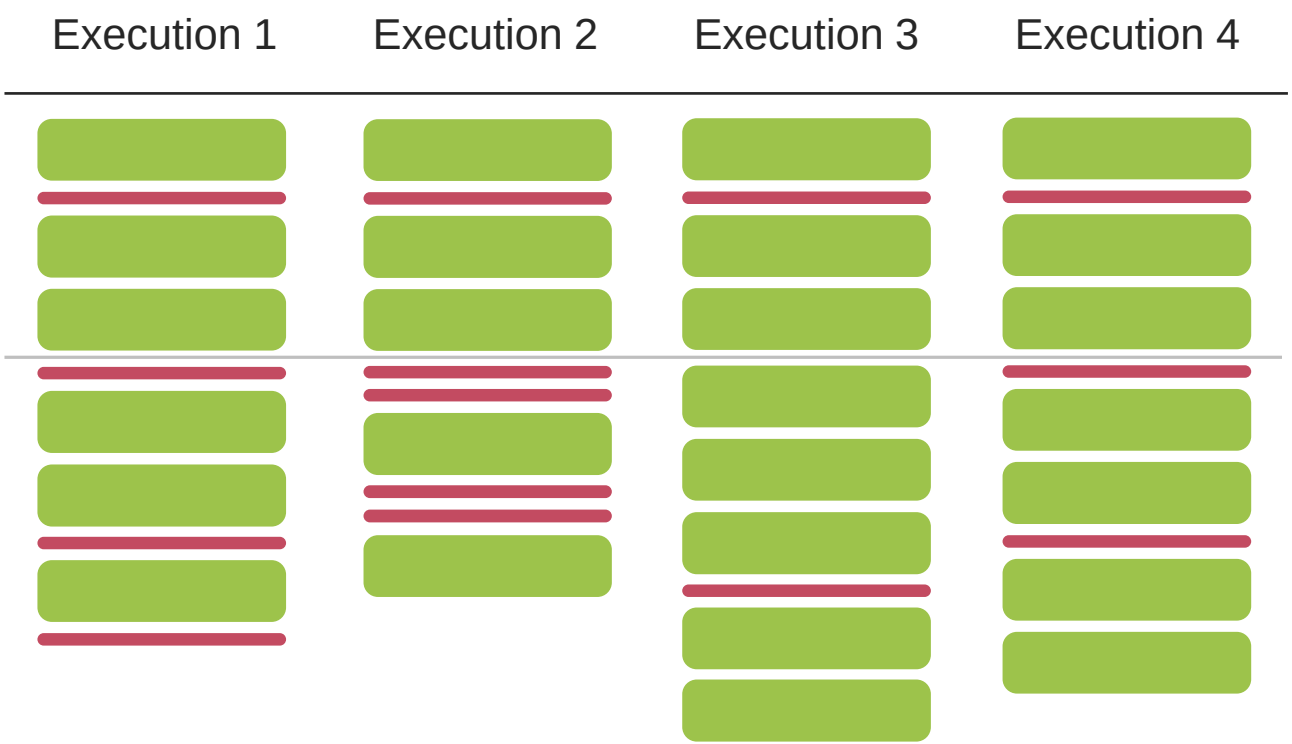

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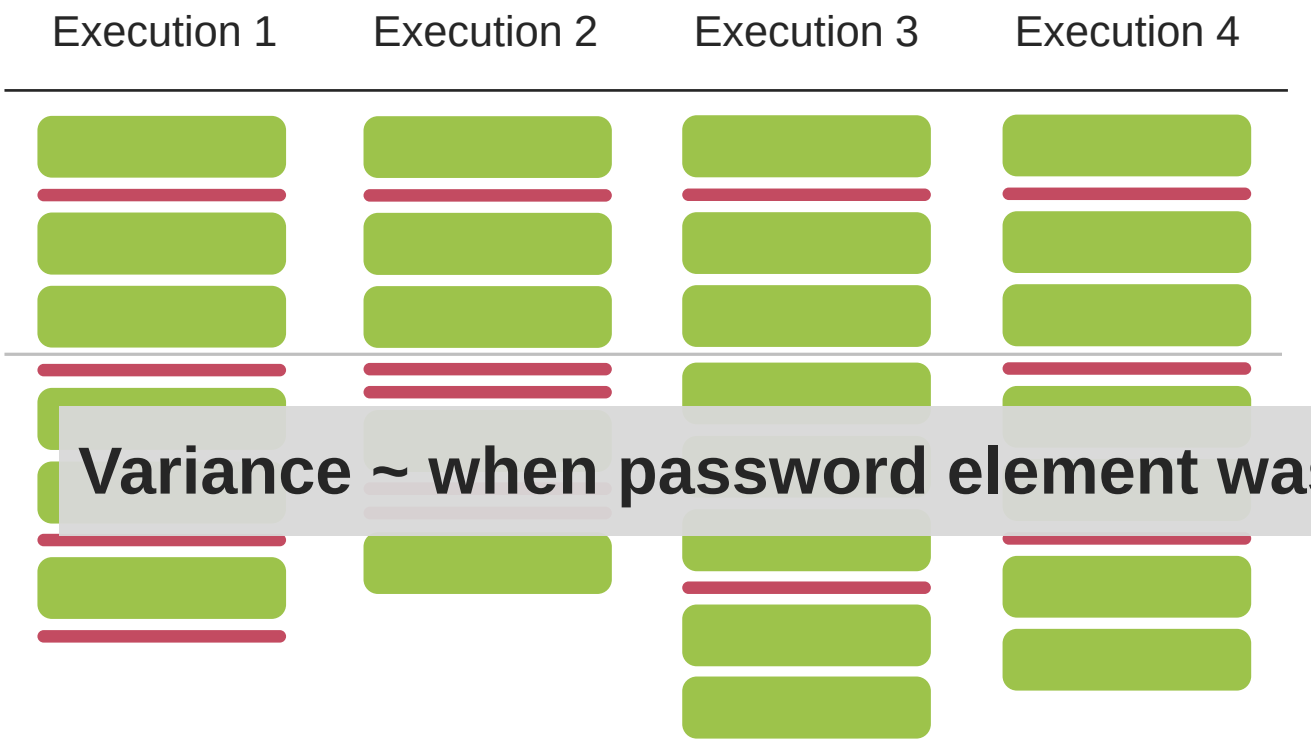
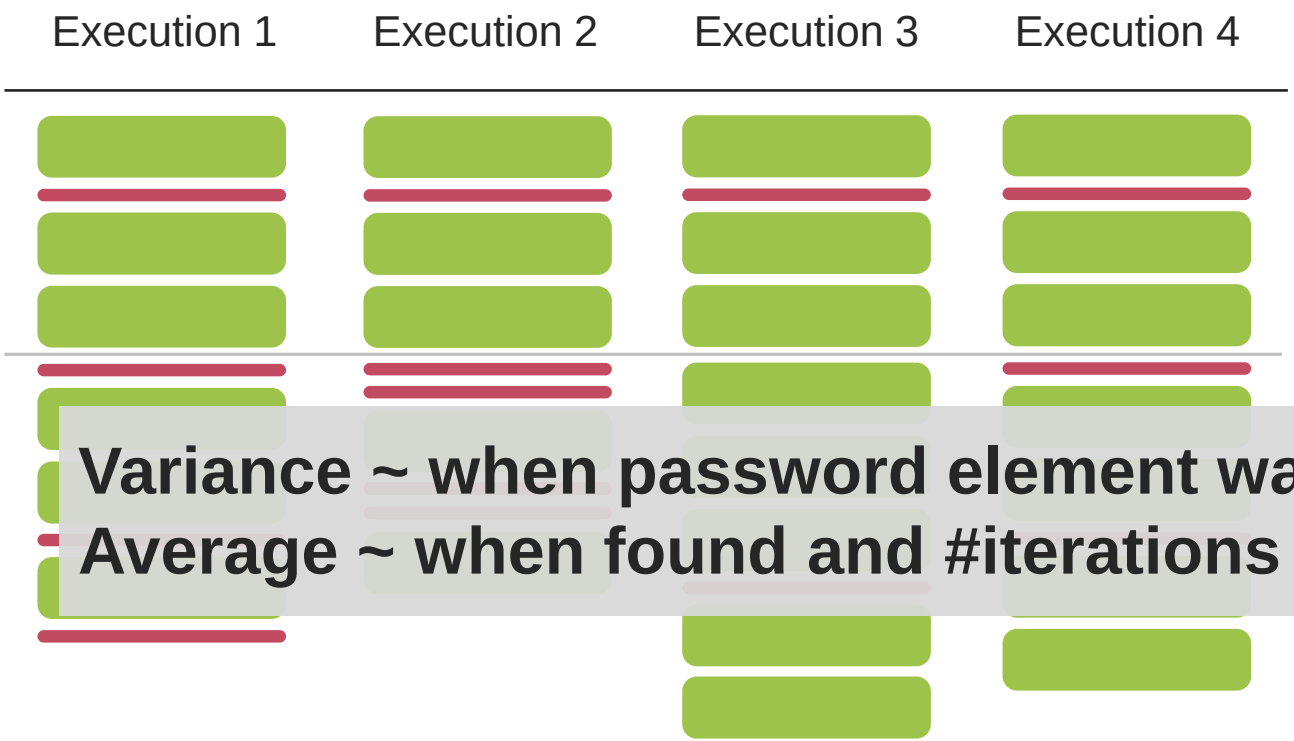


Variance ~ when password element was found

Influence of extra iterations



Variance ~ when password element was found
Average ~ when found and #iterations with big hash

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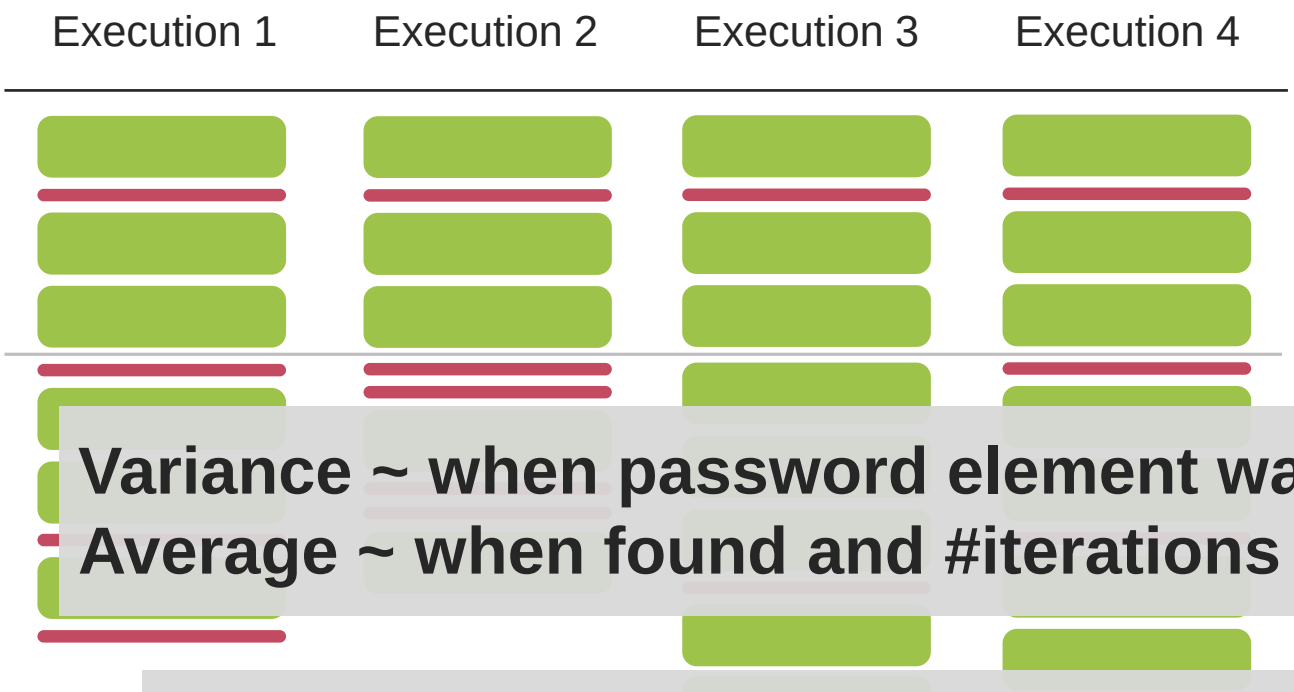

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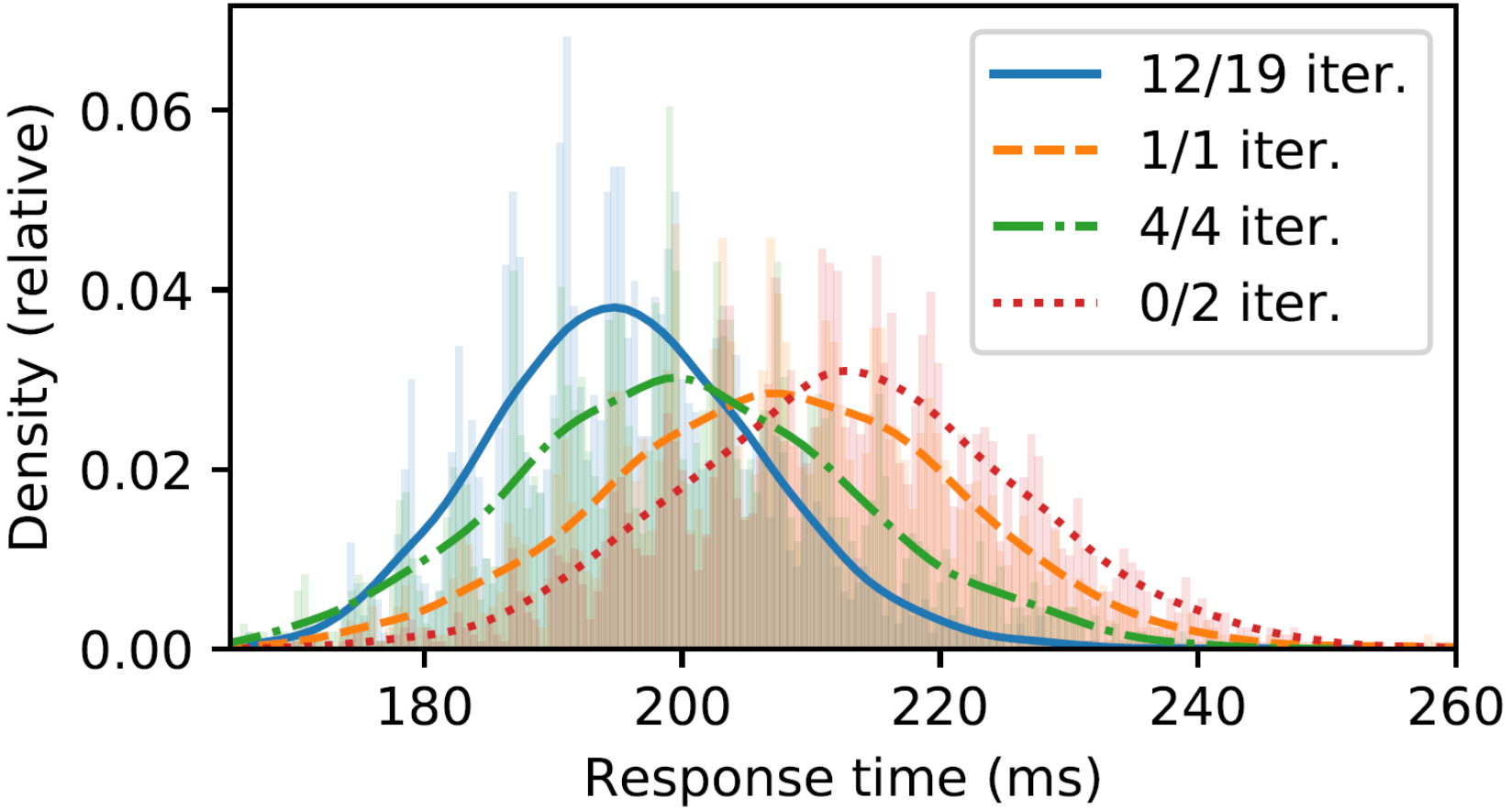
→ Again forms a signature of the password

Raspberry Pi 1 B+



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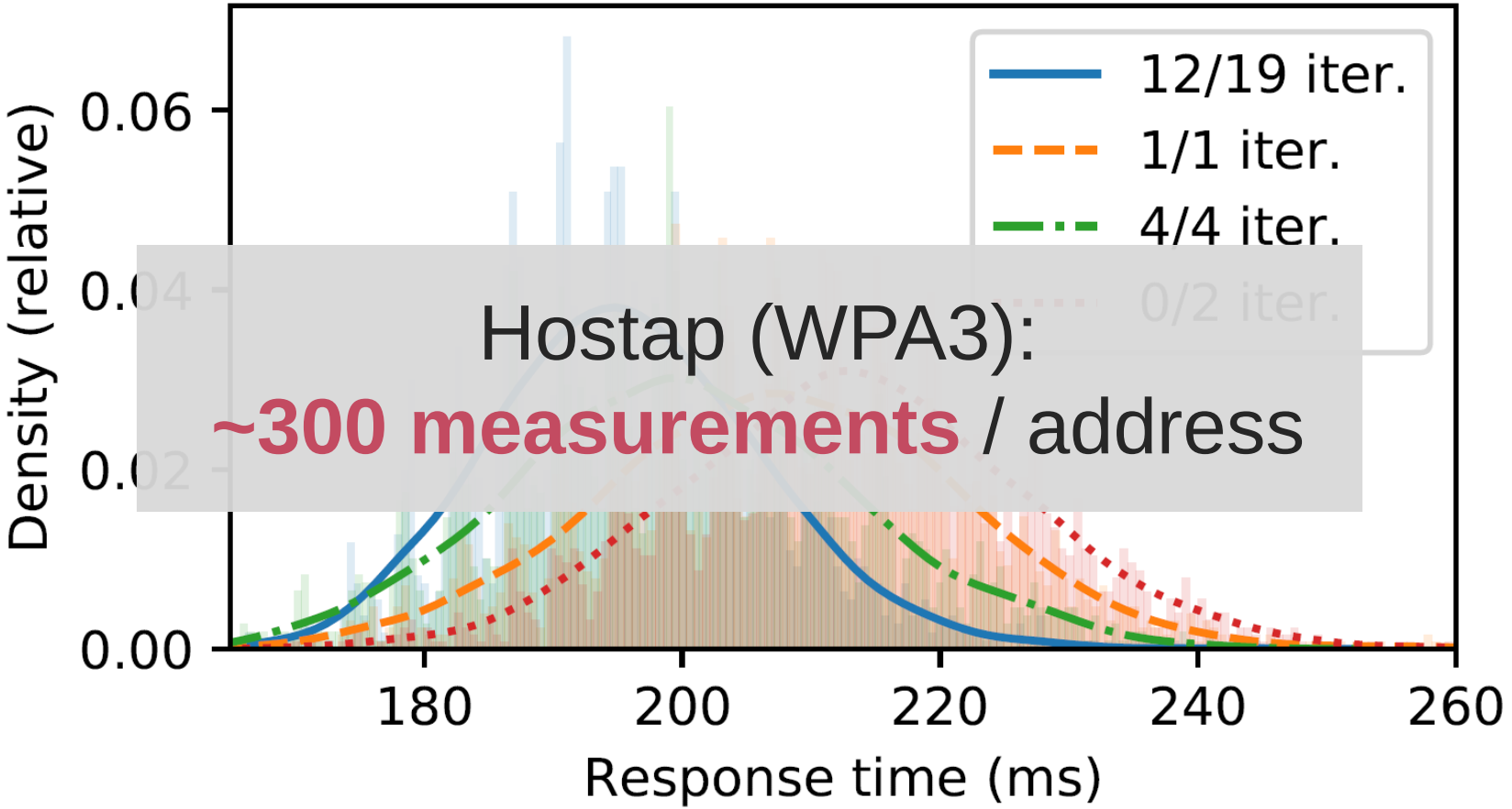
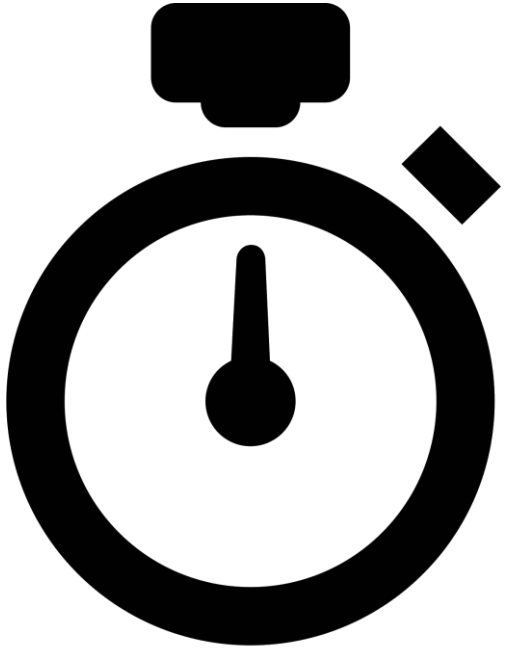


Hostap (WPA3):
~300 measurements / address



Cache Attacks

Hash-to-curve: Quadratic Residue

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NIST curves: use Flush+Reload to detect if code is executed in 1st iteration

Hash-to-curve: Qu

Use as clock to detect in which iteration we are

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Brainpool: use Flush+Reload to detect if code is executed in 1st iteration

There’s a lot more!

Implementation-specific vulnerabilities

- Invalid curve attacks, reflection attacks, **bad randomness**

Wi-Fi specific attacks

- Downgrades to WPA2 & denial-of-service

Practical impact

- Brute-force attacks on GPUs: $1 for RockYou database
- 802.11 being updated to use **Shallue-Woestijne-Ulas**

Thank you! Questions?

Lessons learned:

- Must be constant-time and efficient
- Allow offline computation of P
- Discuss impact of bad randomness
- Limit number of parameters (e.g. curves)
- **Dragonfly is hard to implement securely**

https://wpa3.mathyvanhoef.com