



# Complex Paths and Derelict Sentinels

software engineering underpinnings of recent NTP vulnerabilities

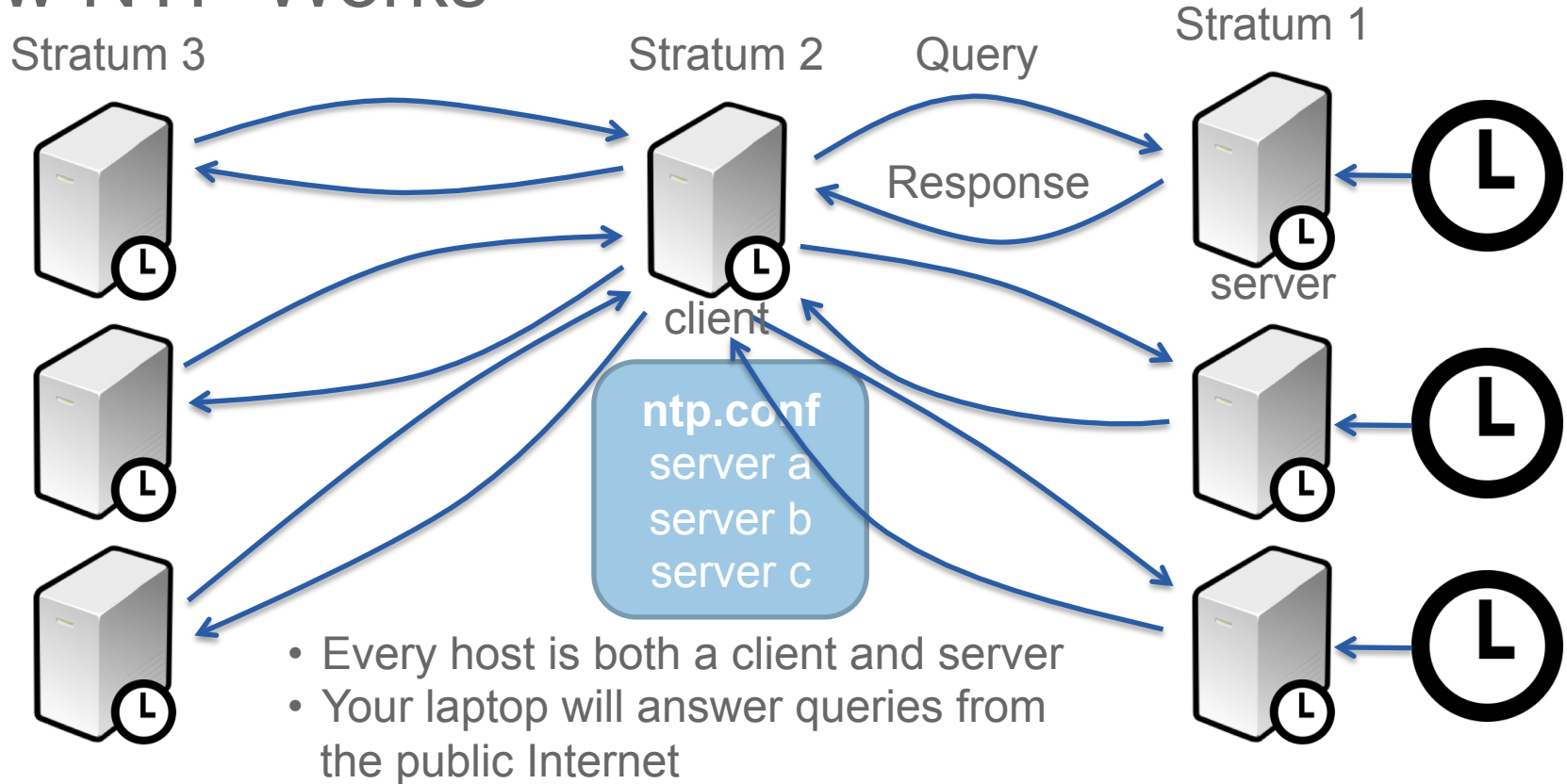
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All opinions expressed are  
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# How NTP Works



# Preventing Off-Path Impersonation Attacks

## NTP Packet

LI	Ver	Mode	Stratum (8)	Poll (8)	Precision (8)
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Root delay (32)

Root dispersion (32)

Reference Clock Id (32)

Reference Clock Timestamp (64)

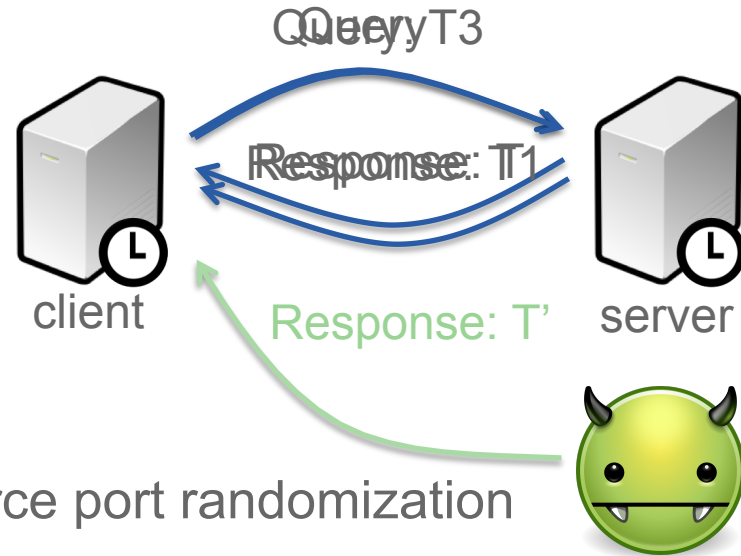
T1: Origin Timestamp (64)

T2: Receive Timestamp (64)

T3: Transmit Timestamp (64)

Keyid (32, optional)

Digest (128+, optional)



- No source port randomization
- TEST2: Drop packet unless T3 in query == T1 in response
- Transmit timestamp has  $\approx$  32-bits entropy
- Similar to TCP sequence number randomization

# NTP's packet consistency checks

```
def receive( pkt ):
    # ...
    if pkt.T3 == 0:
        flash |= test3 # fail test3
    elif pkt.T3 == org:
        flash |= test1 # fail test1
        return
    elif broadcast == True:
        pass # skip further tests
    elif interleave == False:
        if pkt.T1 == 0:
            xmt = 0
        elif (xmt == 0 or pkt.T1 != xmt):
            flash |= test2 # fail test2
            if (rec != 0 and pkt.T1 == rec):
                interleave = True
            return
        else:
            xmt = 0 # pass test2, clear xmt
    elif (pkt.T1 == 0 or pkt.T2 == 0):
        flash |= test3 # fail test3
    elif (rec != 0 and rec != pkt.T1):
        flash |= test2
        return # fail interleave test2
    if auth in { ERROR, CRYPTO } \
        or (need_auth and auth != OK):
        return
    if interleave == False:
        rec = pkt.receive_time()
    org = pkt.T3
    if flash == True:
        return
    else:
        process( pkt )
    if interleave == True:
        rec = pk.receive_time()
```

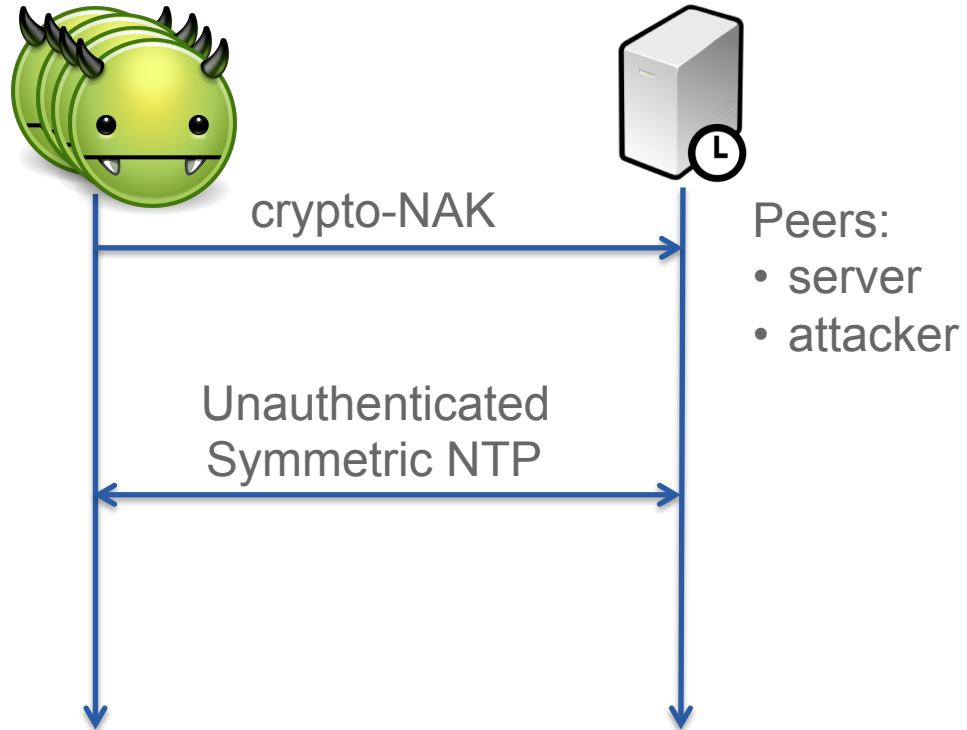
# Crypto-NAK Packets

- “Ephemeral associations are mobilized upon the arrival of a packet and are **demobilized upon error** or timeout.”
- Authentication errors elicit a crypto-NAK response
- Handled “late”, during other packet consistency checks
- Authentication states:  
{ NONE, OK, ERROR, **CRYPTO** }

NTP Crypto-NAK Packet					
LI	Ver	Mode	Stratum (8)	Poll (8)	Precision (8)
Root delay (32)					
Root dispersion (32)					
Reference Clock Id (32)					
Reference Clock Timestamp (64)					
T1: Origin Timestamp (64)					
T2: Receive Timestamp (64)					
T3: Transmit Timestamp (64)					
<i>Keyid (32, optional) == 0x00000000</i>					
<i>Digest (128+, optional)</i>					

# NAK to the Future Vulnerability (CVE-2015-7871)

- Most ephemeral associations
  - auth in {ERROR, CRYPTO}: reject
  - auth == NONE: reject if auth required
  - else: mobilize
- Symmetric active mode packets
  - auth in {NONE, ERROR}: Special handling for certain broken clients
  - else: mobilize
  - (auth == CRYPTO): crypto-NAK packets mobilize new symmetric associations
- keyid == 0: **Unauthenticated association**



# Refclock spoofing

