Synchronisation Challenges for Wireless Networks

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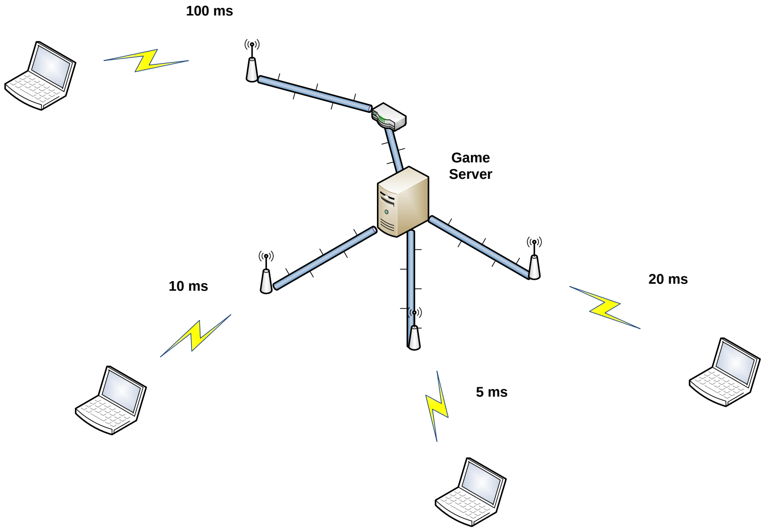
Introduction

- Synchronisation applications
- Computer Clocks
- Synchronisation Protocols
- Wireless Issues
- Wireless Sensor Networks (WSNs)
- WSN Time protocols
- Current Work

Synchronisation Applications

- **MMOG (Massive Multiplayer Online Game)**
  - Game server/s handles 1000s of players simultaneously
  - Those further away experience slower response times – Game unfair
  - Synchronise clients – Game server slows packet stream to nearer server
  - Result – equal response times to all



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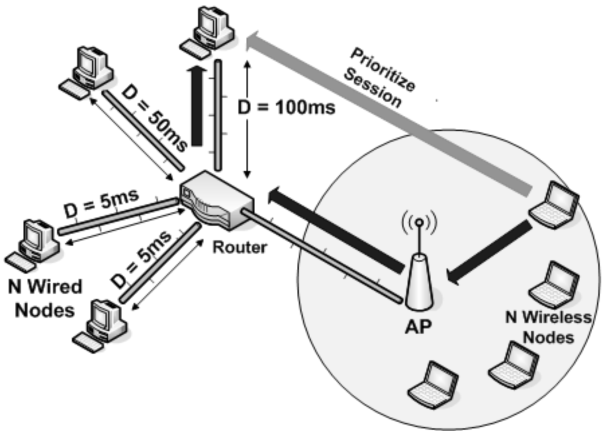
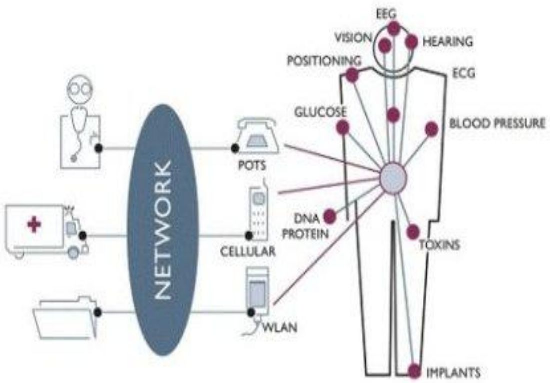
Synchronisation Applications

- **VoIP**
  - **Congested traffic in 802.11 network - large M2E delays (>150ms) for clients further away**
  - **Synchronise clients – AP determines clients further away and prioritises their traffic**
  - **Result – network can help equalise QoS for all VoIP clients**

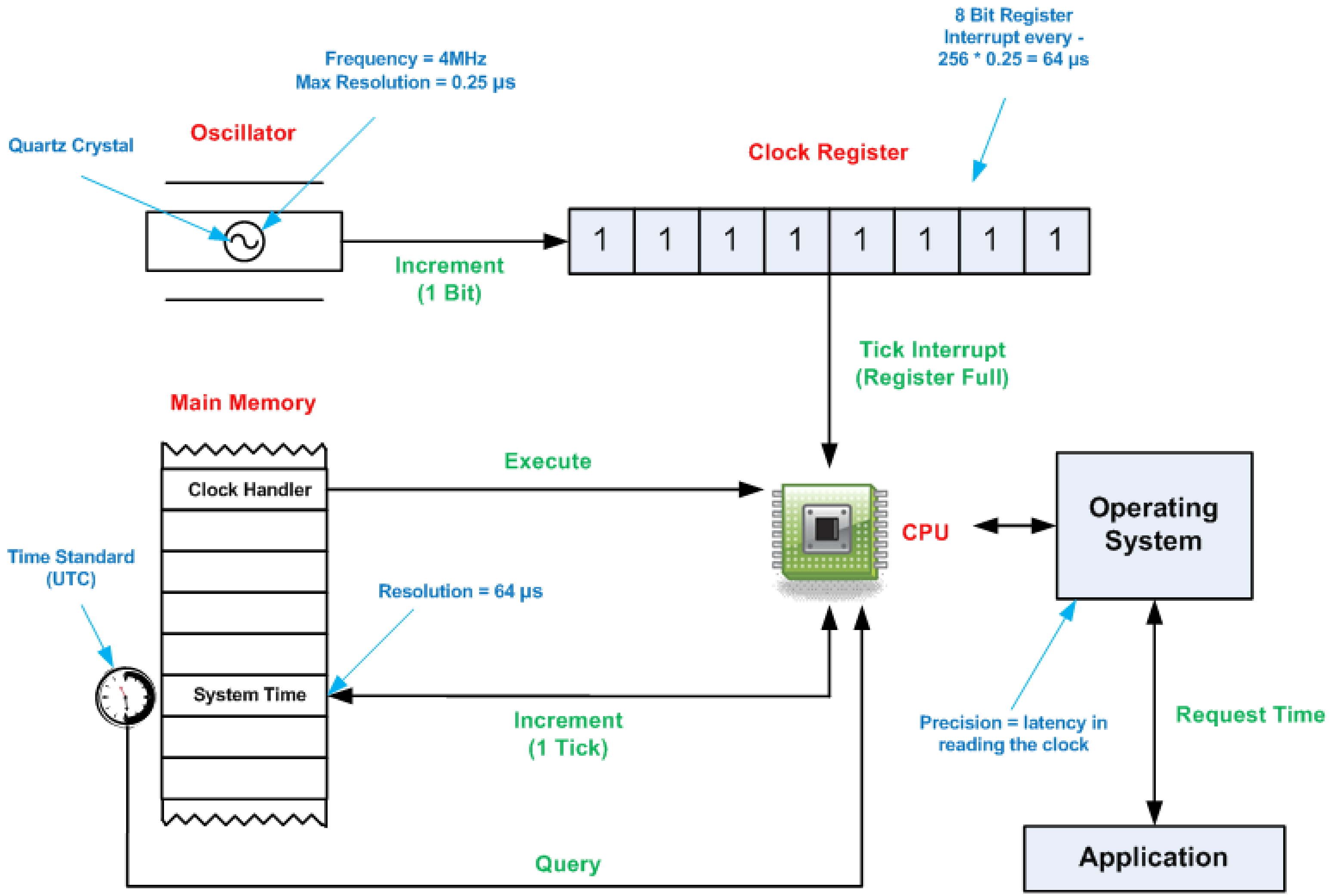


Synchronisation Applications

- **WBAN (Wireless body Area network)**
  - Sensors measure vital parameters of body – heart beat, blood pressure, temperature etc.
  - Data transmitted to base station – collated and structured for analysis
  - Better evaluation of condition based on analysis of multiple parameters
  - Must timestamp sensor data – compare different parameters at specific time
  - Requires synchronised sensors

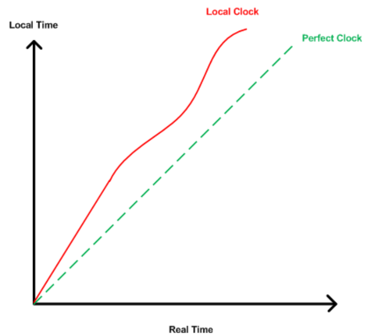


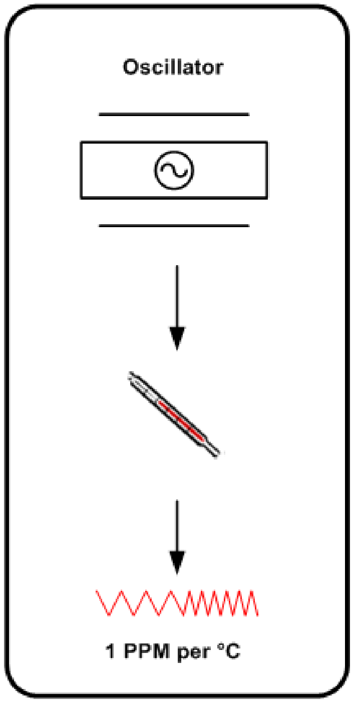
Computer Clock Operation



Computer Clocks

- Typical computer clocks based on mechanical vibration of **quartz crystal**
- Frequency of quartz oscillator dictated by –
  - Shape of crystal (disk, fork)
  - Physical environment (temperature, pressure, power)
- Clock subject to temporary and permanent frequency offsets
- Results in significant drift from real time
- Typical quartz clocks can have errors of **10** to **100 ppm** (i.e. **1** to **9** s per day)





Computer Clocks

- Can increases clock accuracy by –
  - Selecting cut for specific environment (lowest temperature coefficient)(XOs)
  - Controlling operating environment (OCXOs)
  - Use an atomic based clock
- Costly approaches
- Require more feasible solution - Time synchronisation protocols

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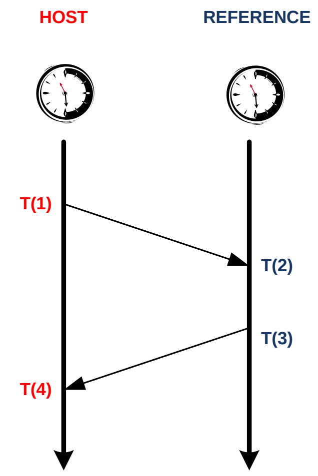
Time Synchronisation

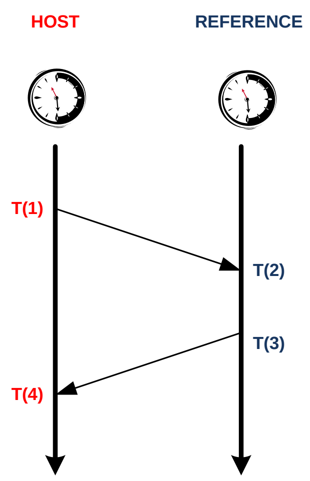
- **Pair-wise synchronisation** - common approach
  - **Refer to external time reference which is connected via some communication link**
  - **Obtain timestamps T(1), T(2), T(3) and T(4)**
  - **Determine propagation time and hence clock offset**
  - **Correct time**
- **Issue**
  - **assumes symmetrical network delays**
  - **Large asymmetrical delays degrade performance**



$$\Delta = \frac{T(2) + T(3) - T(1) - T(4)}{2}$$

Sources of Synchronisation Error

- **Un-deterministic message latencies**
- **Send Time**
  - Construct message & send to NIC (context switches, system calls)
- **Access Time**
  - Access communication medium (MAC rules)
- **Propagation Time**
  - Traverse link between sender and receiver
  - Speed of signal, queues and access times in network nodes
- **Receive Time**
  - NIC receive time & application receive time



$$\Delta = \frac{T(2) + T(3) - T(1) - T(4)}{2}$$

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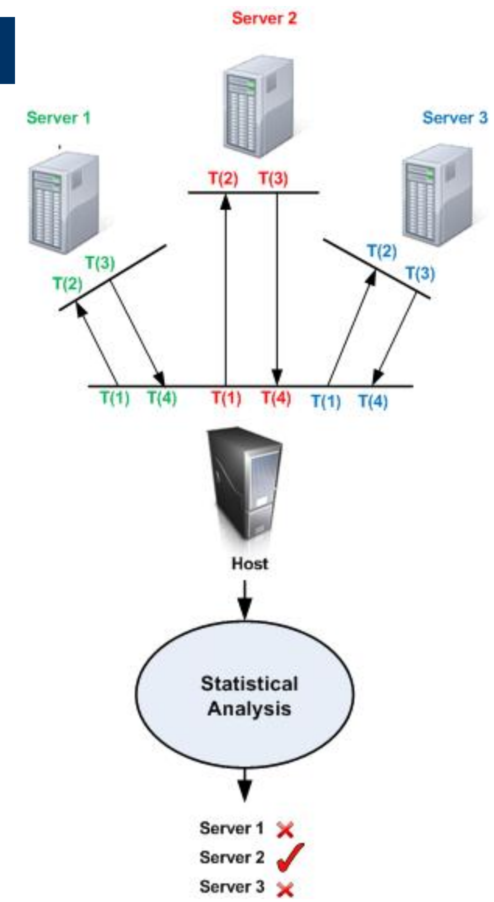
NTP

- Designed for **dynamic** and **variable latency** packet-switched networks
- Host obtains time from multiple time references
- Uses proven statistical methods to determine most accurate reference
- Sub-millisecond accuracies LAN .. Less so on WAN



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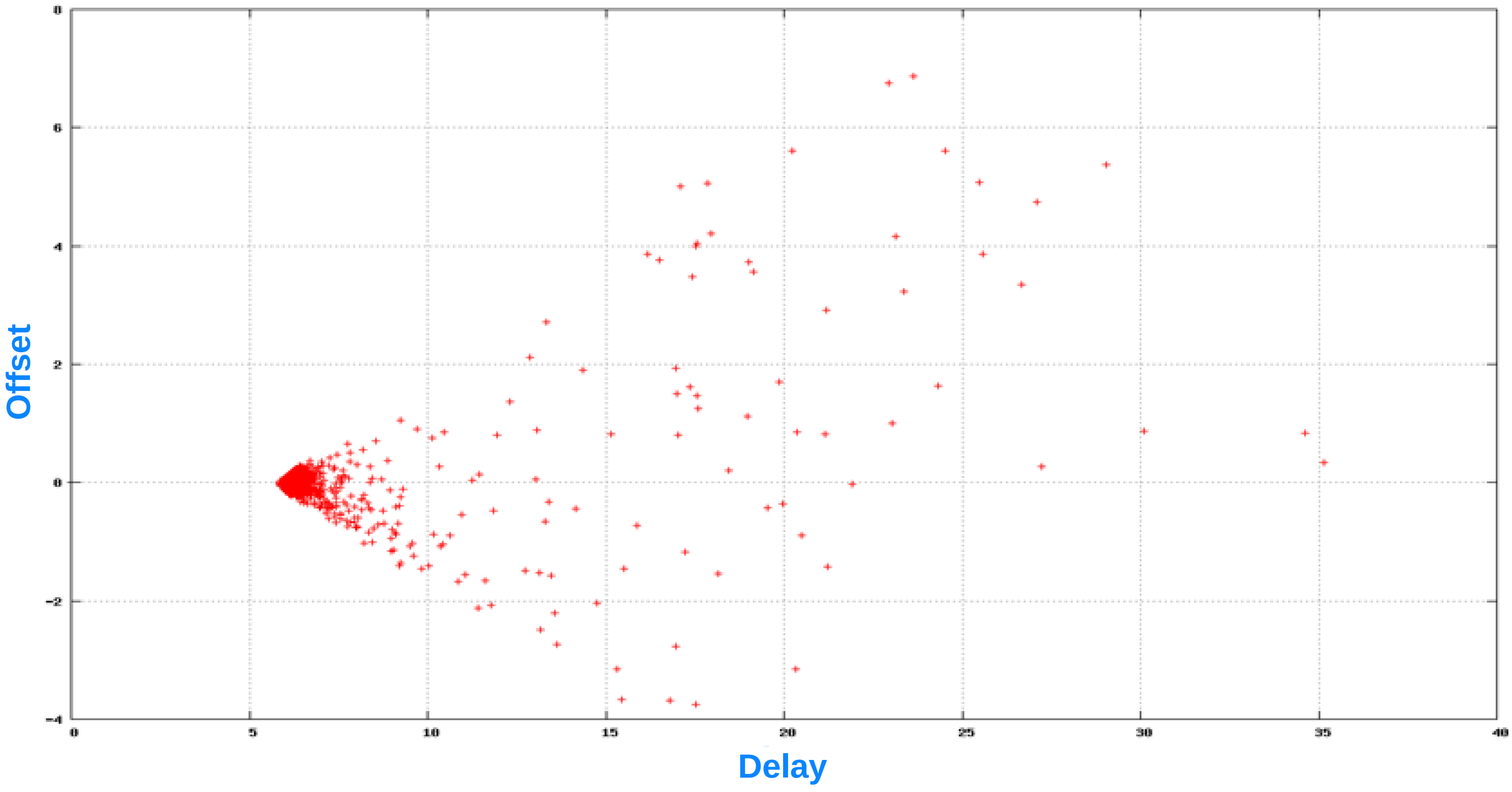
NTP

- **How NTP mitigates effects of potential asymmetry –**

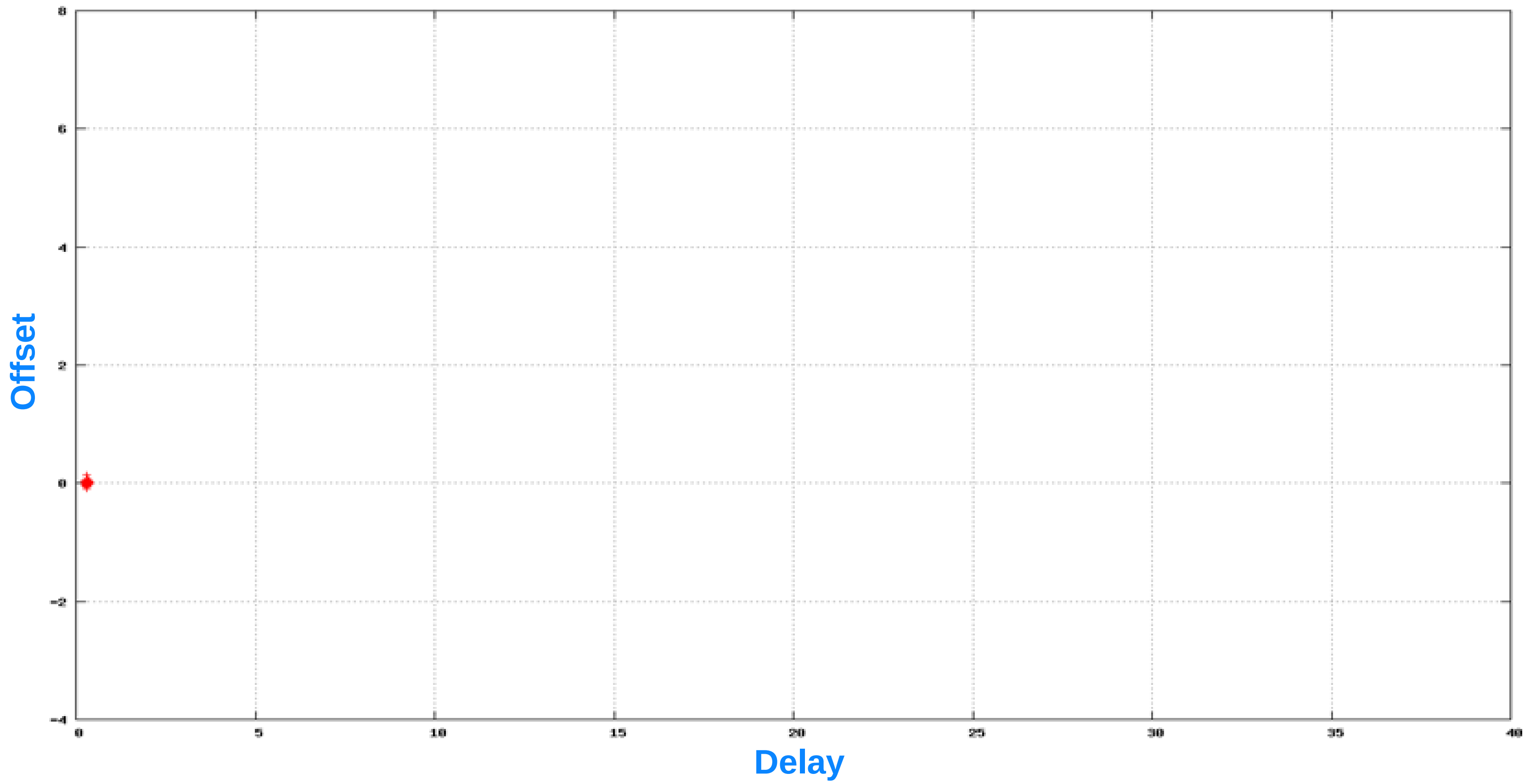
- **Multiple references**
  - **Majority rules – eliminate those that disagree with majority (falsetickers)**
  - **Combine offsets of most accurate references – more accurate final estimation of offset**

- **Clock Filter algorithm**
  - **Packets with lowest round-trip delay – more accurate data calculation of propagation delay**

NTP



NTP



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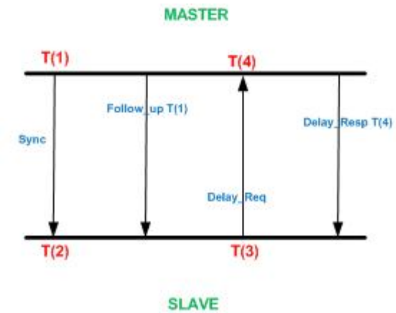
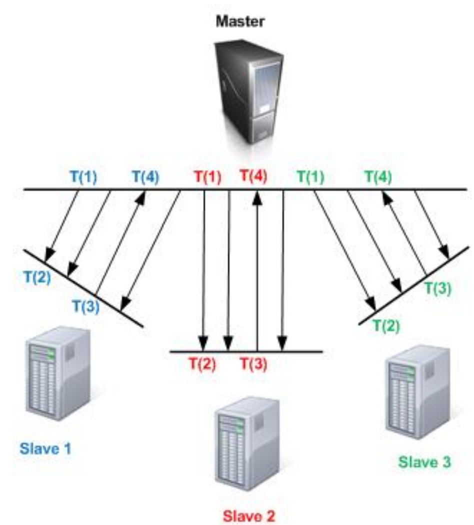
PTP

- Designed for **local managed networks**
- Host obtains time from a single designated master clock
- Network's composite nodes (switches, hubs) may be PTP aware - eliminate residence time
- PTP hardware may be used – timestamp packets at physical layer
- Sub-microsecond accuracy





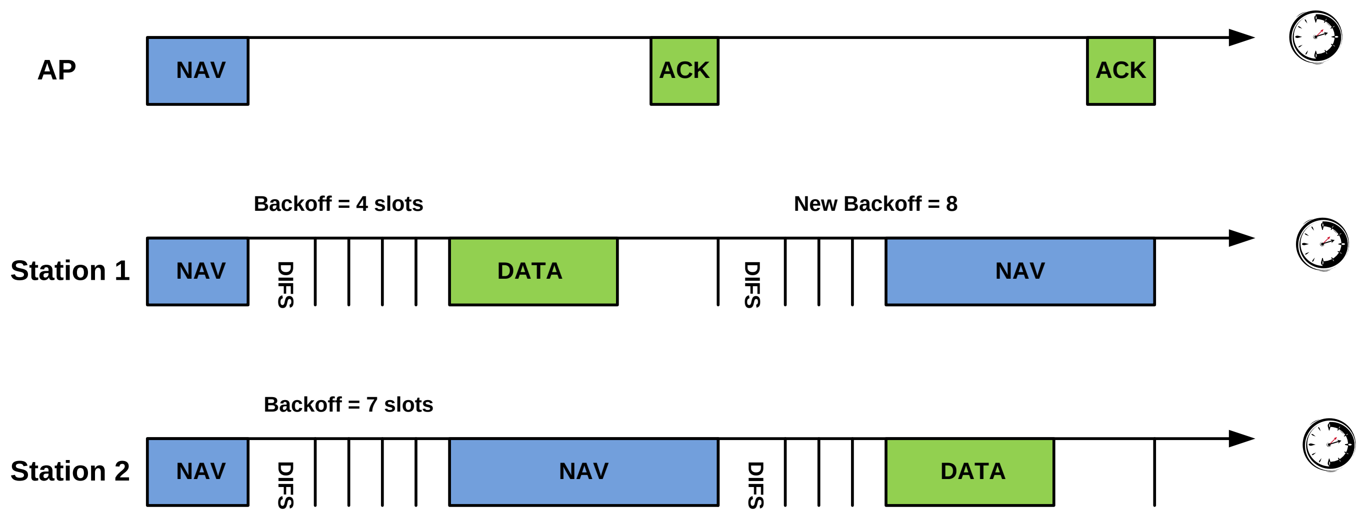
Issues

- NTP and PTP use **pair-wise synchronisation** - assume symmetrical network delays
- Large asymmetrical delays degrade performance
- Perform well over **wired networks** (good network infrastructure reduces traffic congestion)
- **Wireless networks** pose bigger problem
- Shared medium → high contention delays → asymmetric delays

802.11

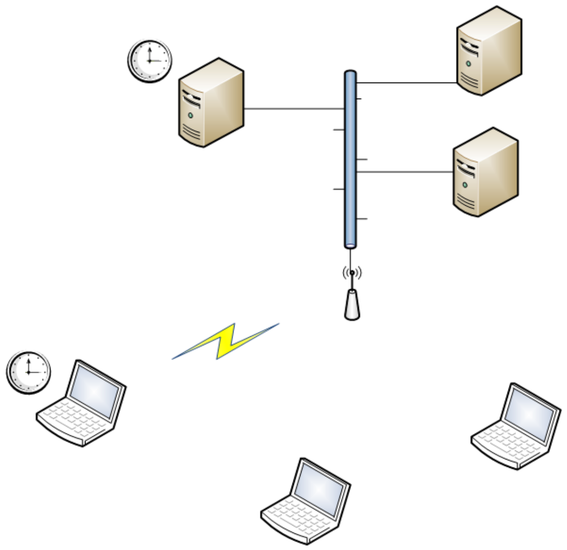
- **802.11 access rules**
  - **Access controlled by the Distributed Coordination Function (DCF)**
  - **DCF uses CSMA/CA**
  - **Checks medium is free using virtual (NAV) and physical carrier sensing**
  - **NAV counter – represnts time medium is reserved for**
  - **If medium is busy, backs off for random time interval to avoid collision**
  - **Failed transmission results in double the contention window (bounds on random time interval)**

802.11


AP
NAV
ACK
ACK
Backoff = 4 slots
New Backoff = 8
Station 1
NAV
DIFS
DATA
DIFS
NAV
Backoff = 7 slots
Station 2
NAV
DIFS
NAV
DIFS
DATA

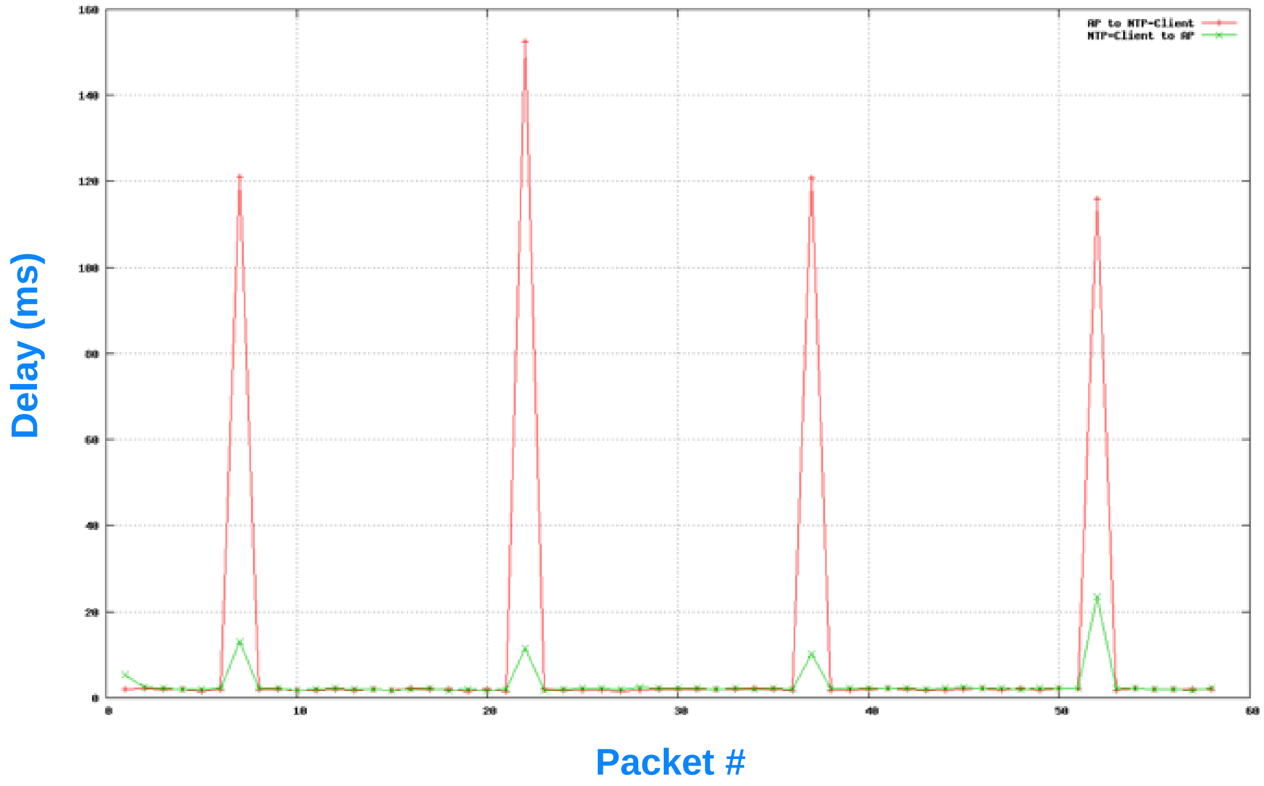
NS2

- Simulated transport of NTP packets over 802.11
  - 60 minute simulations – NTP request every minute
  - Web -clients download web-pages at minute intervals – Initially random
  - WebPages – 312KB – Average webpage size



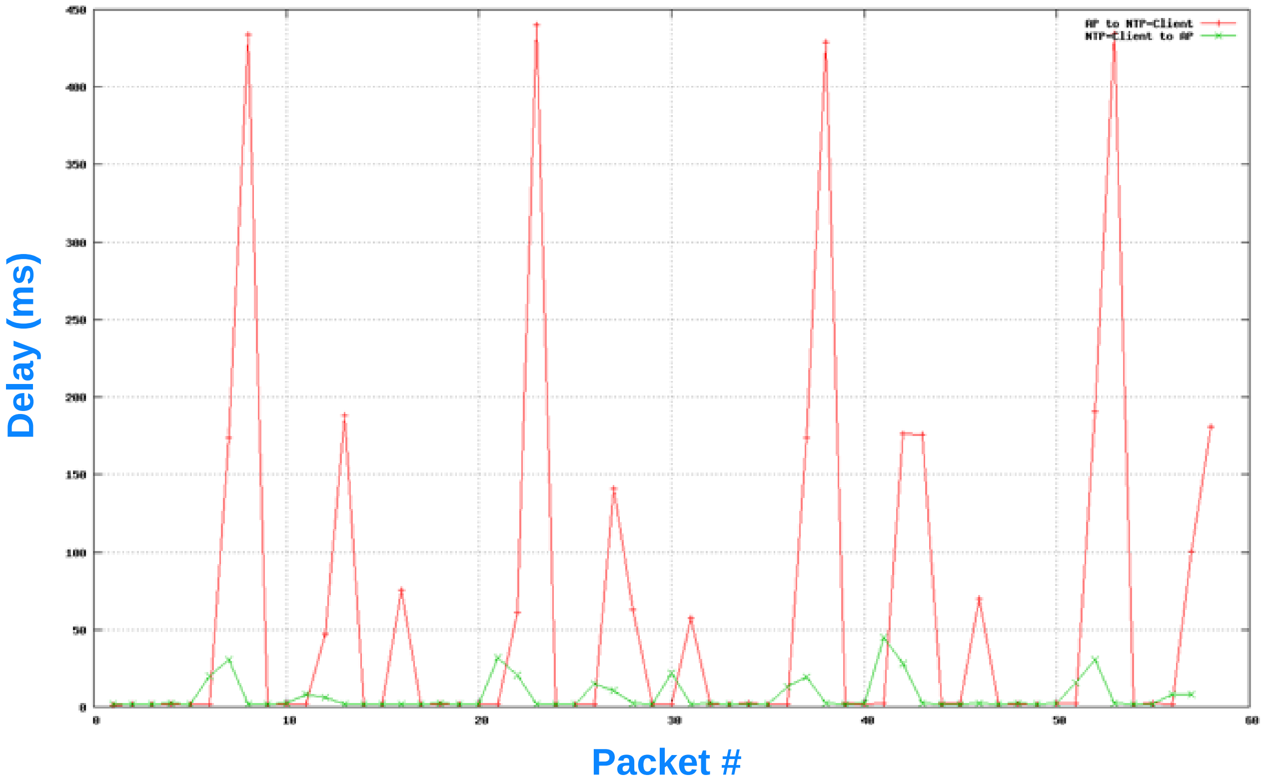
NS2

- 1 Competing Web-client -> Max asymmetrical delay of 140 ms



NS2

- 5 Competing Web-clients → Max asymmetrical delay of 440 ms



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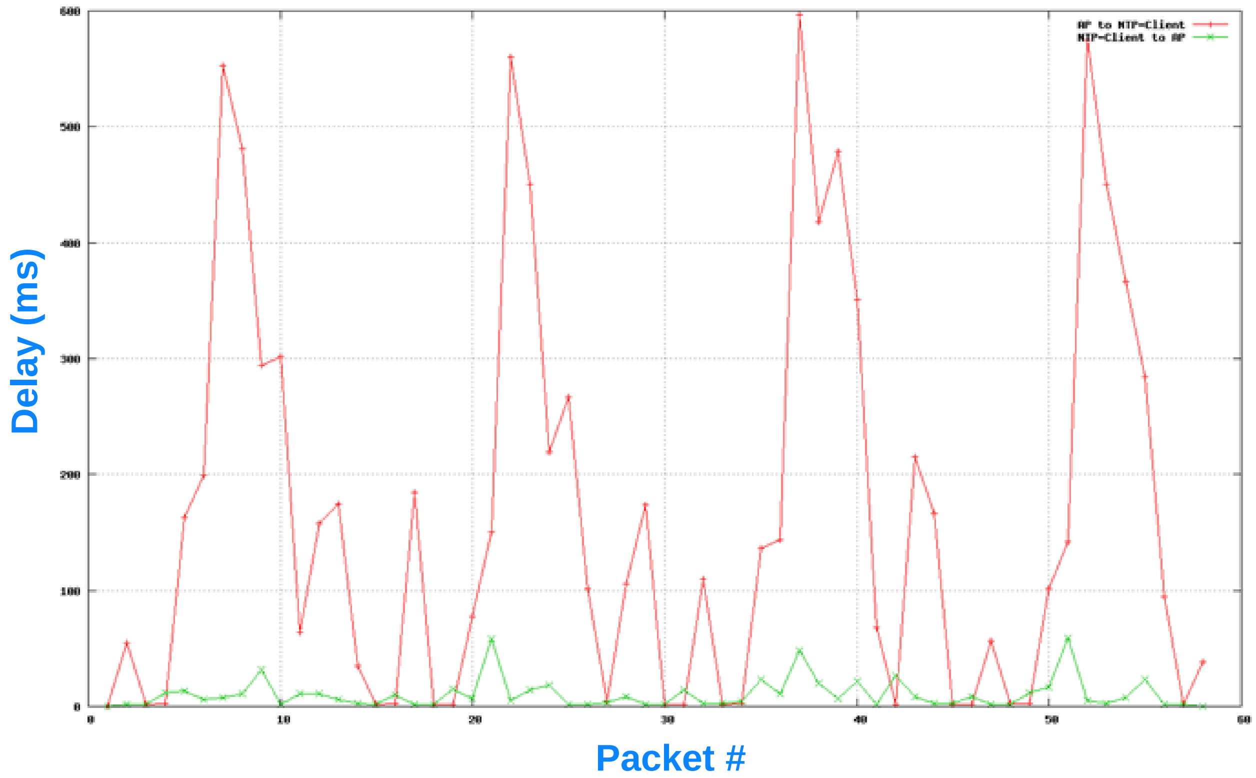
NS2

- 10 Competing Web-clients → Max asymmetrical delay of 580 ms



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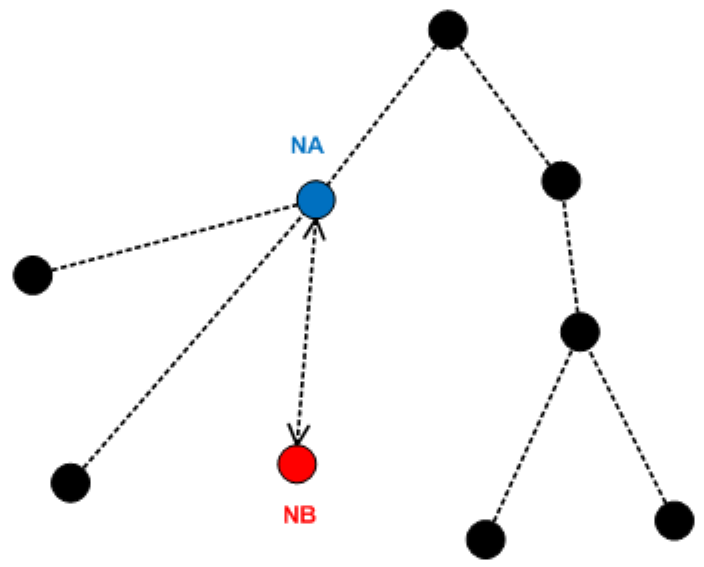
Sensor Networks

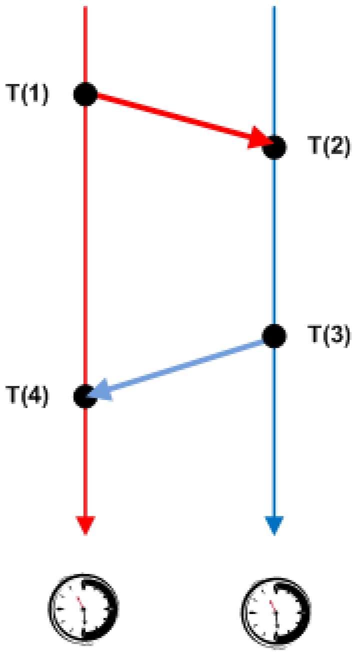
- Miniature computing devices – (e.g. Tyndall motes - 25 mm cubed, 16MHz, 128kb static RAM, 802.15.4 Transceiver)
- Connected via some wireless protocol (tree, ad-hoc)
- Sense and collect physical data
- Most applications require global time - timestamp data to allow collation – analyse system

- Time synchronisation important

Sensor Time Synchronisation

- 2 main approaches –
  - **Round-Trip Synchronisation –**

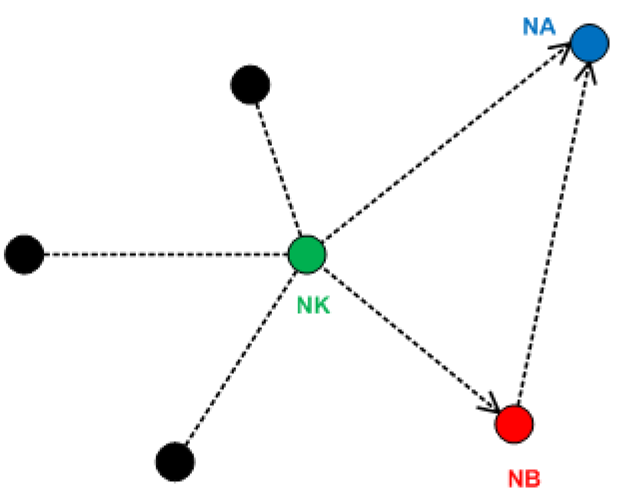


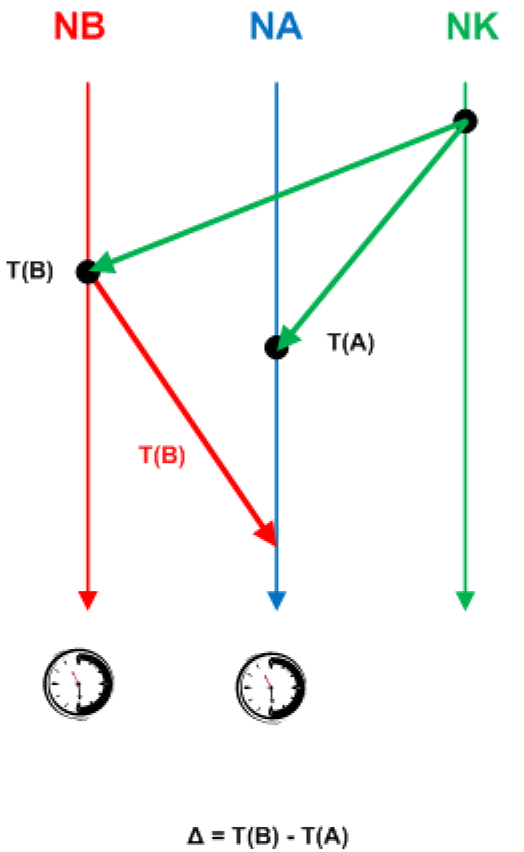


$$\Delta = \frac{(T(2) - T(1)) - (T(3) - T(4))}{2}$$

Sensor Time Synchronisation

– **Reference Broadcast Synchronisation –**





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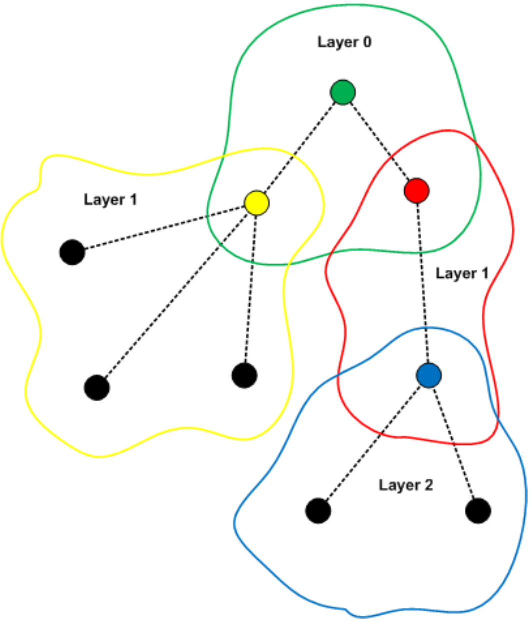
TPSN

- Network organized into tree structure
- 1st layer sync off root node using round-trip synchronisation and adjust their clocks
- 2^{nd} layer sync off first layer etc.
- Packets time-stamped at MAC layer after medium is accessed (similar to PTP)



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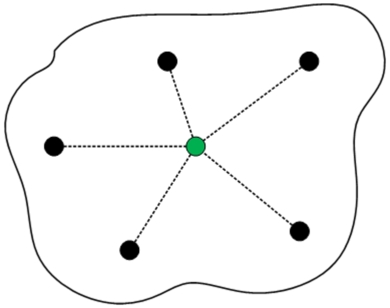
RBS

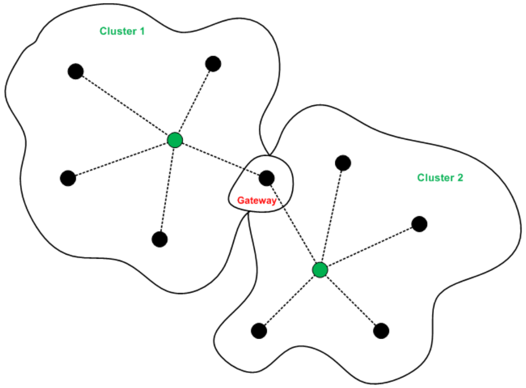
- Network organized into clusters
  (multiple nodes & 1 beacon node)



- Reference broadcast synchronisation used to sync clusters

- Timescale of one node transformed to timescale
  of any other node (relative time synchronisation)

- Multi-hop synchronisation – node placed in vicinity of 2
  or more clusters – acts as gateway between clusters



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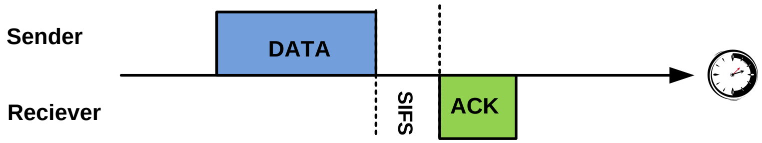
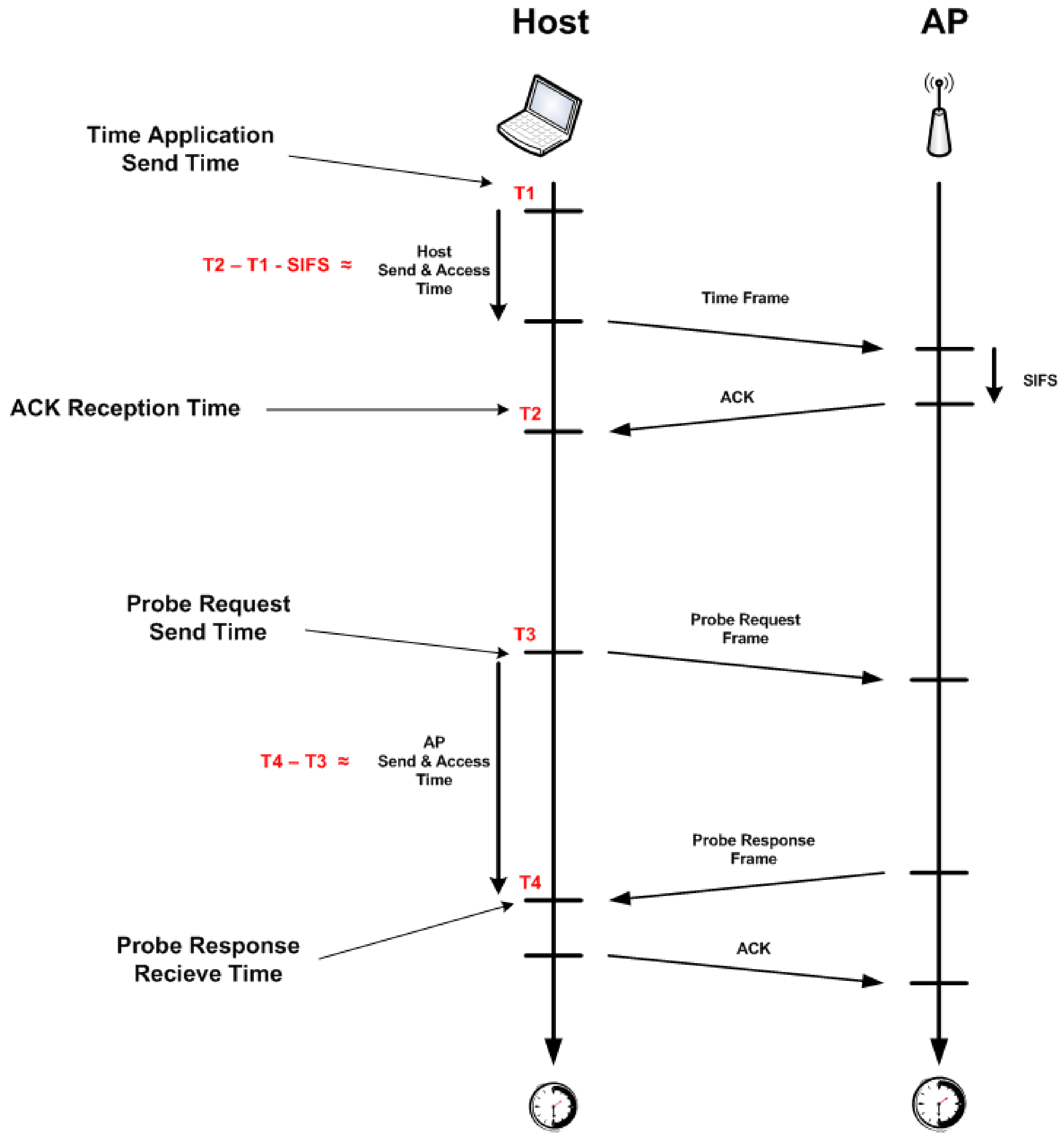
Current Work : Wireless solutions

- **Determination of Medium Access Times**
  - **Similar to PTP physical layer time stamping**

- **802.11 - positive acknowledgements**



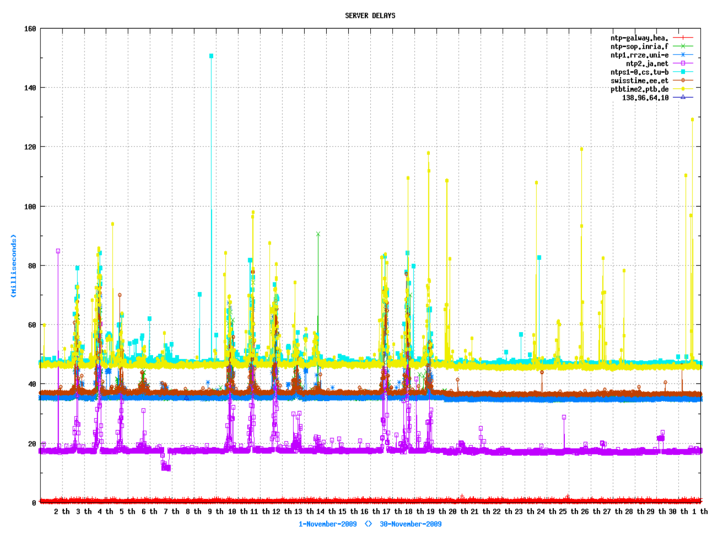

Host
AP
Time Application
Send Time
T1
T2 – T1 - SIFS ≈
Host
Send & Access
Time
Time Frame
SIFS
ACK
ACK Reception Time
T2
Probe Request
Send Time
T3
Probe Request
Frame
T4 – T3 ≈
AP
Send & Access
Time
Probe Response
Frame
T4
Probe Response
Recieve Time
ACK

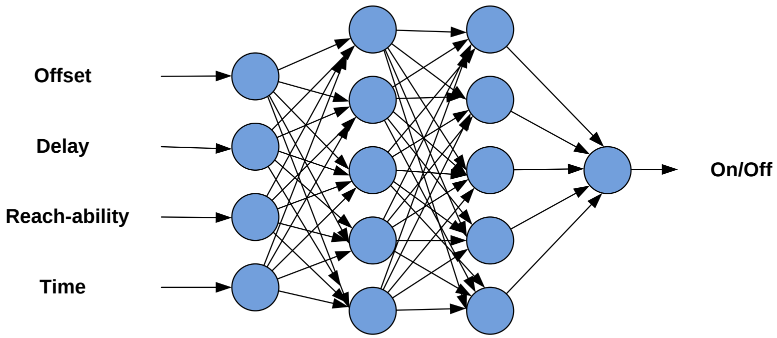
Current Work : Wireless solutions

- **Improvement of Synchronisation through Data Analysis –**
- Analyse past data – identify network trends – shut off time protocol
- Analyse using statistical means (correlation of data types, dispersion of delay)
- Analyse using a neural network – adapt to un-forseen network changes

Current Work

- **Improvement of Synchronisation through Data Analysis**





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Current Work : Sensor Networks

- **Investigate scalability of RBS and TPSN**
- **RBS**
  - **Communication overhead**
  - **Memory overhead**
  - **Processing overhead**
- **TPSN**
  - **Multiple hops in large networks – error added at each hop**
  - **Leaves poorly synchronised**