Complex Paths and Derelict Sentinels

software engineering underpinnings of recent NTP vulnerabilities

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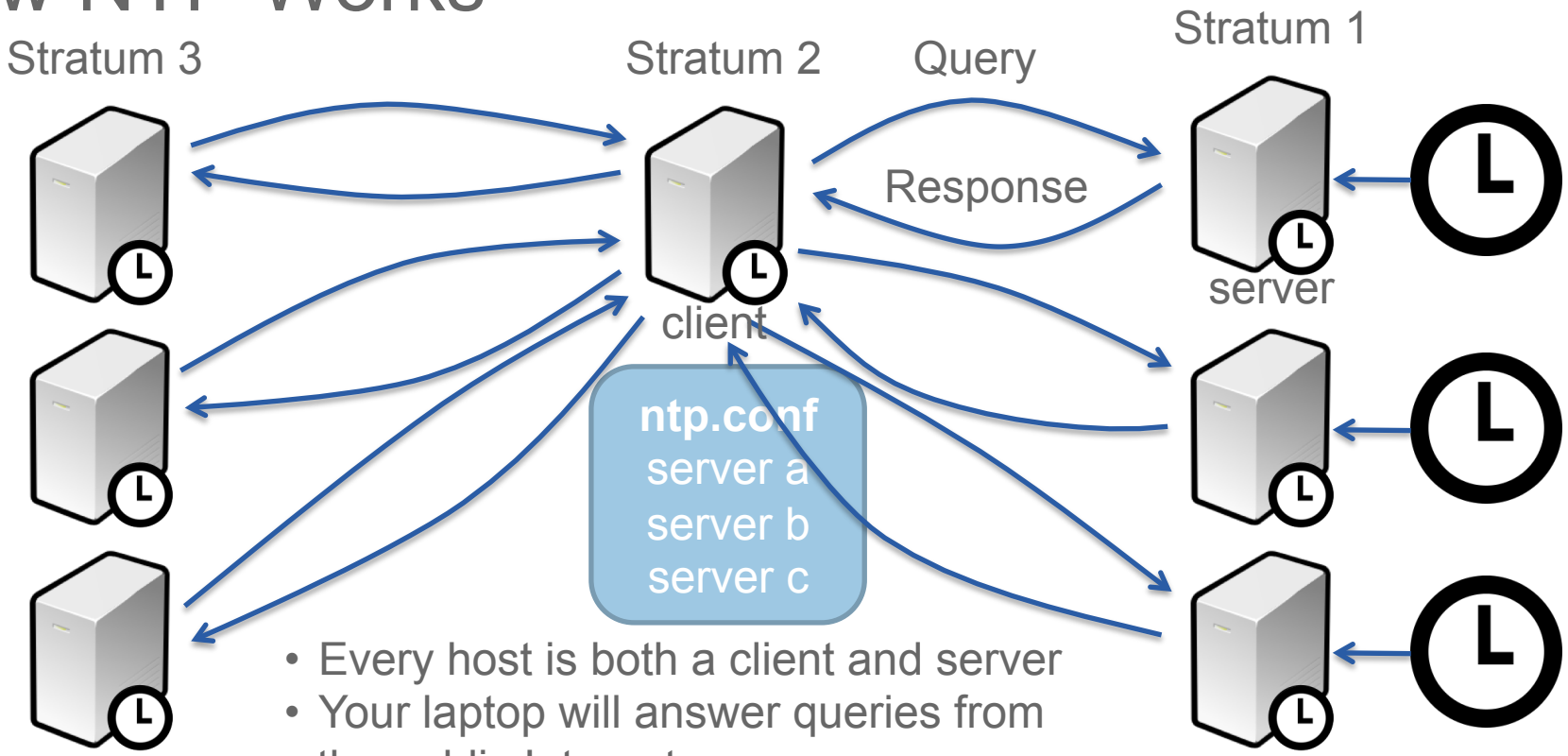
How NTP Works



- Every host is both a client and server
- Your laptop will answer queries from the public Internet

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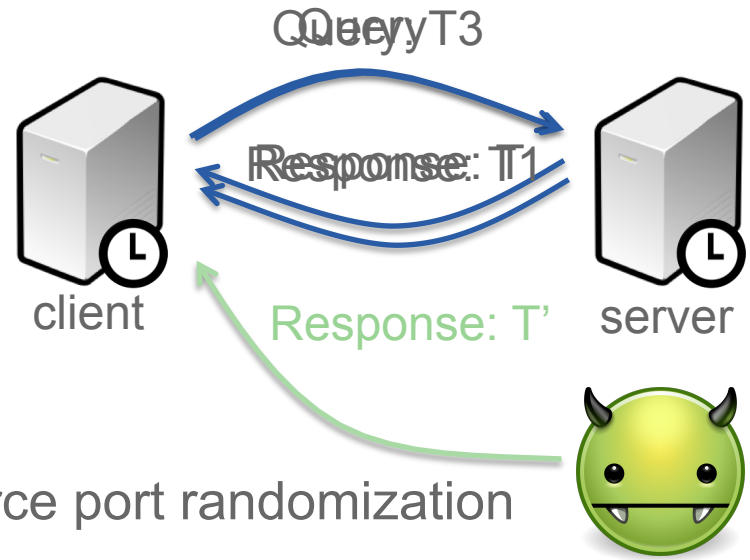
Slide Credit: Sharon Goldberg & Aanchal Malhotra

Preventing Off-Path Impersonation Attacks

NTP 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)					
Keyid (32, optional)					
Digest (128+, optional)					



- No source port randomization
- TEST2: Drop packet unless T3 in query == T1 in response
- Transmit timestamp has ≈ 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					
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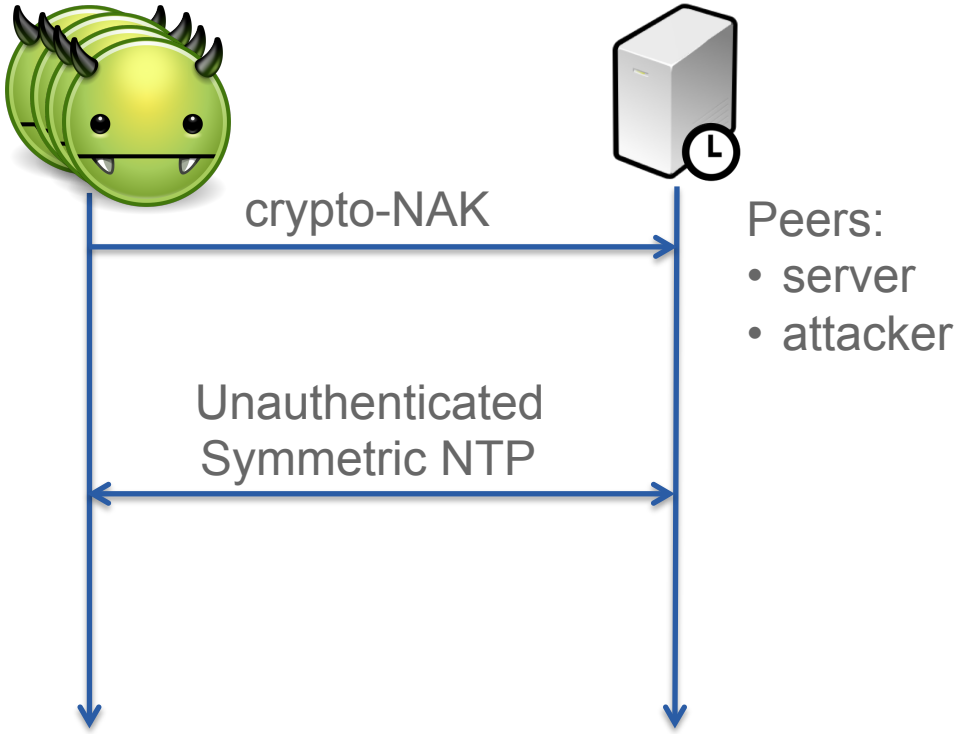
Reference Clock Timestamp (64)					
T1: Origin Timestamp (64)					
T2: Receive Timestamp (64)					
T3: Transmit Timestamp (64)					
Keyid (32, optional) == 0x00000000					
~~*Digest (128+, optional)*~~					

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