DUPEFS: Leaking Data Over the Network With Filesystem Deduplication Side Channels

Andrei Bacs and Saidgani Musaev, VUSec, Vrije Universiteit Amsterdam;

Kaveh Razavi, ETH Zurich; Cristiano Giuffrida and Herbert Bos,

VUSec, Vrije Universiteit Amsterdam

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Background

- **Filesystem&Dedup**
  - Inline Deduplication
  - Basic write workflow
  - Data identifiers
  - Deduplication tables
  - Deduplication granularity

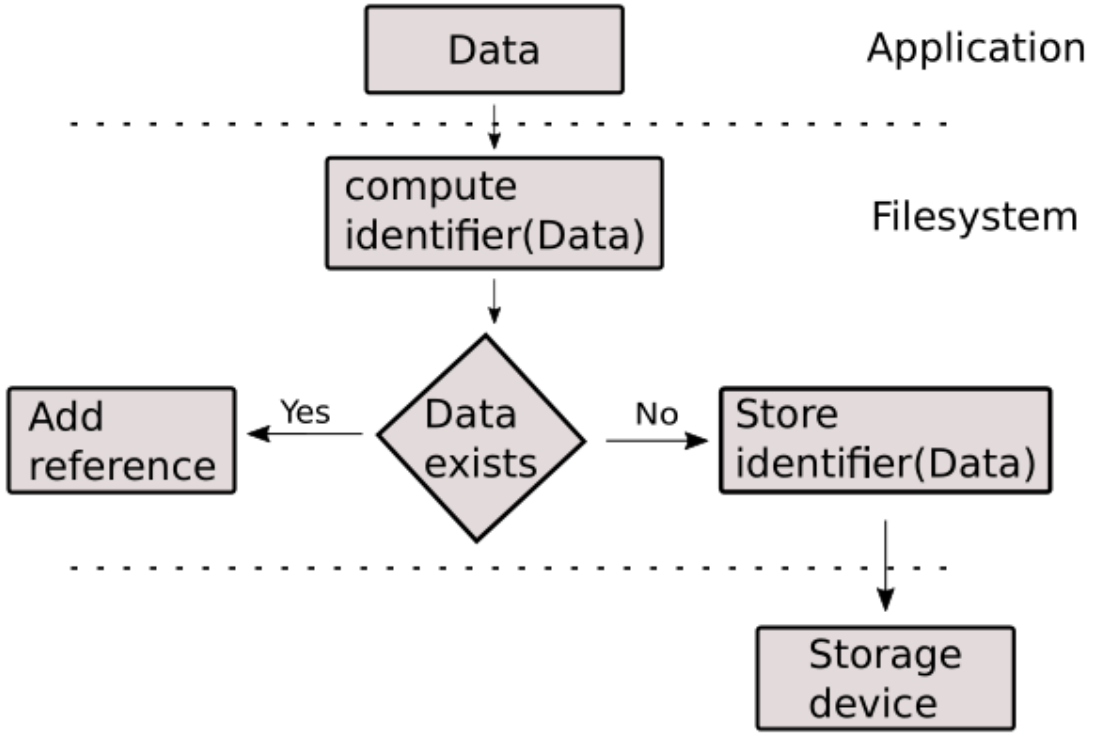
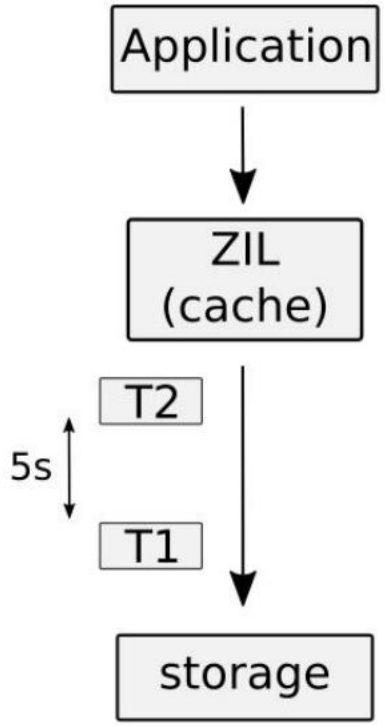
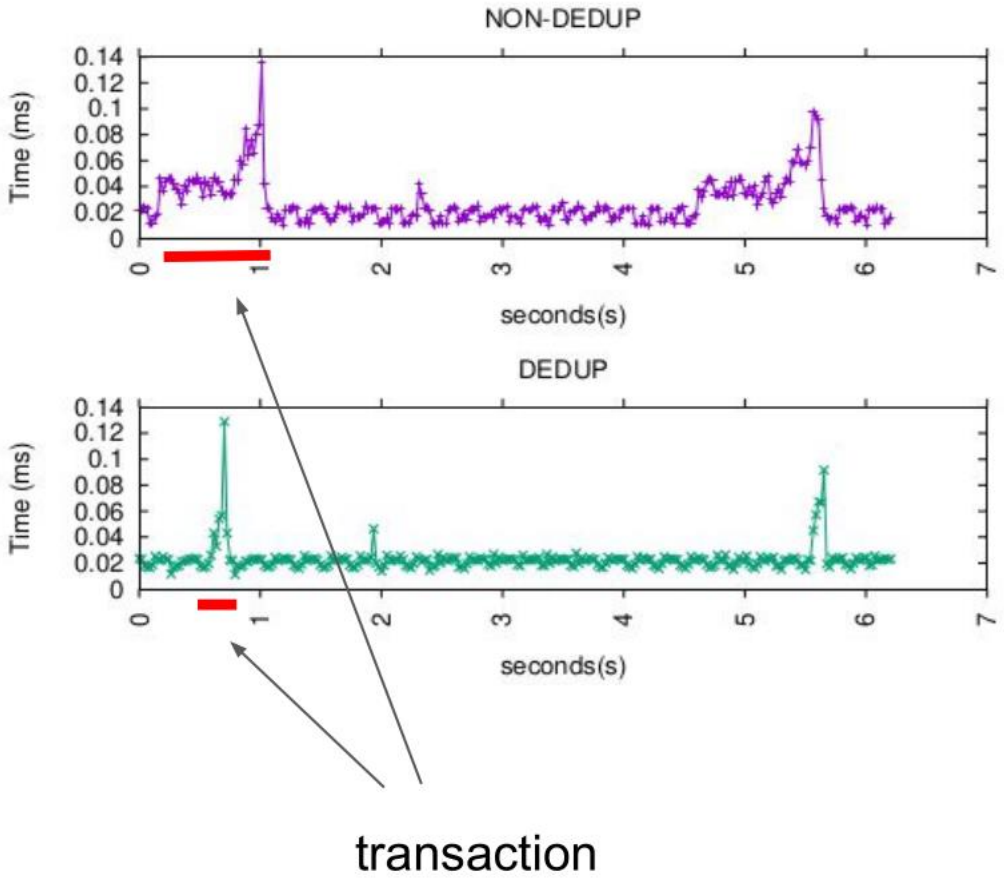


Figure 1: Write path with deduplication.

Deduplication timing side channel



Write path with deduplication



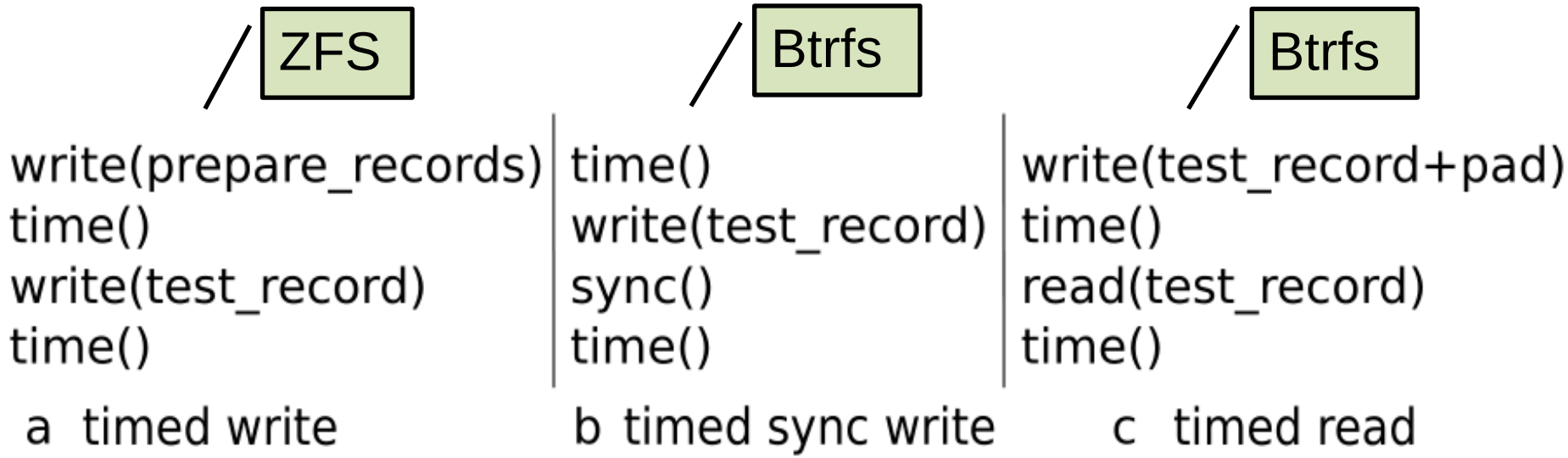
Transaction is shorter (pulse width) for duplicate data

Background

- **ZFS**
  - Transactional copy-on-write filesystem
  - Deduplication record(128KB)&deduplication table(DDT)
- **Btrfs**
  - Extent(128KB)： The data are stored in extents
  - COW filesystem
- **Primitive**
  - The timed write primitive
  - The timed read primitive

Attack Primitives

- carefully-chosen sequence of file operations



Attack Challenges

- **Filesystem asynchronous I/O operations**
  - intermediary caches
  - transactional behavior
  - ✓Exploitation technique: filesystem cache massaging
- **Deduplication granularity**
  - typical record size 128KB (ZFS and Btrfs)
  - ✓Exploitation technique: alignment probing
- **Week amplification in a remote attack**
  - ✓Exploitation technique: secret spraying

Threat Model

- Attacker and victim have access to the same filesystem
- The filesystem uses inline deduplication and default settings
- No limit on I/O operations

DUPEFS Exploitation

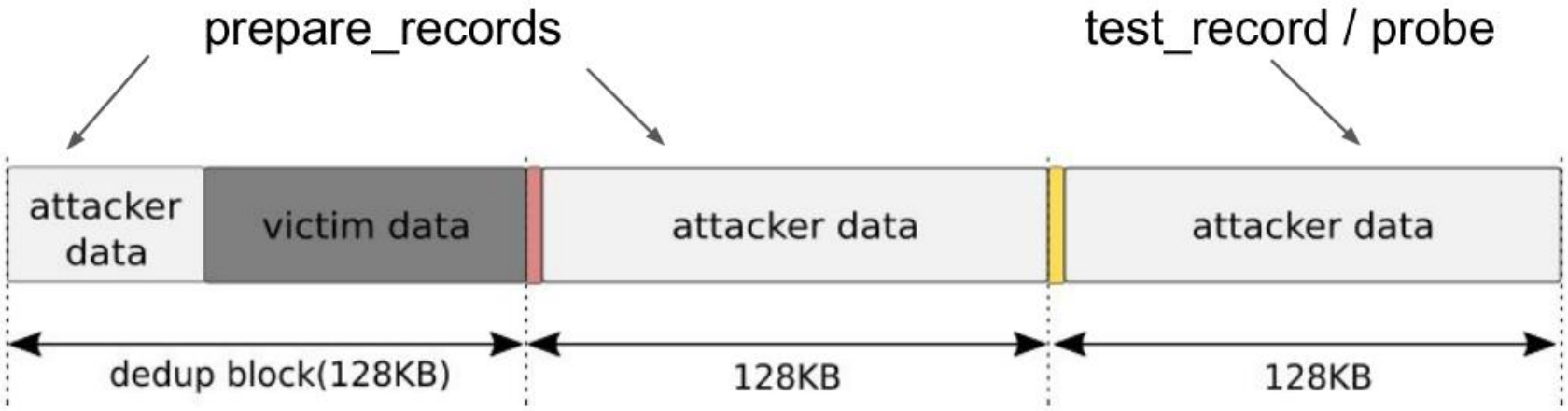
- **Data fingerprinting**
  - reveal the presence of existing known but inaccessible data
- **Data exfiltration**
  - exfiltrate secret data from a system (or sandbox)
- **Data leak**
  - leak secret data from a remote system
  - alignment probing
  - secret spraying

Alignment probing

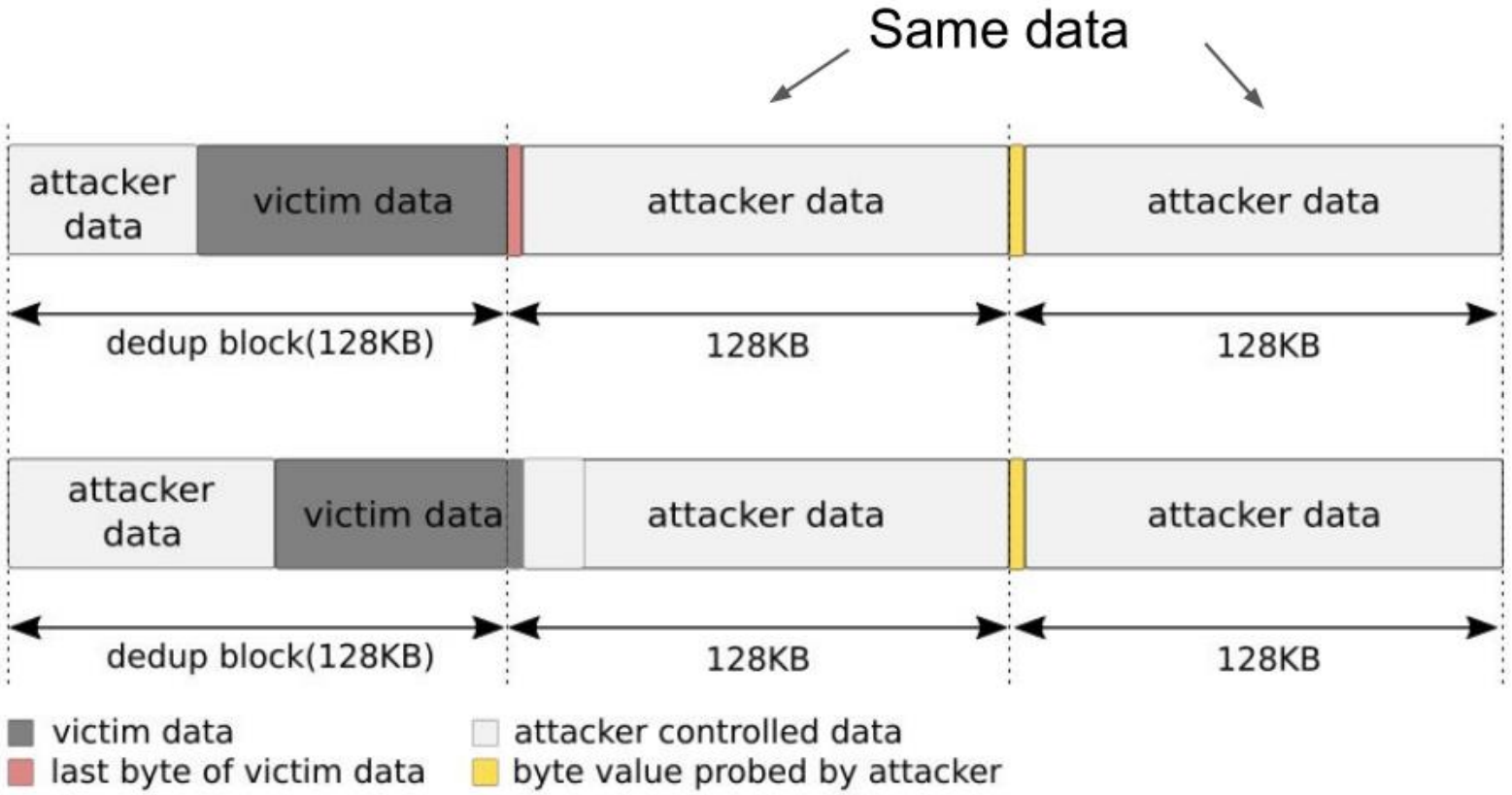
- Enables byte granularity
- Reduces entropy

Timed write primitive

```
write(prepare_records)
time( )
write(test_record)
time( )
```

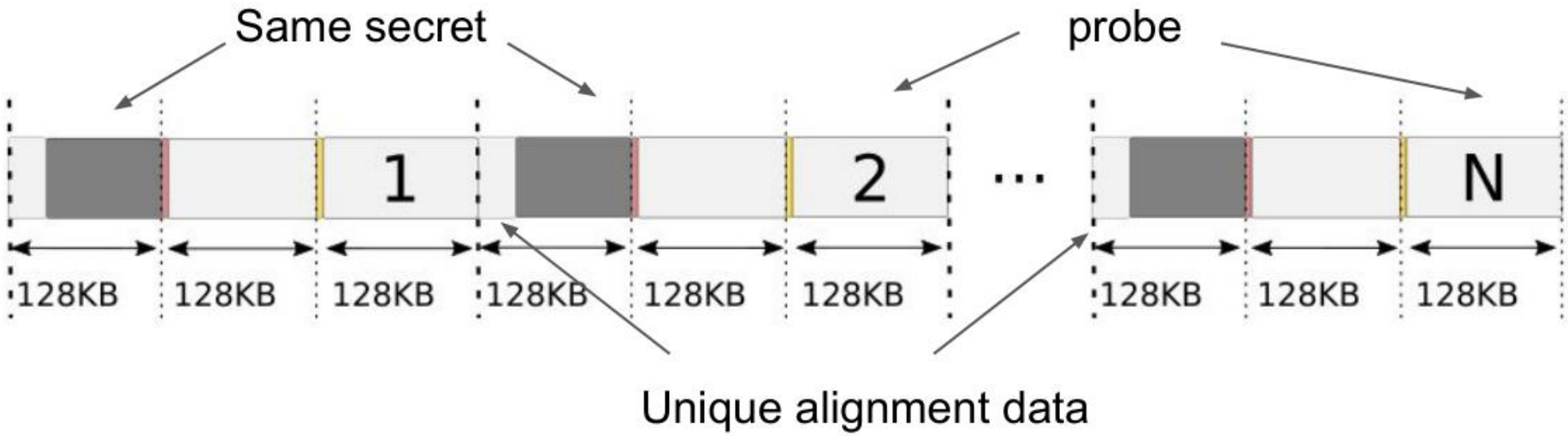


Alignment probing



Secret spraying

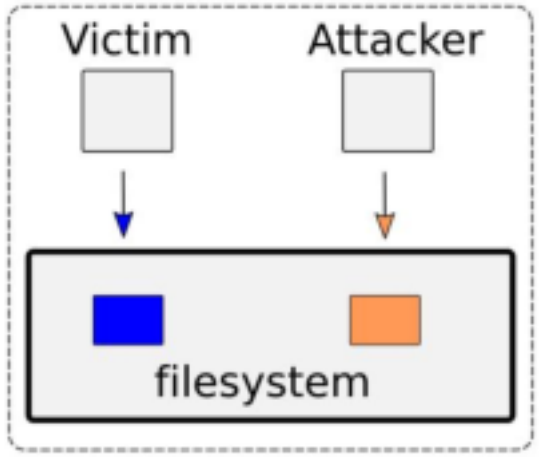
- Amplifies the timing signal
- N dedup events per correct guessed byte



Data Fingerprinting/exfiltration

➢ Data Fingerprinting

- Btrfs-based synchronous write primitive
- local exploitation scenario



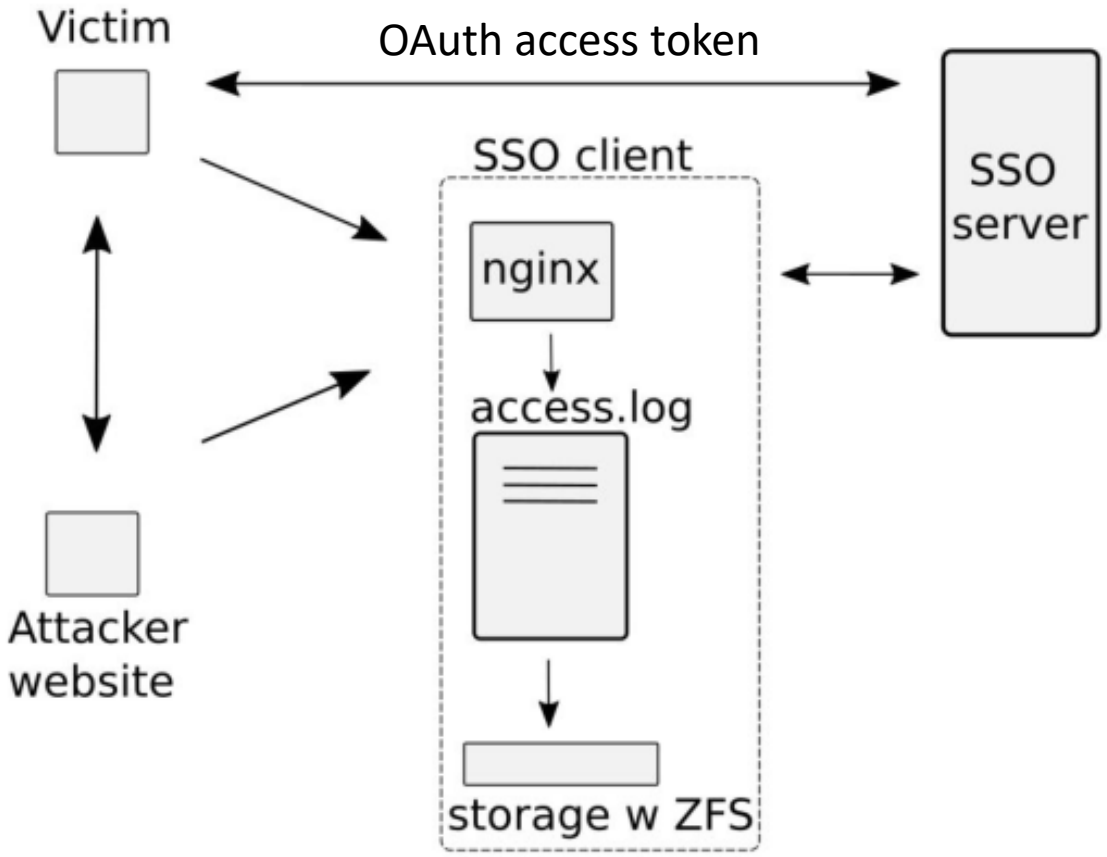
Local: data fingerprinting, exfiltration

➢ Data exfiltration

- Btrfs-based synchronous write primitive
- A local unprivileged attacker (or “sender”) seeks to exfiltrate data from a sandbox over a covert channel.

Data leak

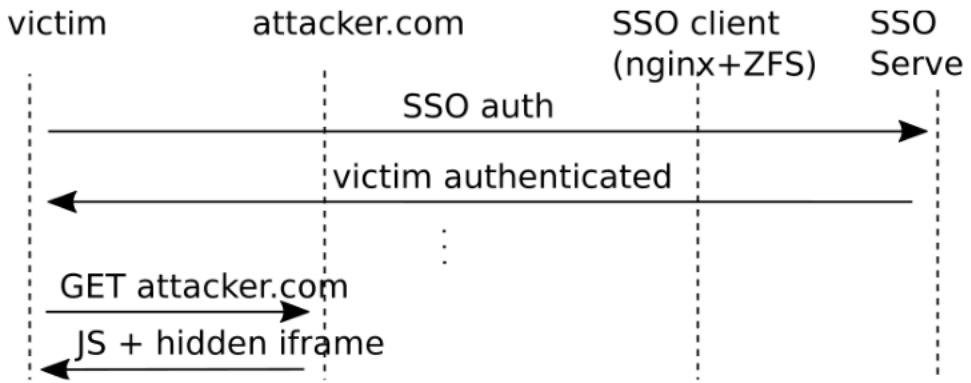
- targets access tokens of OAuth 2.0 implicit grant access scheme
- SSO client runs nginx on top of ZFS and logs requests
- access tokens are encoded in the request and do not expire during attack
- SSO client does not offer X-Frame-Options



Data leak


victim
attacker.com
SSO client
(nginx+ZFS)
SSO
Server
SSO auth
victim authenticated

Data leak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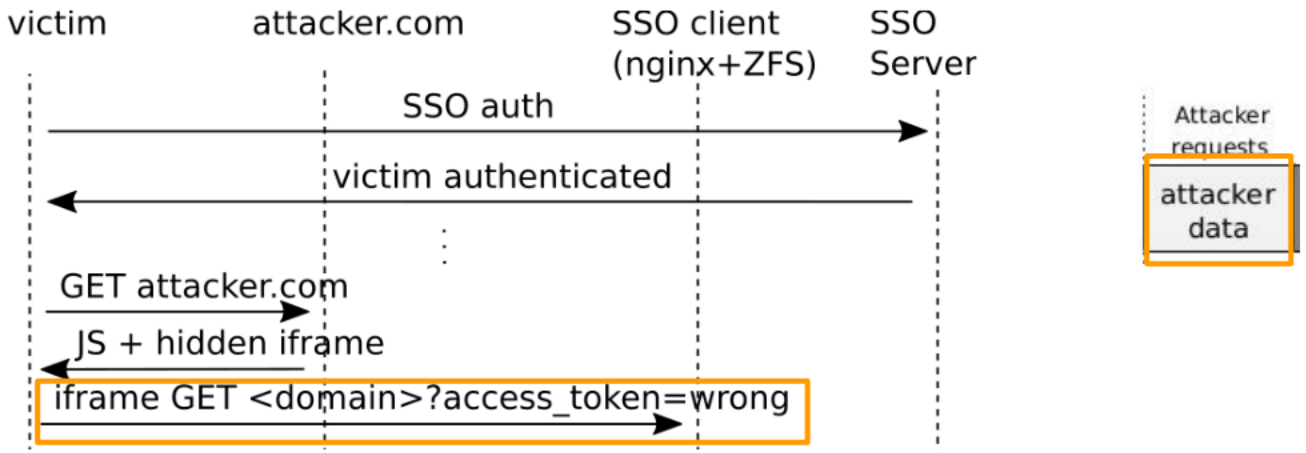
GET attacker.com
JS + hidden iframe

Data leak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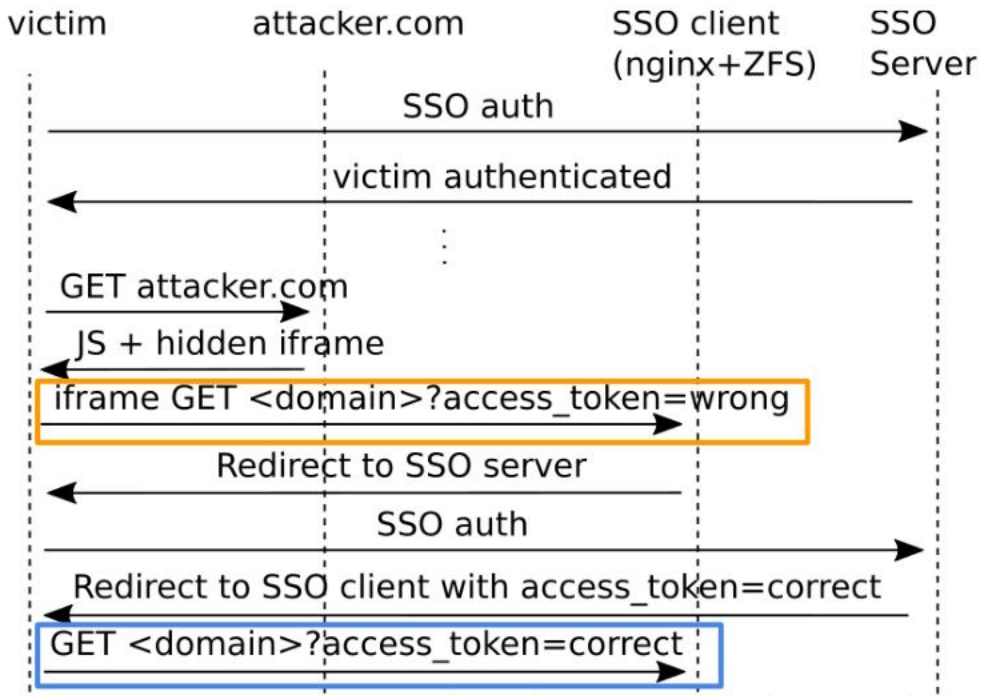
GET attacker.com
JS + hidden iframe
iframe GET <domain>?access_token=wrong
Attacker
requests
attacker
data

Data leak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iframe GET <domain>?access_token=wrong
Redirect to SSO server
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Redirect to SSO client with access_token=correct
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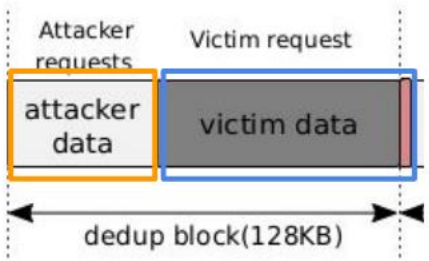
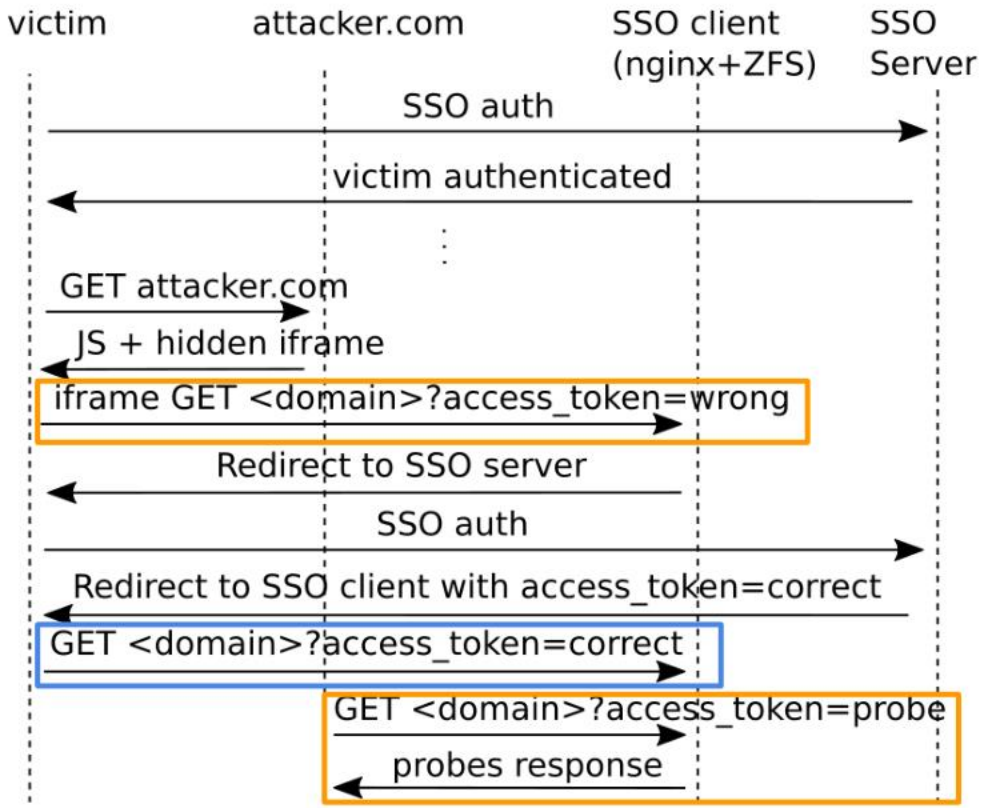

Attacker requests
Victim request
attacker data
victim data
dedup block(128KB)

Data leak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probes response


Attacker requests
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Attacker requests
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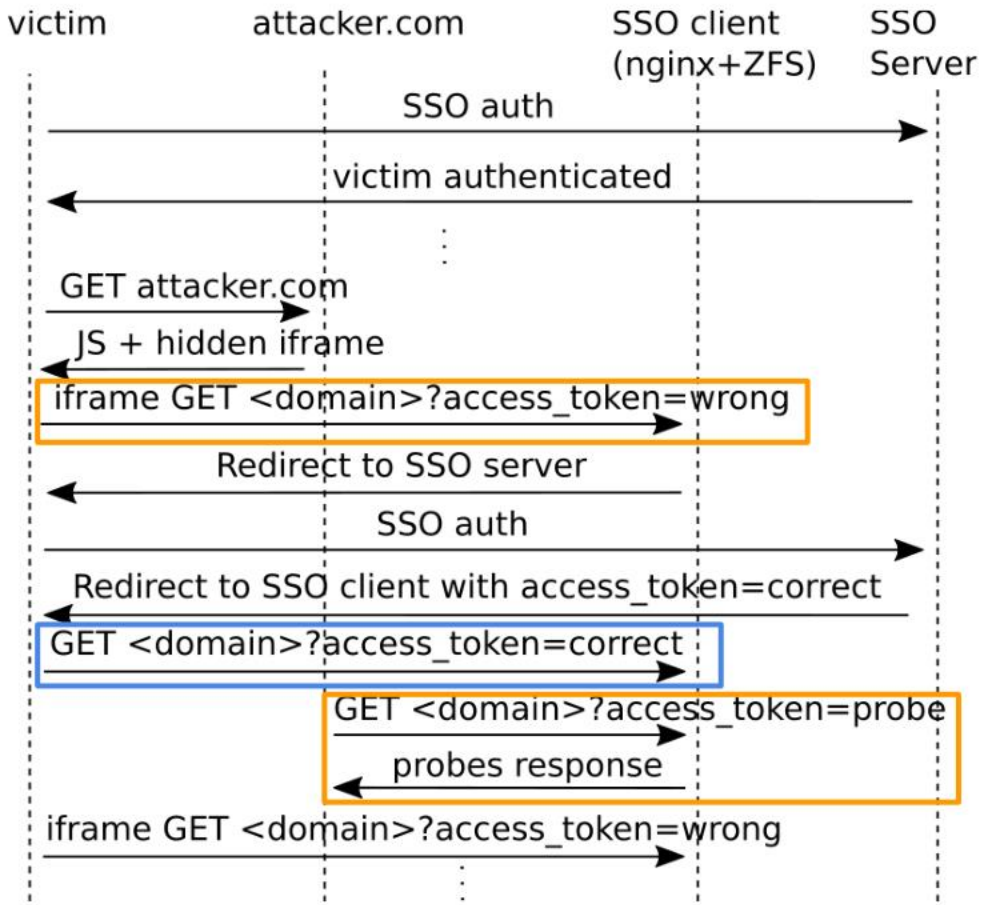
victim data
attacker data
attacker data
dedup block(128KB)
128KB
128KB
victim data
last byte of victim data
attacker controlled data
byte probed by attacker

Data leak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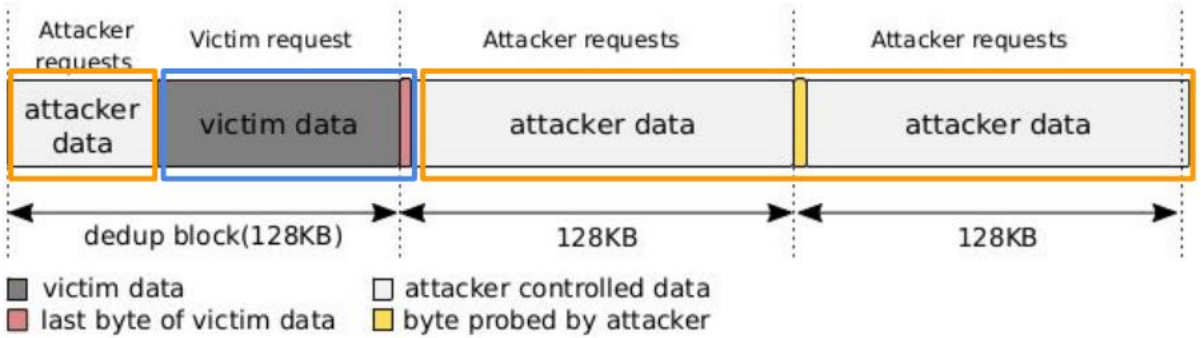
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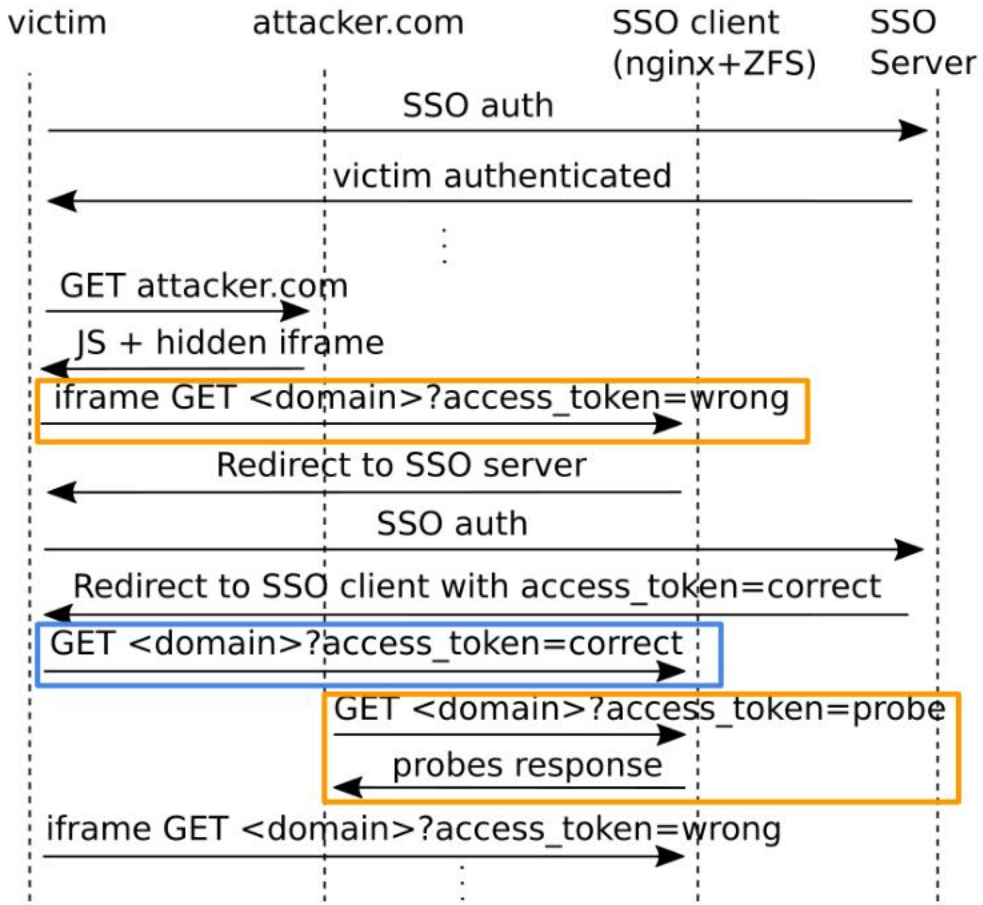
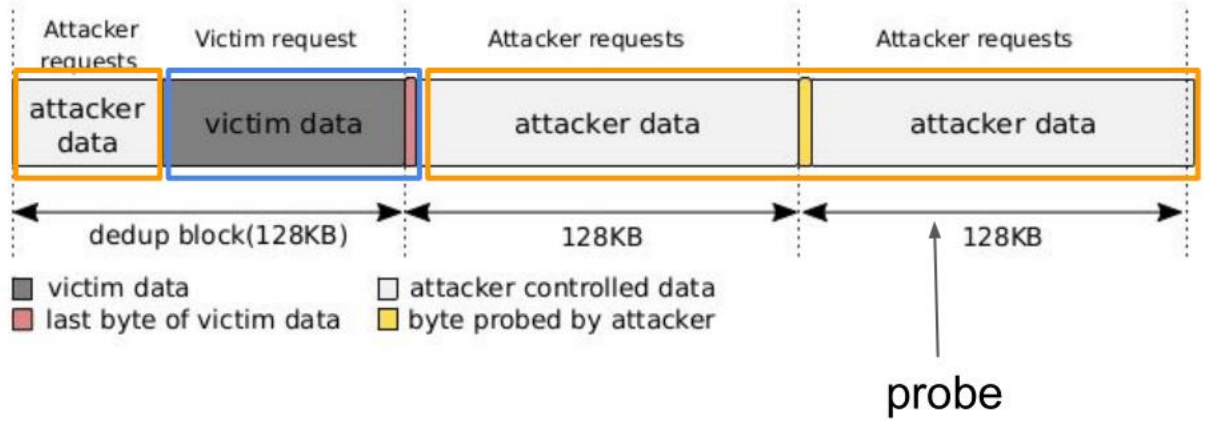
Data leak





- correct byte value probe produces transaction durations < threshold

Evaluation

- **Data fingerprinting**
  - DUPEFS can reliably fingerprint thetarget data except the last sub-128 KB chunk of a file. Thus the small (181 KB and 223 KB) files have lower success rates.

Table 1: File fingerprinting

File	Type	Size	Success
config-4.11.3-200.fc25.x86_64	text	181 KB	70%
lena_color.gif	binary	223 KB	55%
libz3.so	binary	22 MB	99%
x86_64-redhat-linux-c++	binary	1 MB	99%

Evaluation

- **Data Exfiltration**

Table 2: Covert channel

N	Bit errors	Time	BR	BER	I/O
20	13	375s	0.320 bps	10.83%	76.8MB
40	14	746s	0.160 bps	11.66%	153.6MB
60	12	1591s	0.075 bps	10.00%	230.4MB
100	6	1873s	0.064 bps	5.00%	384.0MB
120	3	2387s	0.050 bps	2.50%	460.8MB

Evaluation

➢ Data Leak

- OAuth token 22 bytes (base64)
- LAN: 1 hop (RTT 0.1ms)
- WAN: 12 hops (RTT 2ms)

Table 3: LAN 1 byte data leak

Success	Attack time/byte	Probes/byte val	I/O
50%	19.2 min	200	4.9 GB
80%	25.6 min	300	7.3 GB
92%	42.6 min	400	9.8 GB
96%	78.9 min	800	19.6 GB

Table 4: WAN 1 byte data leak

Success	Attack time/byte	Probes/byte val	I/O
64%	24.5 min	200	4.9 GB
87%	38.4 min	300	7.3 GB
94%	59.7 min	400	9.8 GB
94%	110.9 min	800	19.6 GB

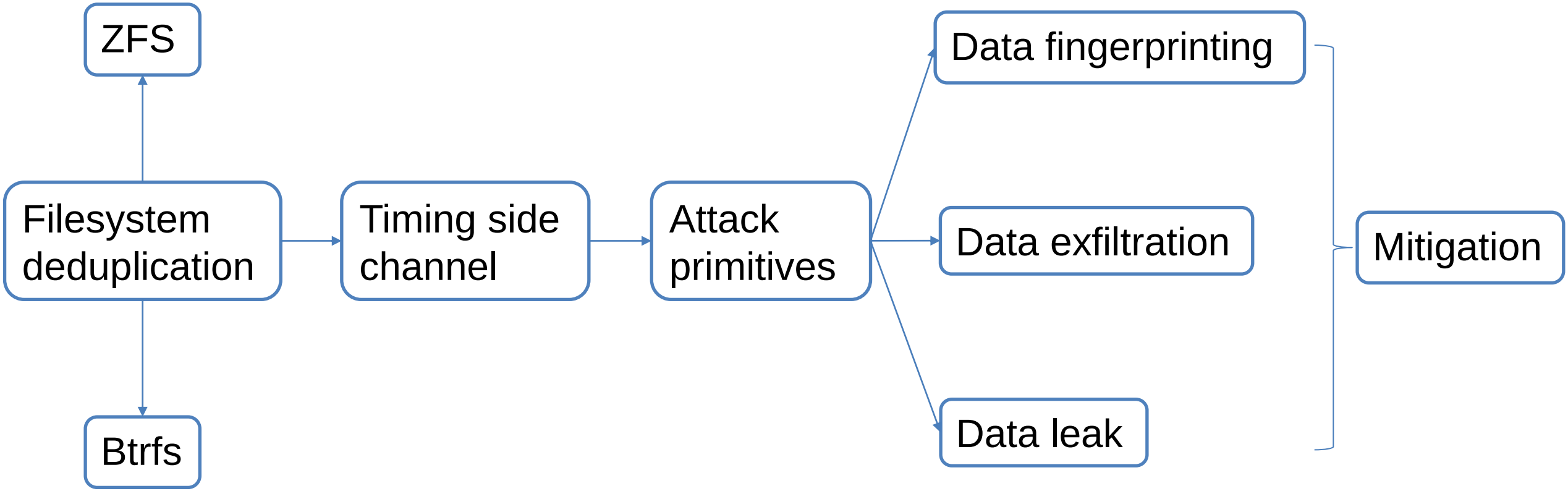
Mitigation

- **Deduplication ideal implementation**
  - Save space
  - Constant time behavior
- **Pseudo-same behavior policy**
  - Perform data overwrite for duplicate data
  - Read path: time jitter
  - Renders remote attacks impractical

Contributions

- Analyze filesystem deduplication side channels, show that despite the challenges, attackers can mount byte-level data leak attacks across the network.
- Introduce DUPEFS's novel attack primitives and demonstrate their feasibility in end-to-end attacks to leak data even across the Internet.
- Describe and analyze mitigations for such attacks.

Conclusion


ZFS
Filesystem deduplication
Btrfs
Timing side channel
Attack primitives
Data fingerprinting
Data exfiltration
Data leak
Mitigation