Preventing (Network) Time Travel with Chronos

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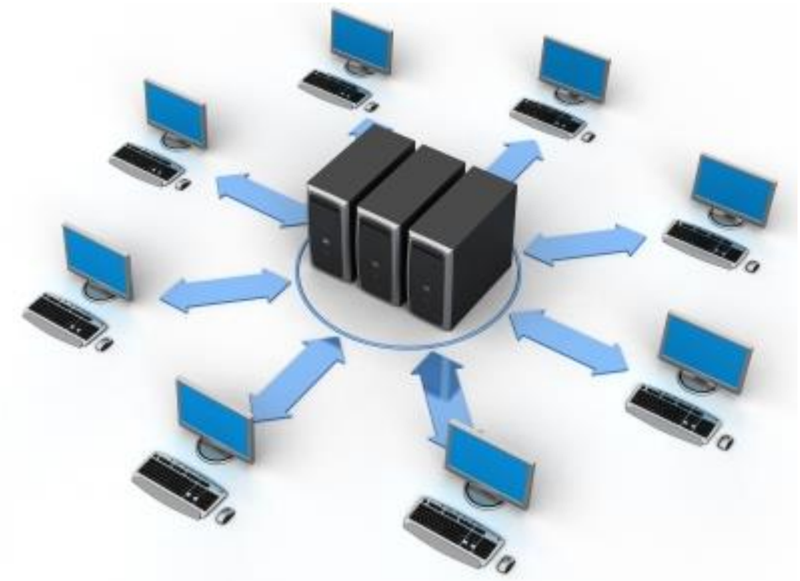
Network Time Protocol (NTP)

- NTP synchronizes time across computer systems over the Internet.

- Many applications rely on NTP for correctness and safety:
  - ➢TLS certificates
  - ➢DNS (and DNSSEC)
  - ➢HTTPS
  - ➢Kerberos
  - ➢Financial applications



NTP Architecture

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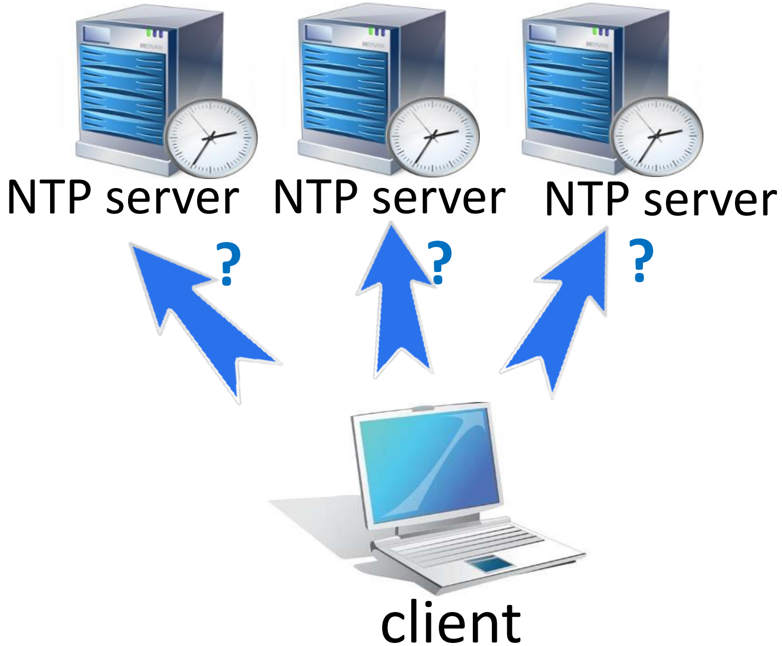
1. **Poll process**:
   The NTP client gathers time samples from NTP servers

Poll process: **NTP queries**



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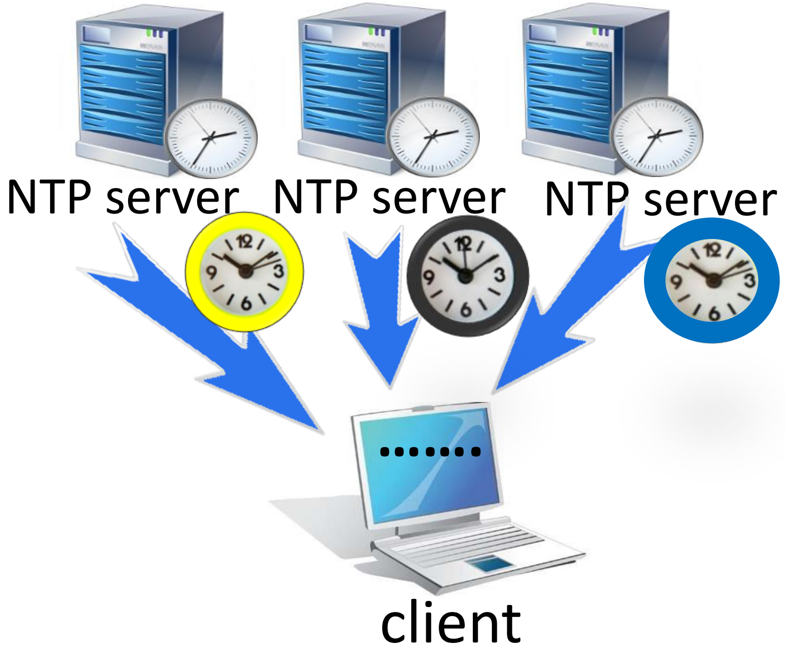

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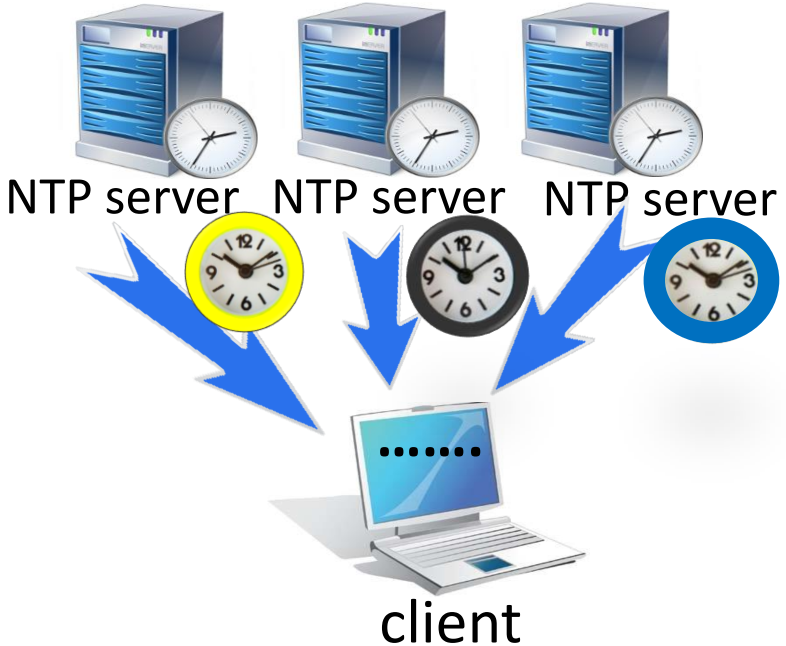

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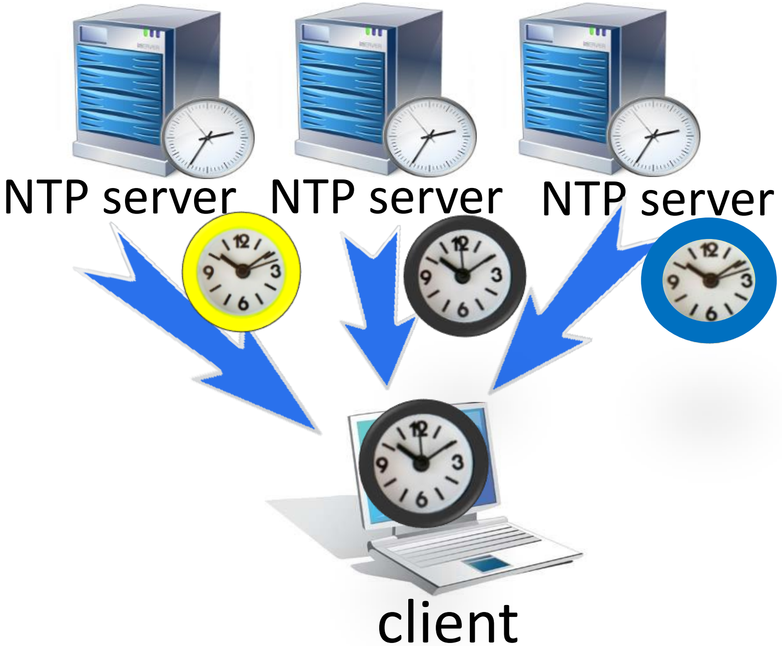
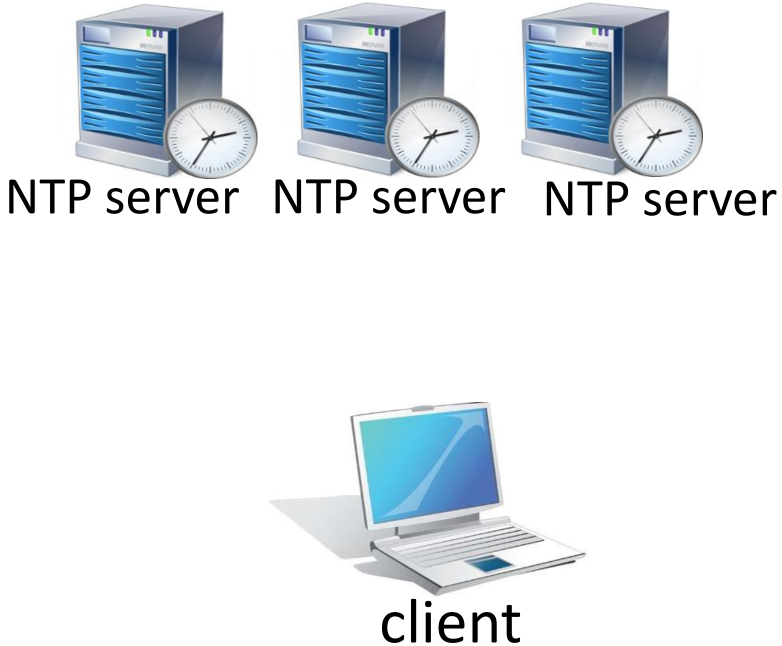


NTP Man-in-the-Middle (MitM) Attack

- NTP is highly vulnerable to time shifting attacks, especially by a MitM attacker
    - Can tamper with NTP responses



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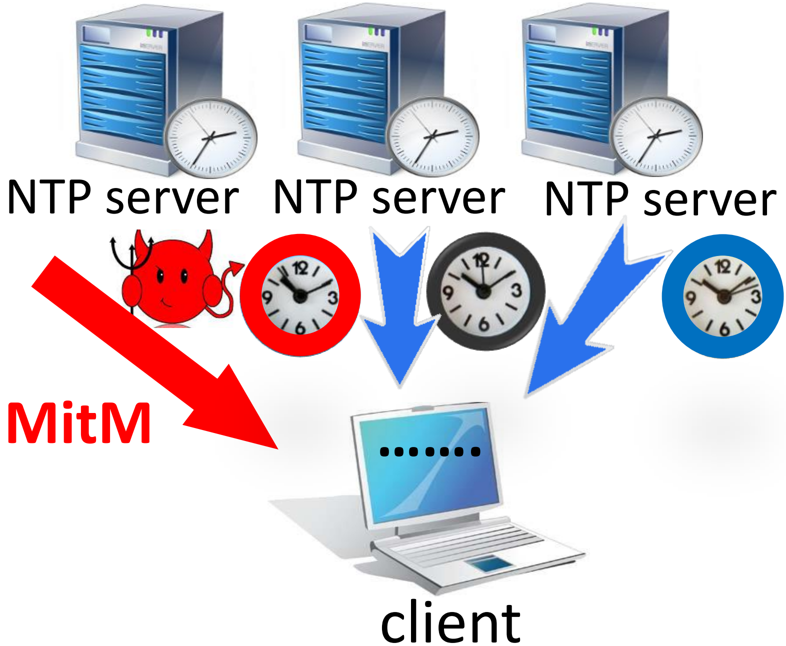

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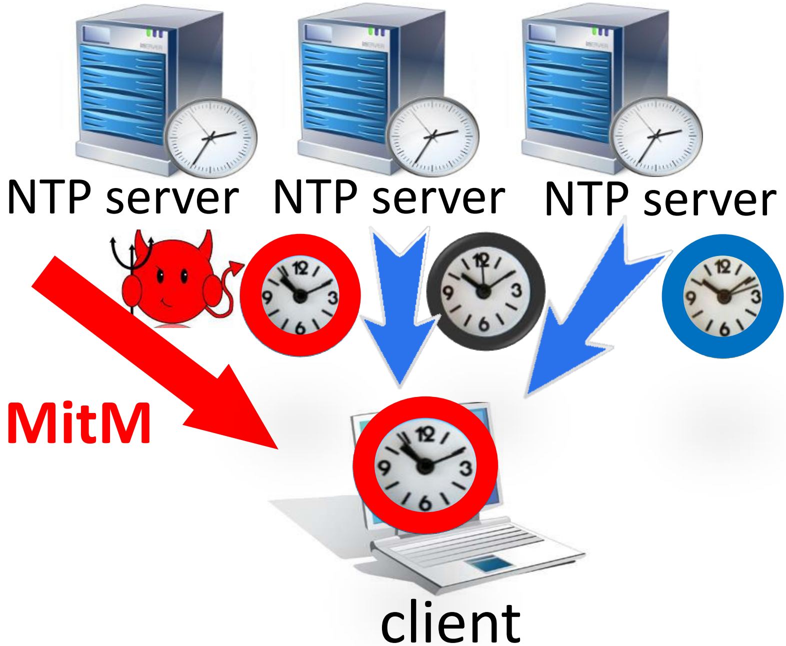
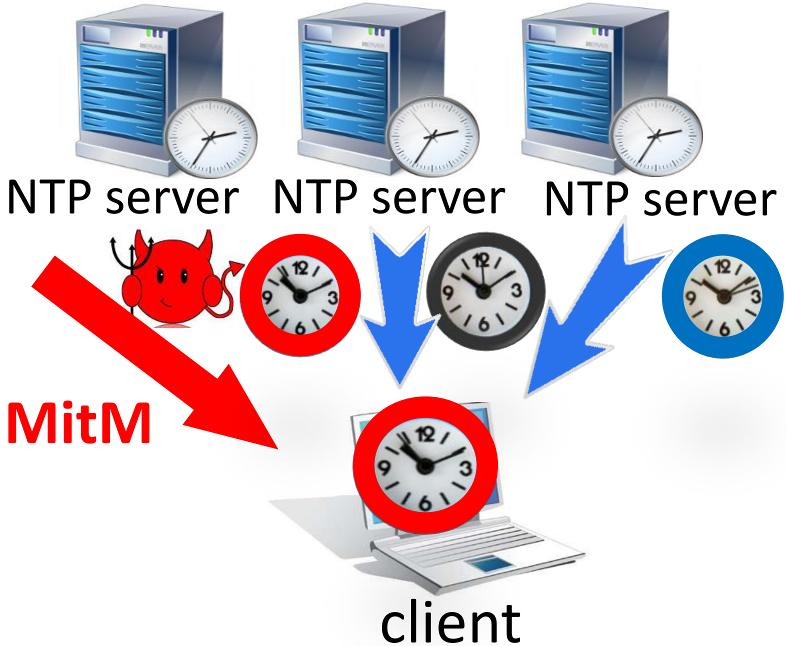


NTP Man-in-the-Middle (MitM) Attack

- NTP is highly vulnerable to time shifting attacks, especially by a MitM attacker
  - Can tamper with NTP responses
  - Can impact local time at client simply by dropping and delaying packets to/from servers **(encryption and authentication are insufficient)**
- Previous studies consider MitM as “too strong for NTP”



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Powerful and sophisticated MitM attackers are beyond the scope of **<u>traditional</u>** threat models

Chronos to the Rescue

The **Chronos NTP client** is designed to achieve the following:

- **Provable security** in the face of fairly powerful MitM attacks
  - ➢ negligible probability for successful timeshifting attacks

- **Backwards-compatibility**
  - ➢ no changes to NTP servers
  - ➢ limited software changes to client

- **Low computational and communication overhead**
  - ➢ query few NTP servers

Threat Model

The attacker:

- Controls a large fraction of the NTP servers in the pool (say, ¼)
- Capable of both deciding the content of NTP responses **and** timing when responses arrive at the client
- Malicious

Chronos Architecture

Chronos’ design combines several ingredients:

- **Rely on many NTP servers**
  - ➢ Generate a large server pool (hundreds) per client
    - ➢E.g., by repeatedly resolving NTP pool hostnames and storing returned IPs
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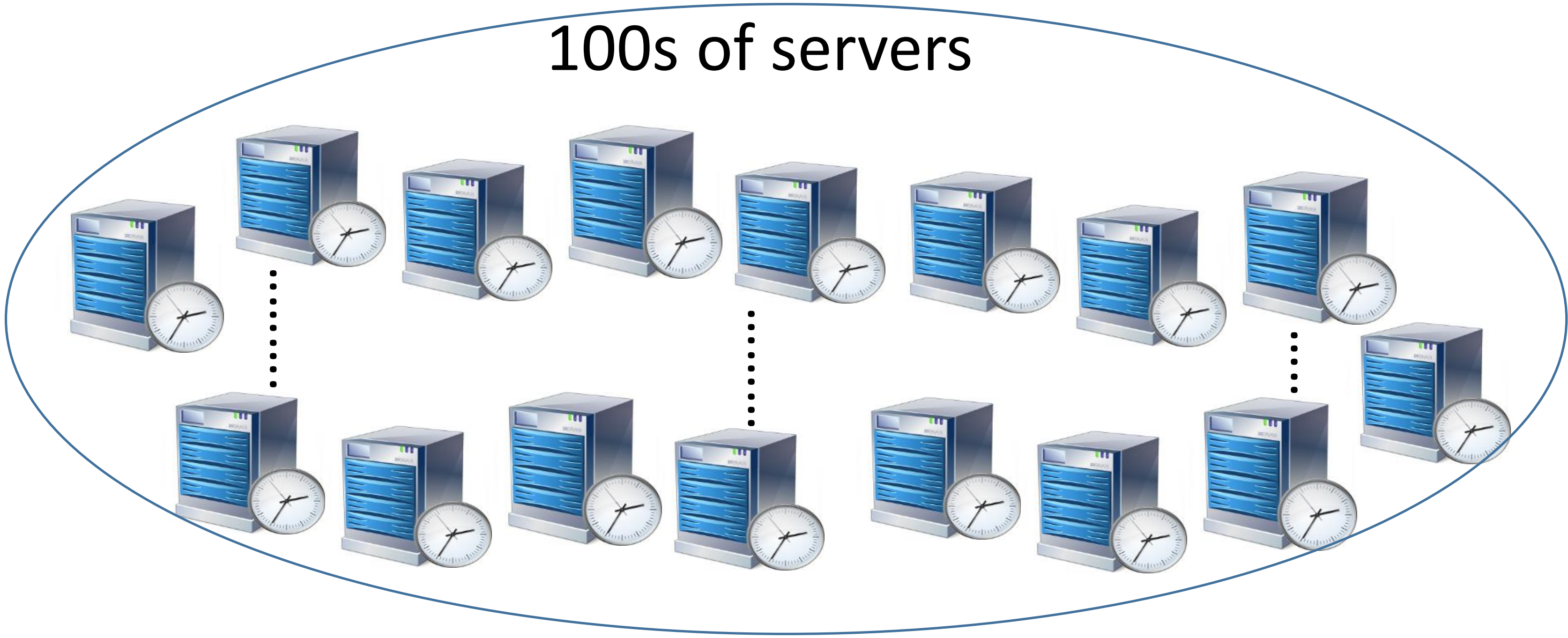
  - ➢ Randomly query a small fraction of the servers in the pool (e.g., 10-20)
  - ➢ Avoids overloading NTP servers
- **Smart filtering**
  - ➢ Remove outliers via a technique used in approximate agreement algorithms
  - ➢ Limit the MitM attacker's ability to contaminate the chosen time samples

Chronos' Time-Update Algorithm: Informal

- Query m (10s of) servers **at random**



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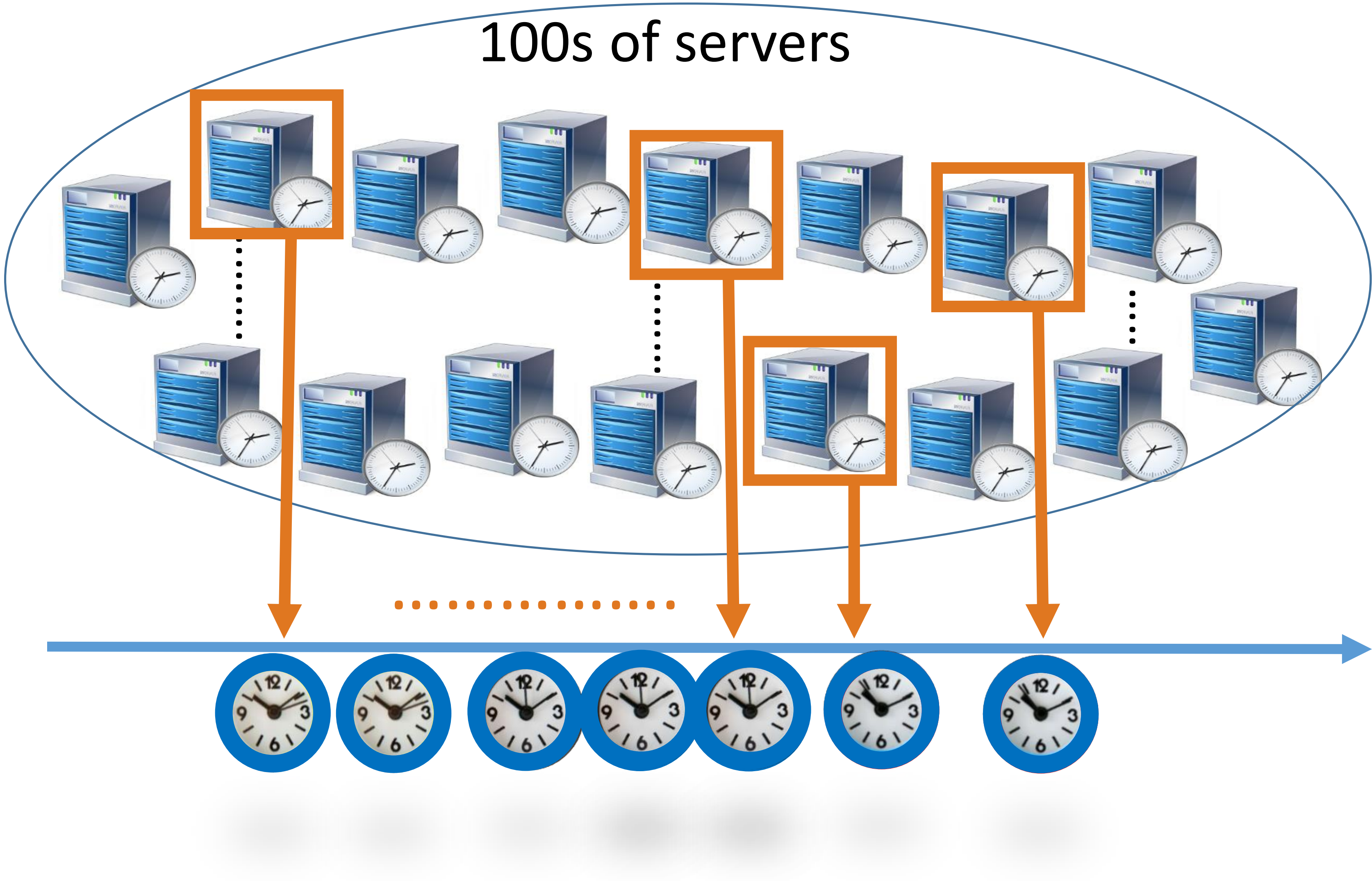

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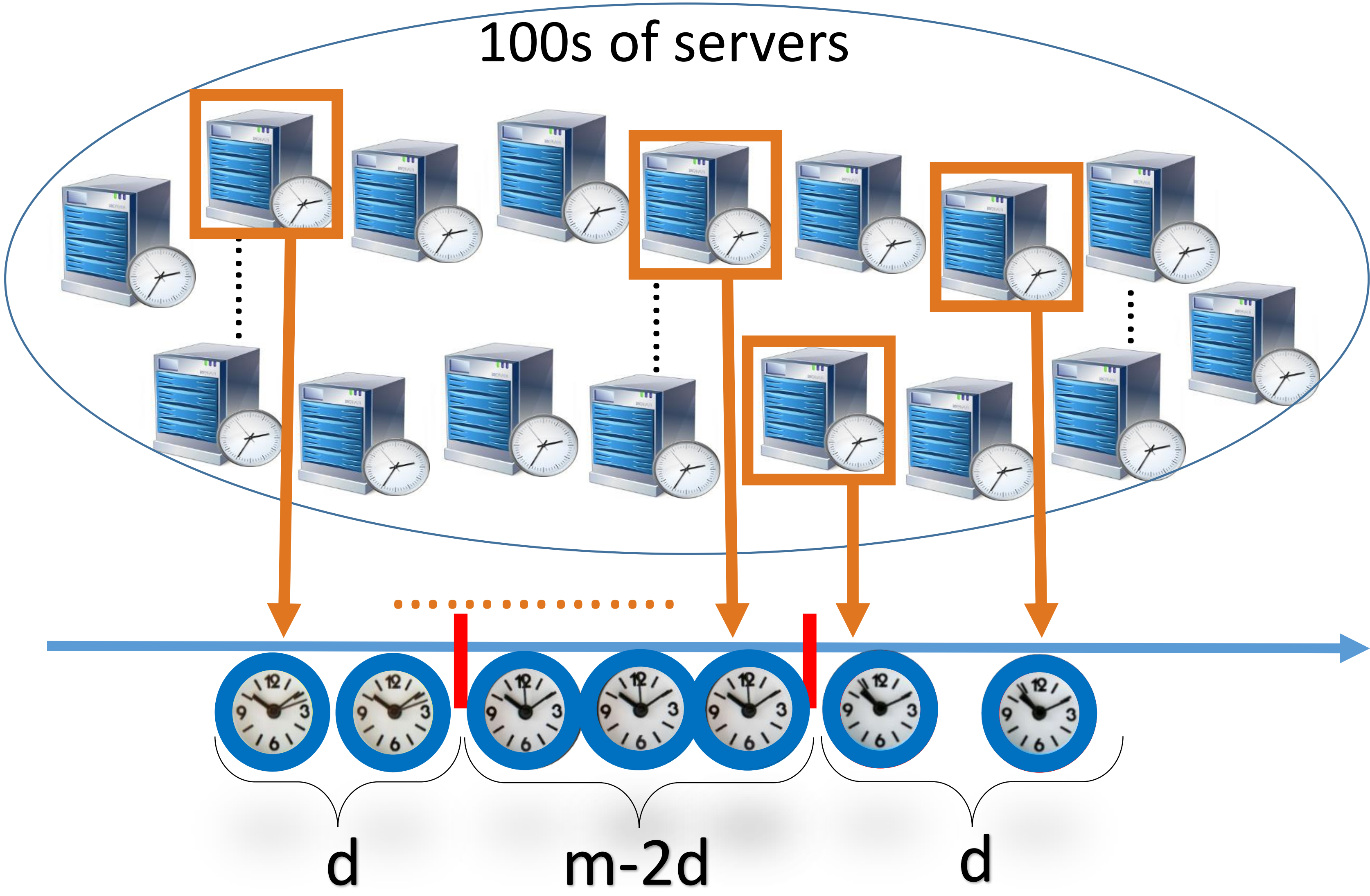

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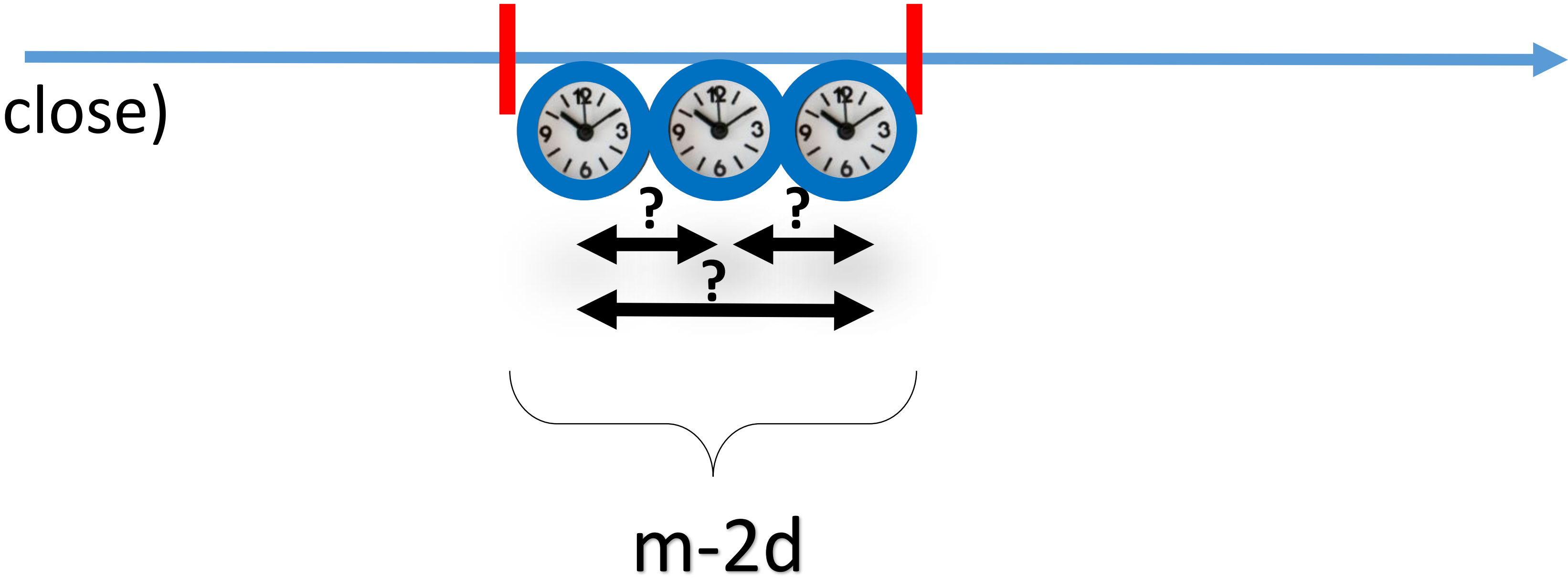
If (the remaining samples are close)



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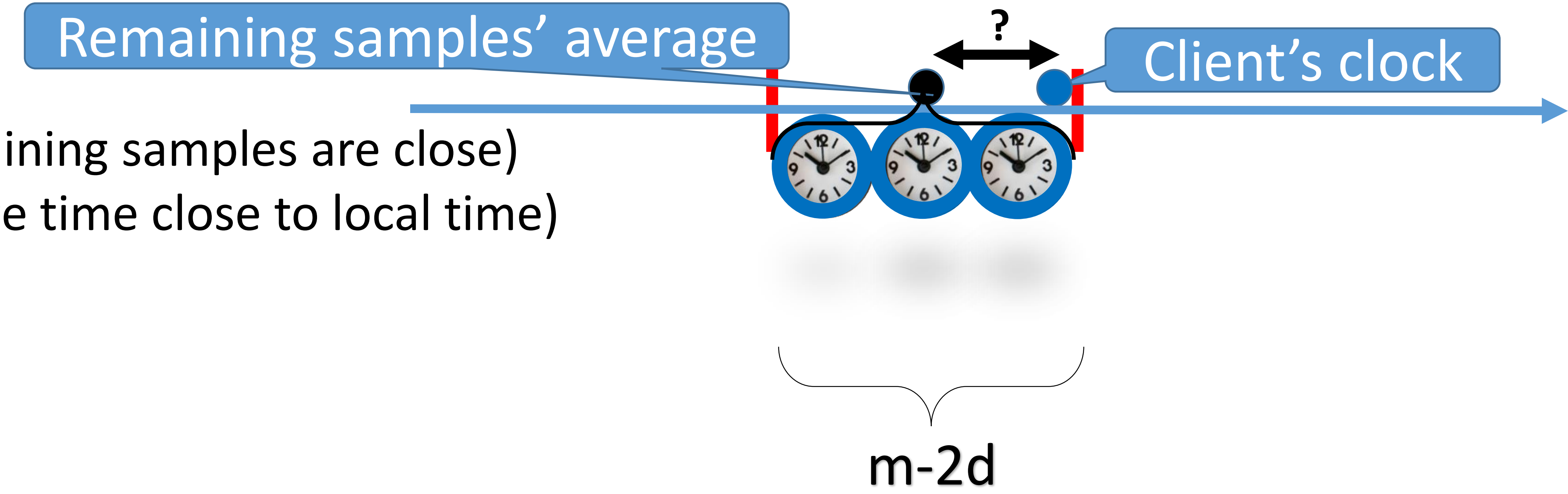

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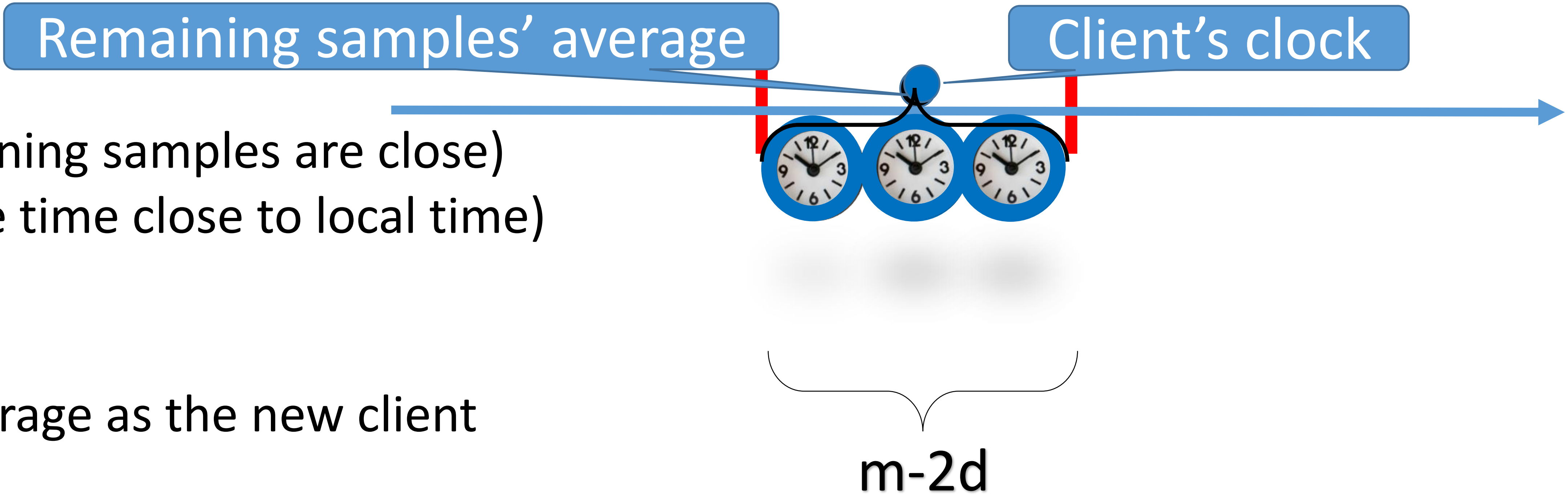

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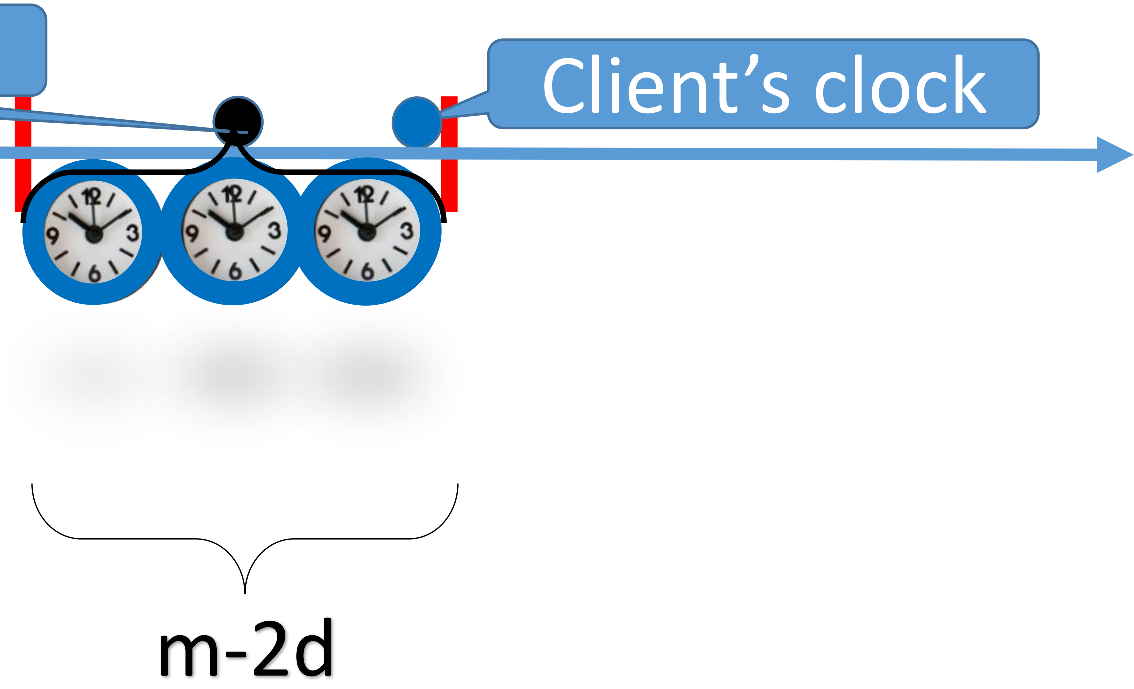

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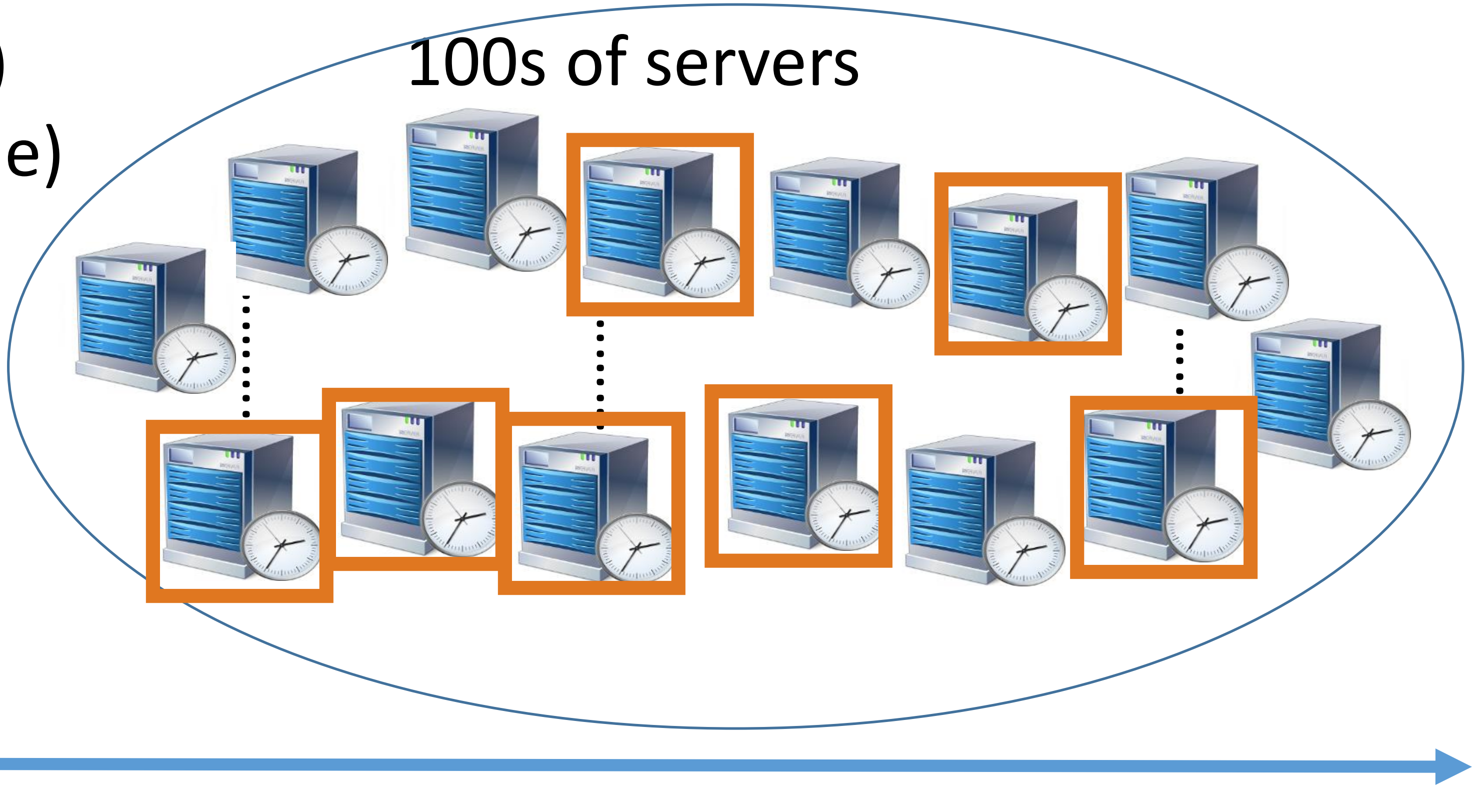

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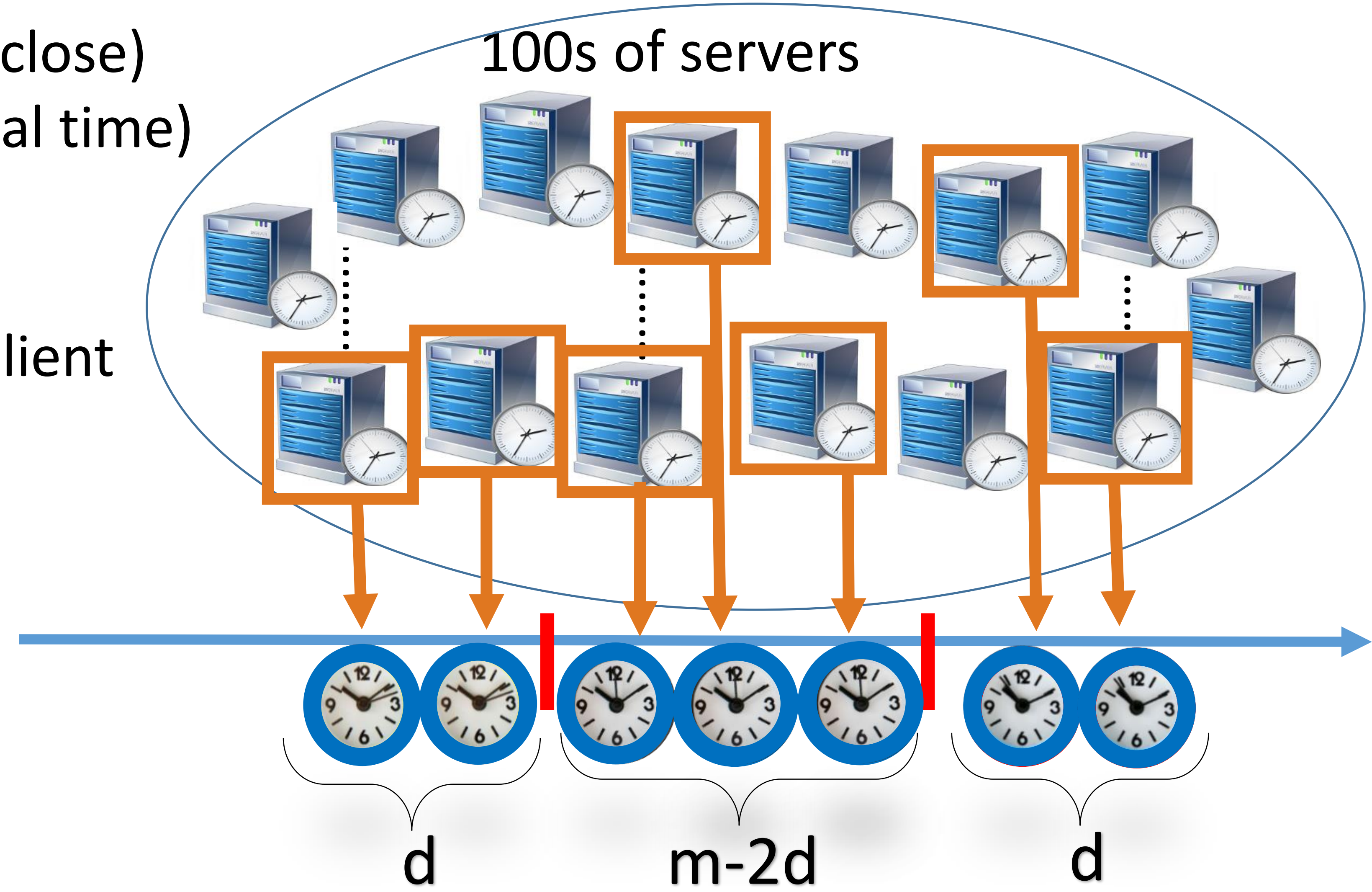

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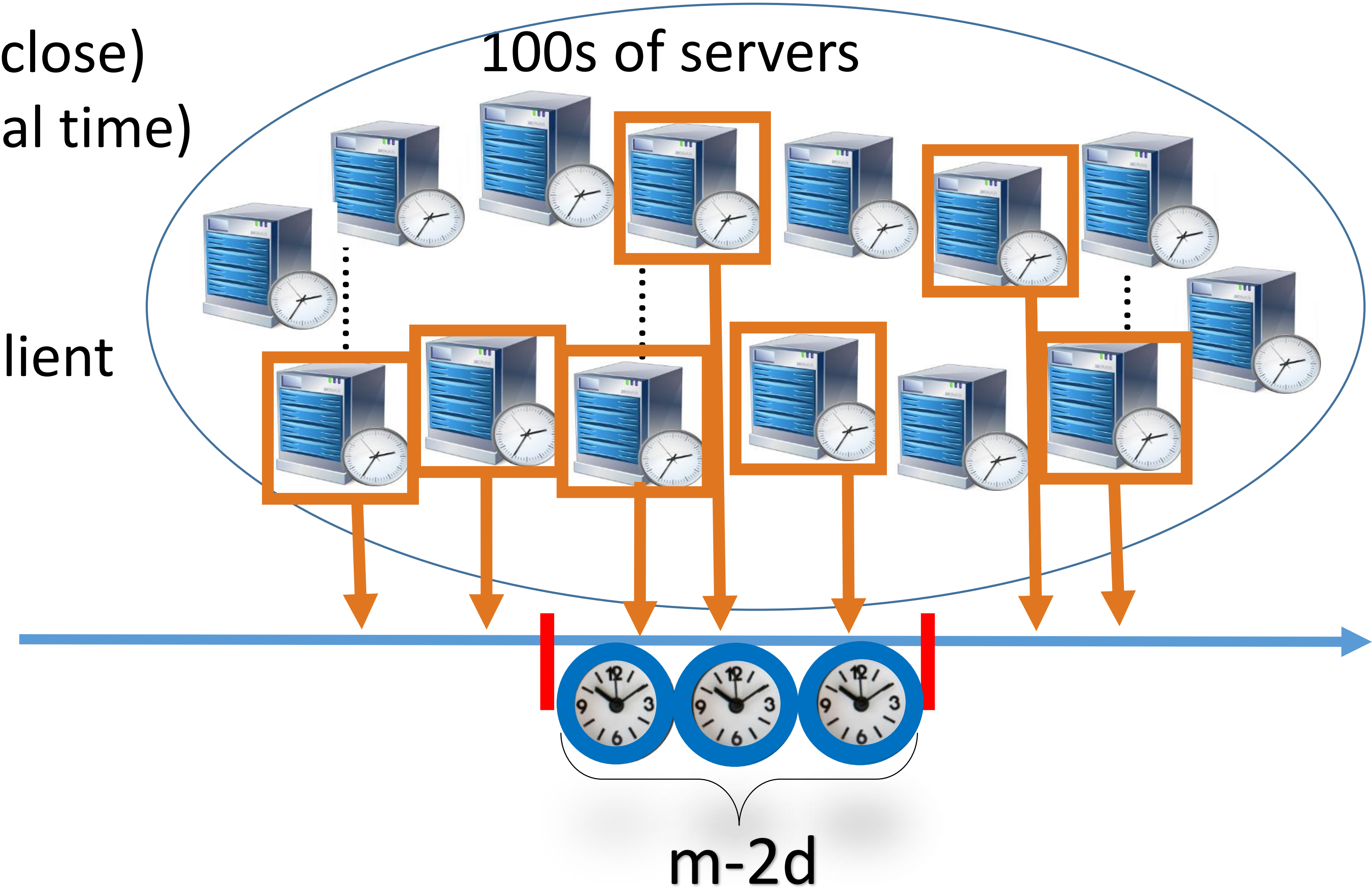

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if check & resample failed k times:

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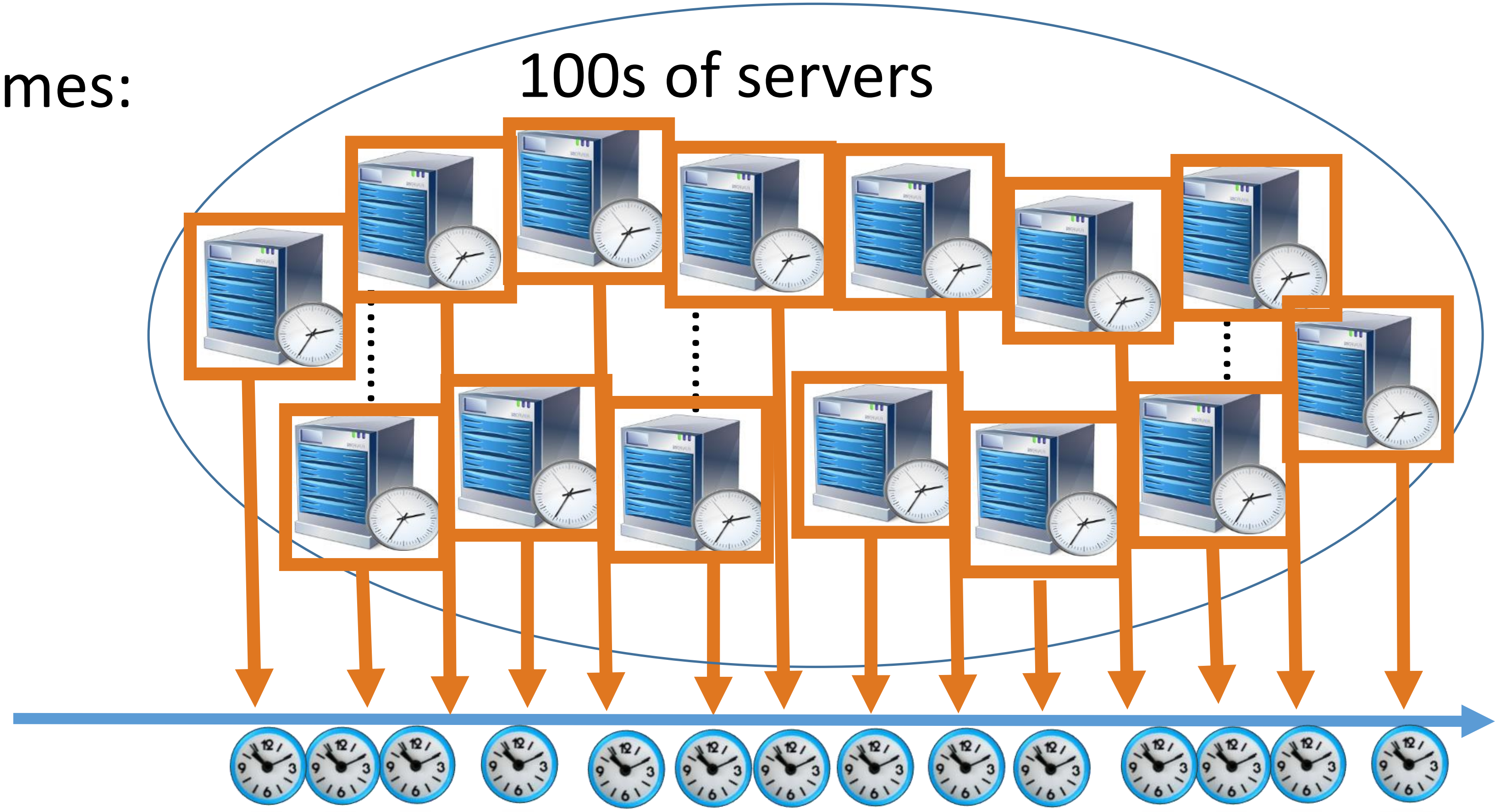
- Sample all servers



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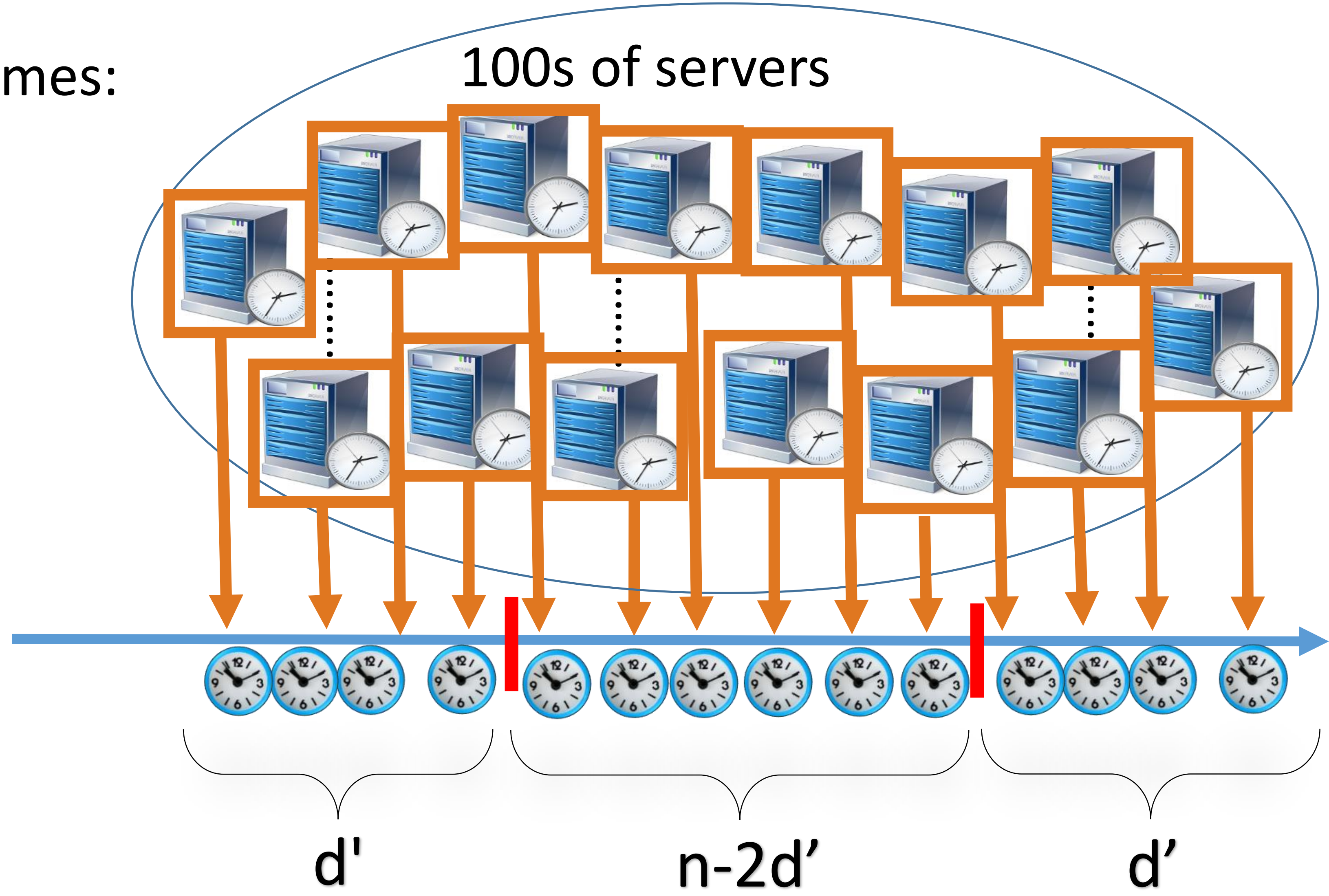

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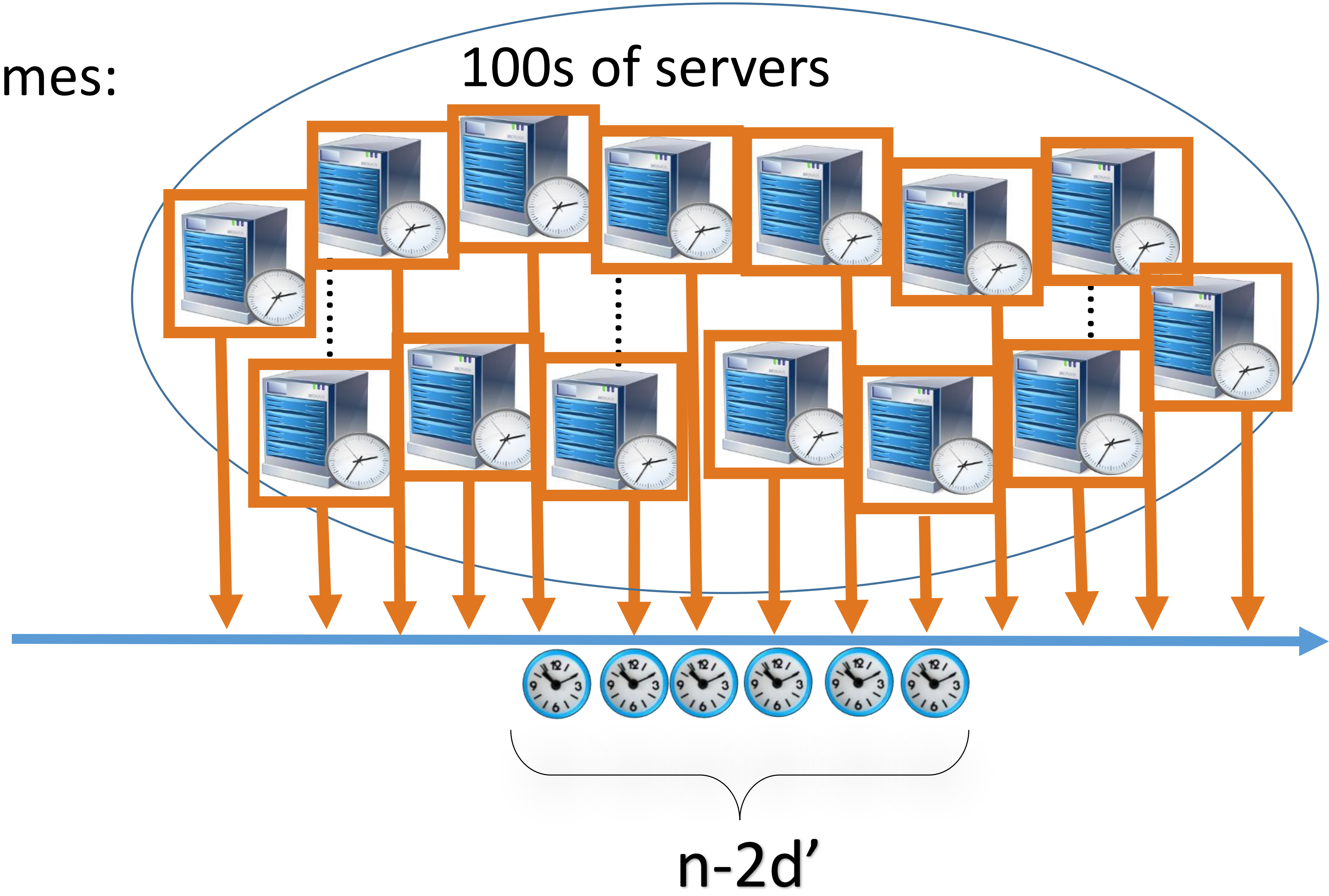

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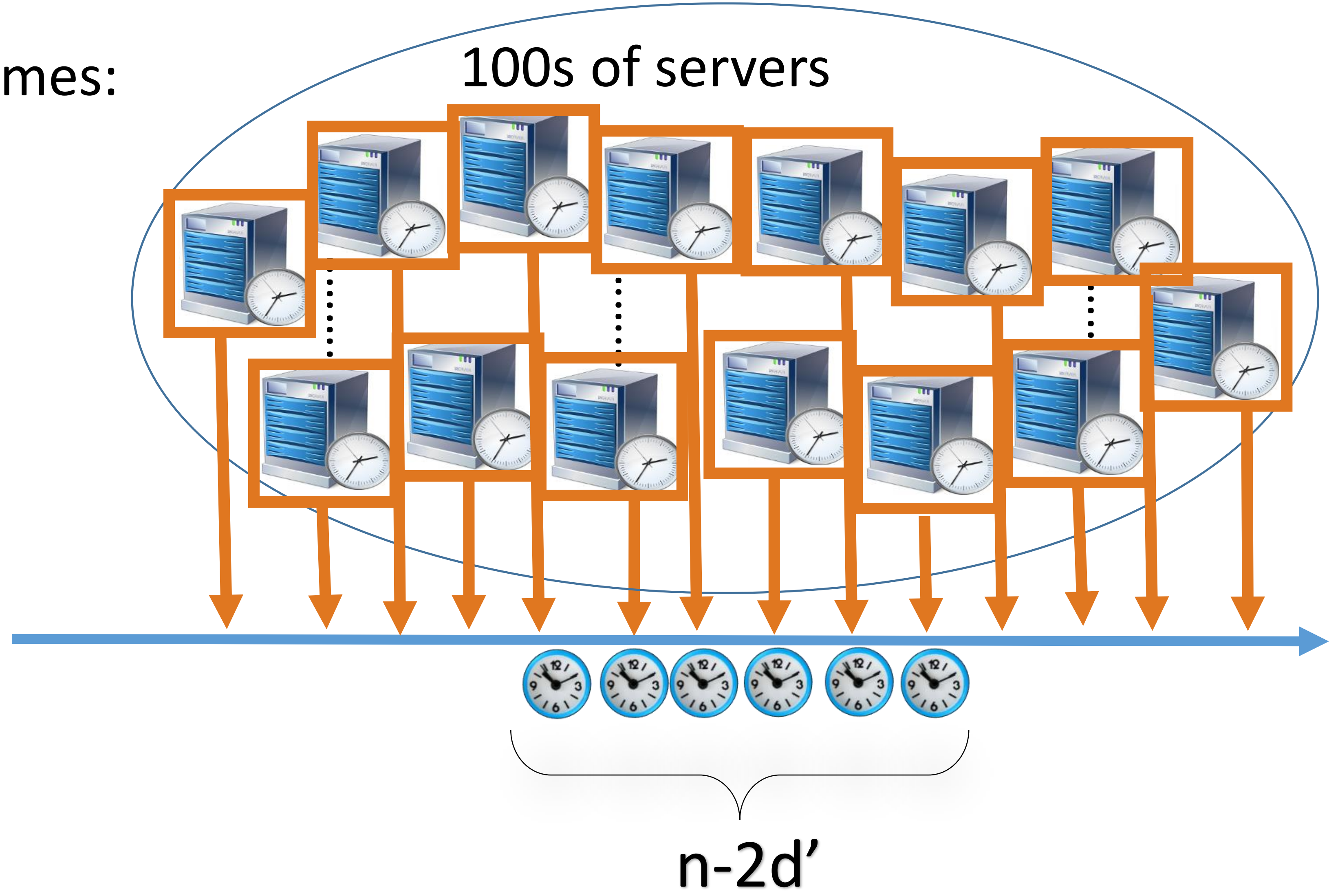

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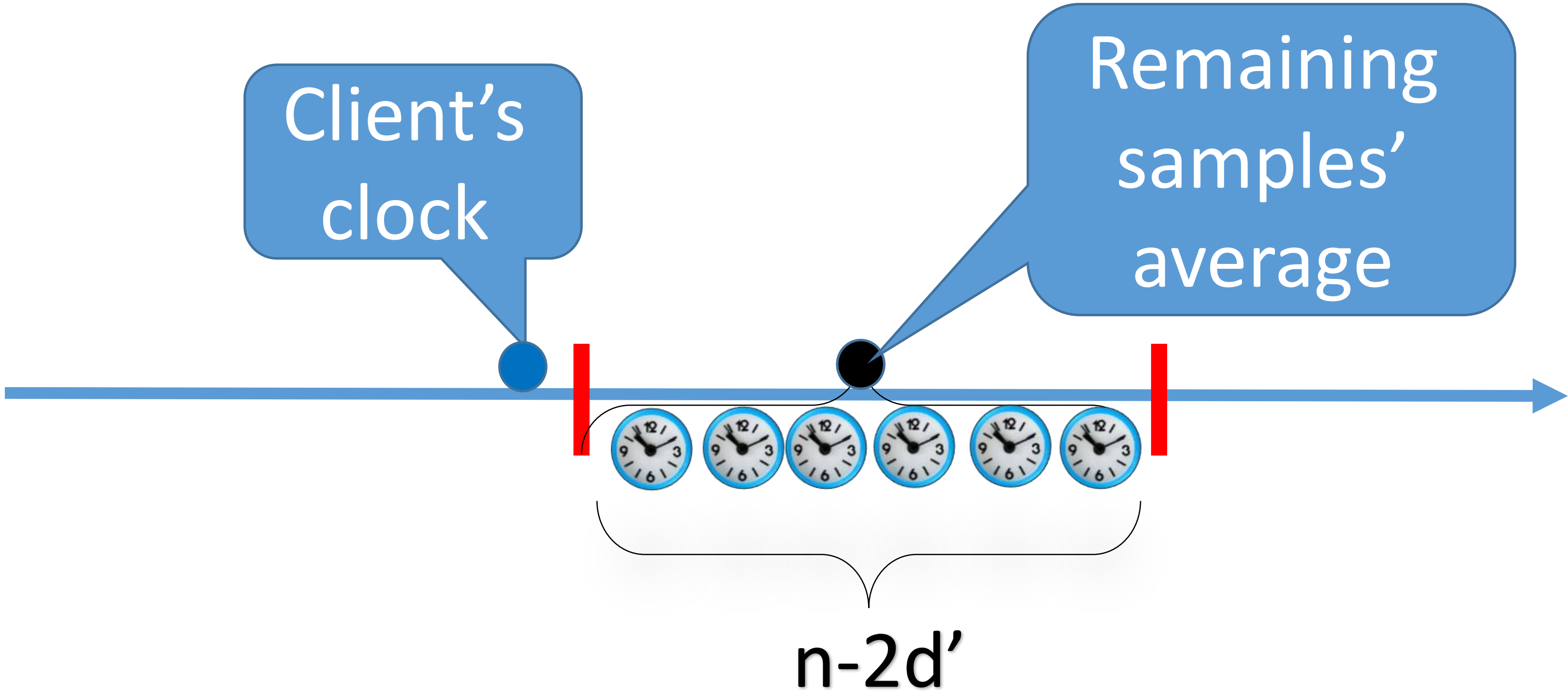

Client's clock

Remaining samples' average

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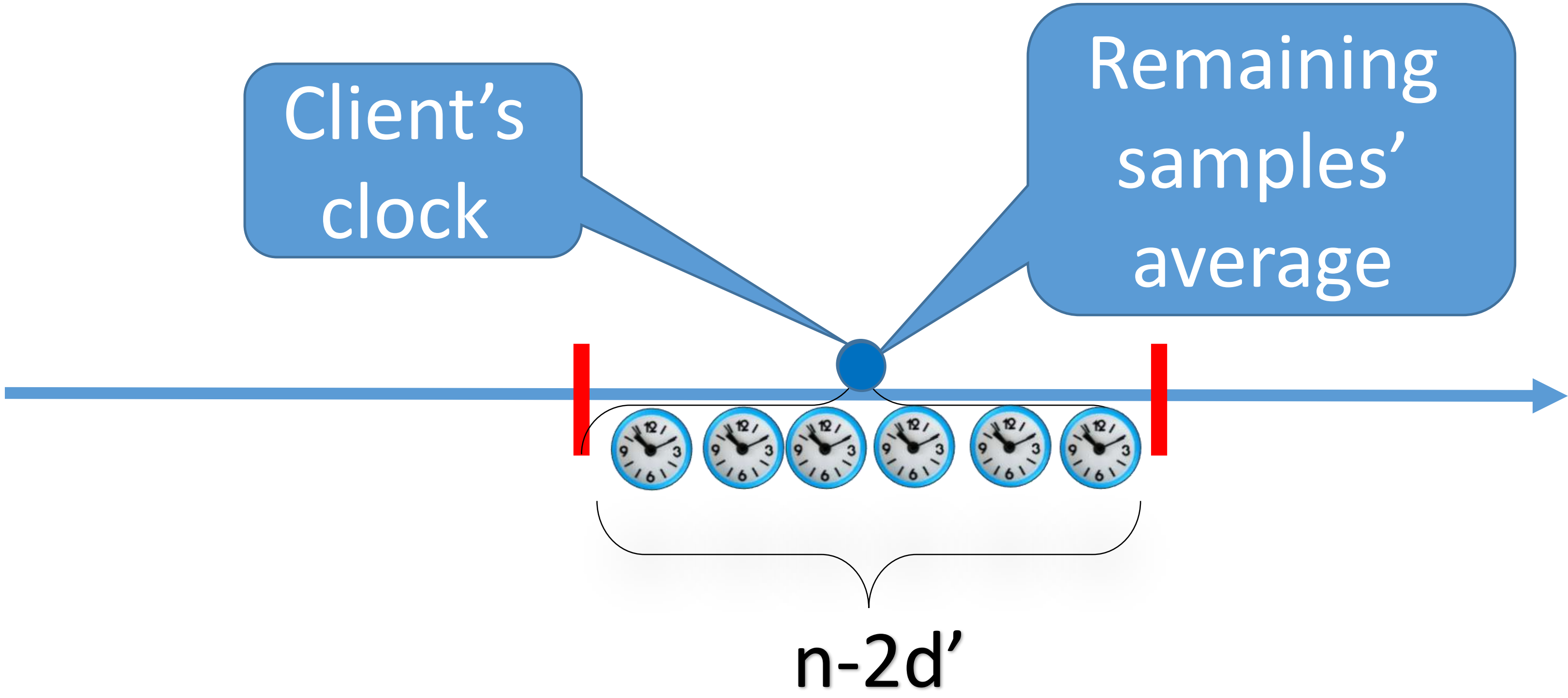


Security Guarantees

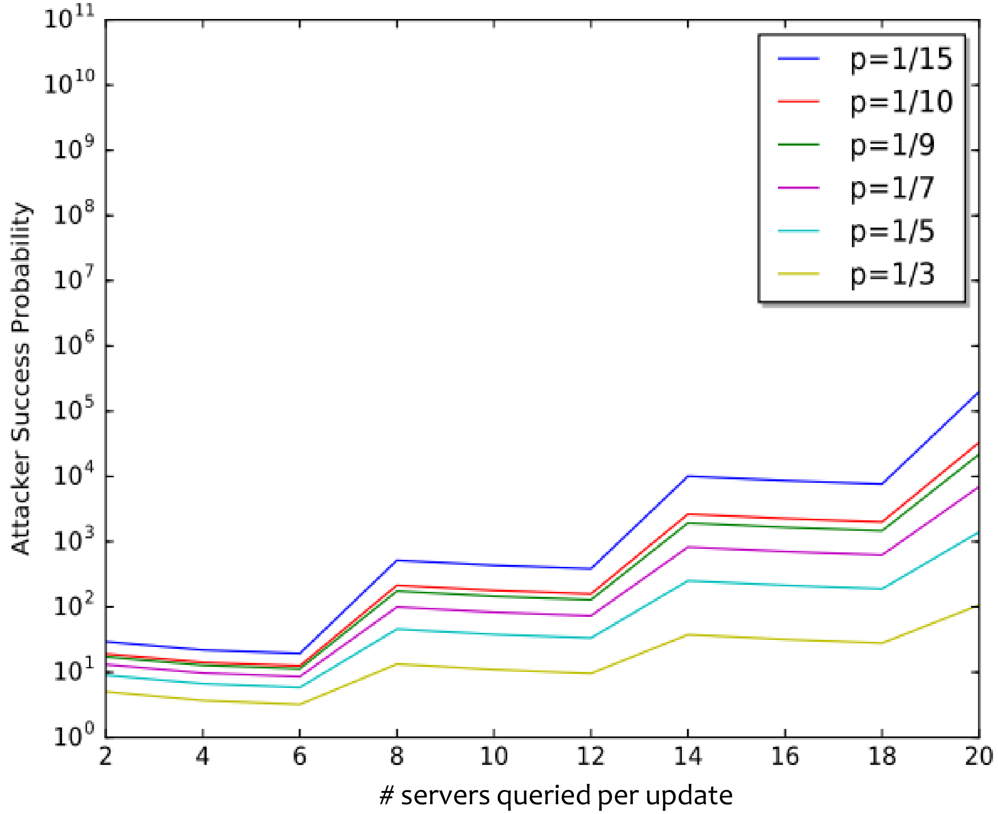
Shifting time at a Chronos client by at least **100ms** from the UTC will take the attacker at least **22 years** in expectation

- … when considering the following parameters:
  - Server pool of 500 servers, of whom 1/7 are controlled by an attacker
  - 15 servers queried once an hour
  - Good samples are within 25ms from UTC (ω=25)

- These parameters are derived from experiments we performed on AWS servers in Europe and the US

Chronos vs. Current NTP Clients

- Consider a pool of 500 servers, a p-fraction of which is controlled by an attacker.
- We compute the attacker's probability of successfully shifting the client's clock
  - ➢ for traditional NTP client
  - ➢ for Chronos NTP client
- We plot the ratio between these probabilities



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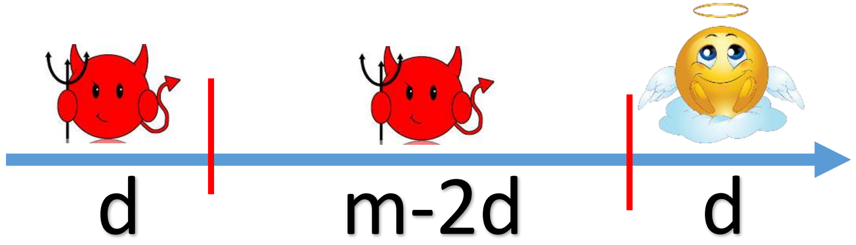

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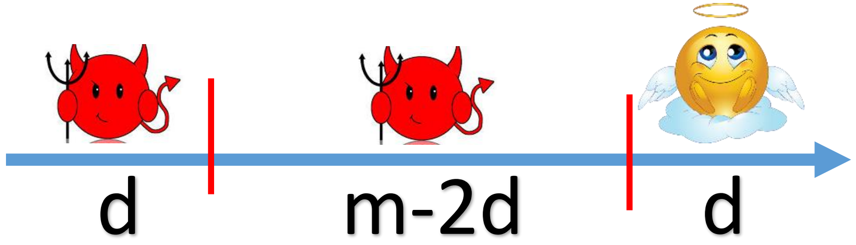

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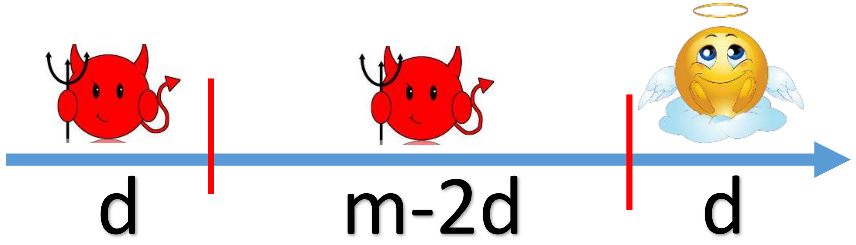

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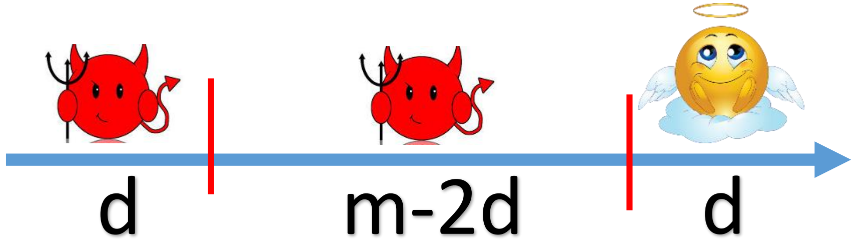

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Consequently, a significant time shift is practically infeasible

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Scenario 2: #(😇) > d #(😈) < m-d

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- **<u>Option I</u>**: Only malicious samples remain
  - <u>Assumption</u>: every good sample at most ω-far from UTC
  - At least one good sample on each side
    - → All remaining samples are between two good samples
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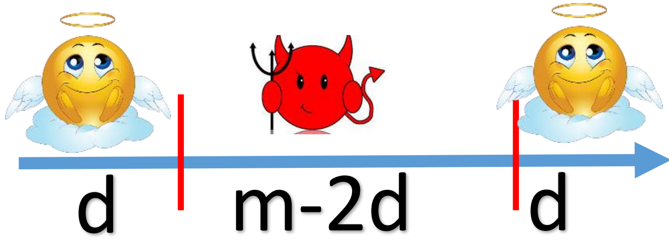

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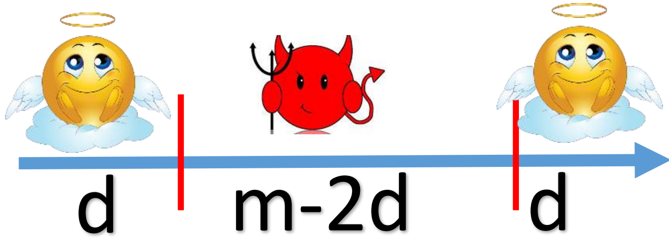
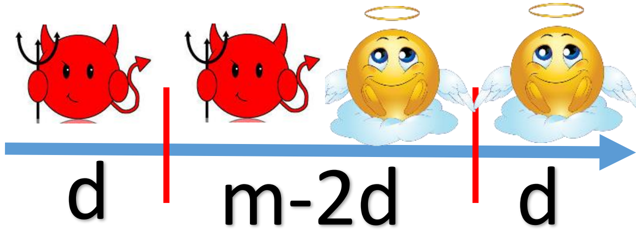


- **<u>Option II</u>**: At least one good sample remains



➢<u>Enforced</u>: Remaining samples within the same 2ω-interval

➢Remaining malicious samples are within 2ω from a good sample

→ Remaining malicious samples are at most 3ω-away from UTC

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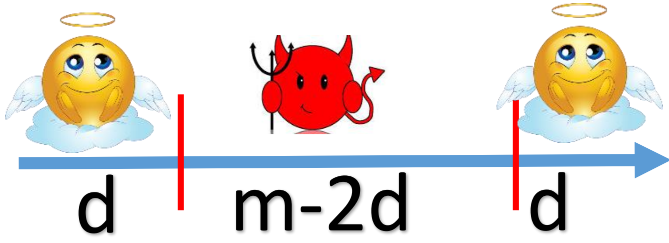

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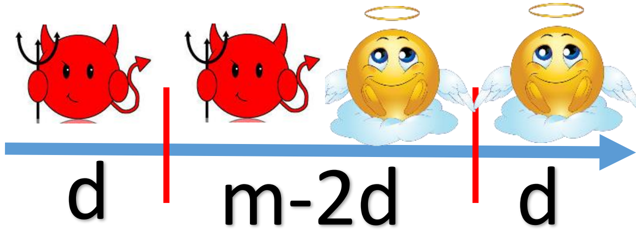

Hence, these attack strategies are ineffective

Can Chronos be exploited for DoS attacks?

- Chronos repeatedly enters Panic Mode.

- Optimal attack strategy requires that attacker repeatedly succeed in accomplishing #(😈) > d #(😇) < m-d
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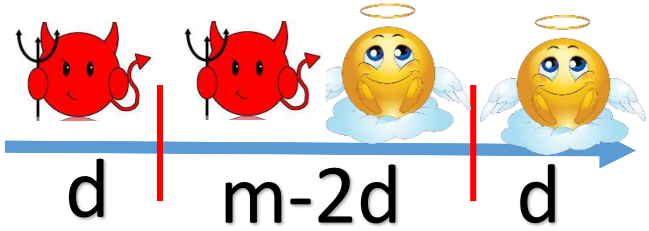

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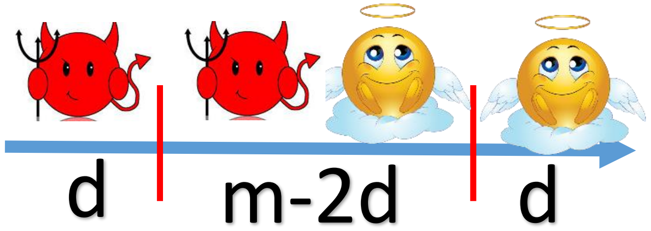

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Even for low Panic Threshold (k=3), probability of success is negligible (will take attacker decades to force Panic Mode)

Observations and Extensions

- When the pool of available servers is small (say, 3), using Chronos's sampling scheme on the entire server pool (n=m), yields meaningful deterministic security guarantees.

- Important implications for PTP security

Conclusion

- NTP is very vulnerable to time-shifting attacks by MitM attackers
  - ➢ Not designed to protect against **strategic** man-in-the-middle attacks
  - ➢ Attacker who controls a few servers/sessions can shift client’s time
- We presented the **Chronos NTP client**
  - ➢ Provable security in the face of powerful and sophisticated MitM attackers
  - ➢ Backwards-compatibility with legacy NTP (software changes to client only)
  - ➢ Low computational and communication overhead

Future Research

- Tighter security bounds?
- Weighing servers according to reputation?
- Benefits of server-side changes?
- Extensions to other time-synchronization protocols (e.g., PTP)?

Thank You

See full paper (@NDSS’18):
http://wp.internetsociety.org/ndss/wp-content/uploads/sites/25/2018/02/ndss2018_02A-2_Deutsch_paper.pdf