Helsinki University of Technology
Communications Laboratory

Synchronization of Next Generation Wireless Communication Systems

Master's Thesis

Author: Jari Nieminen
Supervisor: Prof. Riku Jäntti
Instructor: M.Sc. Mika Husso

Agenda

- Thesis Structure
- Objectives
- Background
- Precision Time Protocol (PTP)
- Parameters & Measurements
- Conclusions

Thesis Structure

- Synchronization and Time
- Synchronization in Wireless Networks
- Synchronization Systems
- Precision Time Protocol (PTP)
- Measurements

Objectives

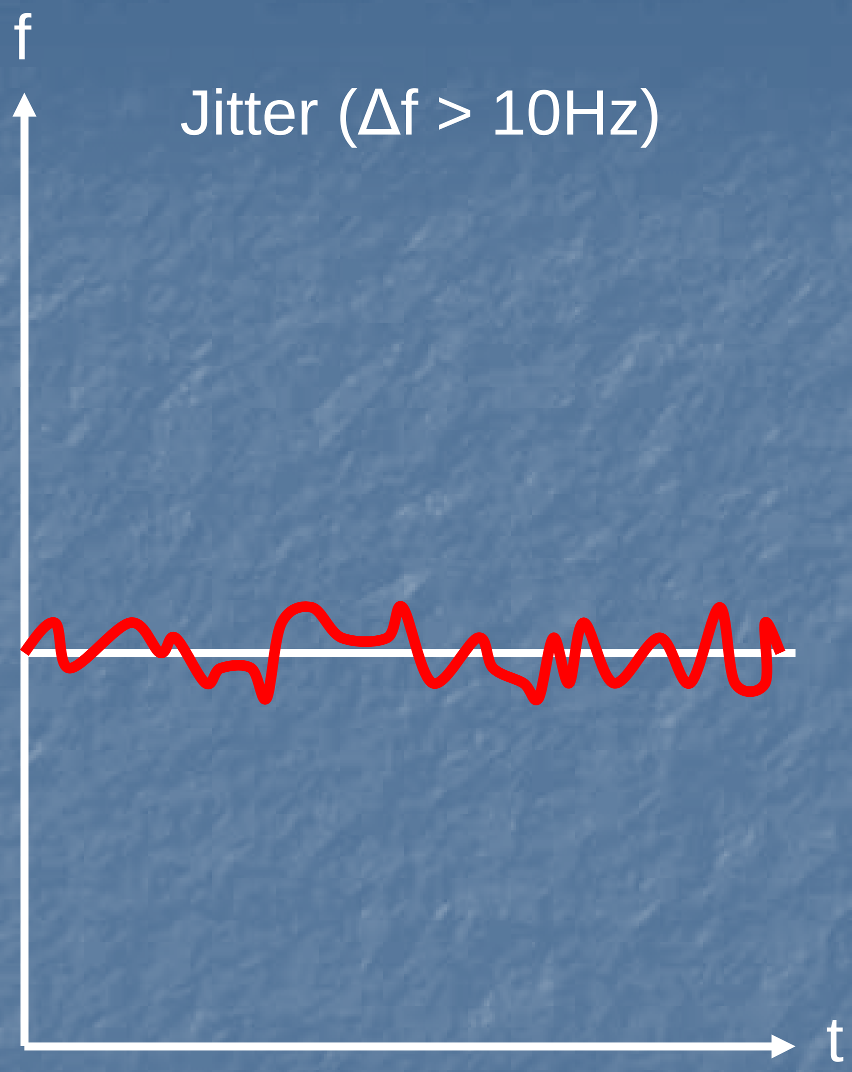
- Find out why wireless systems are synchronized?
- What are the requirements for different wireless communication systems?
- What are the possibilites for carrying out synchronization?
- Pros and cons of different synchronization systems?
- Precision Time Protocol (PTP)? How does it work?
- Is the achievable synchronization accuracy with PTP enough for wireless systems in practice?

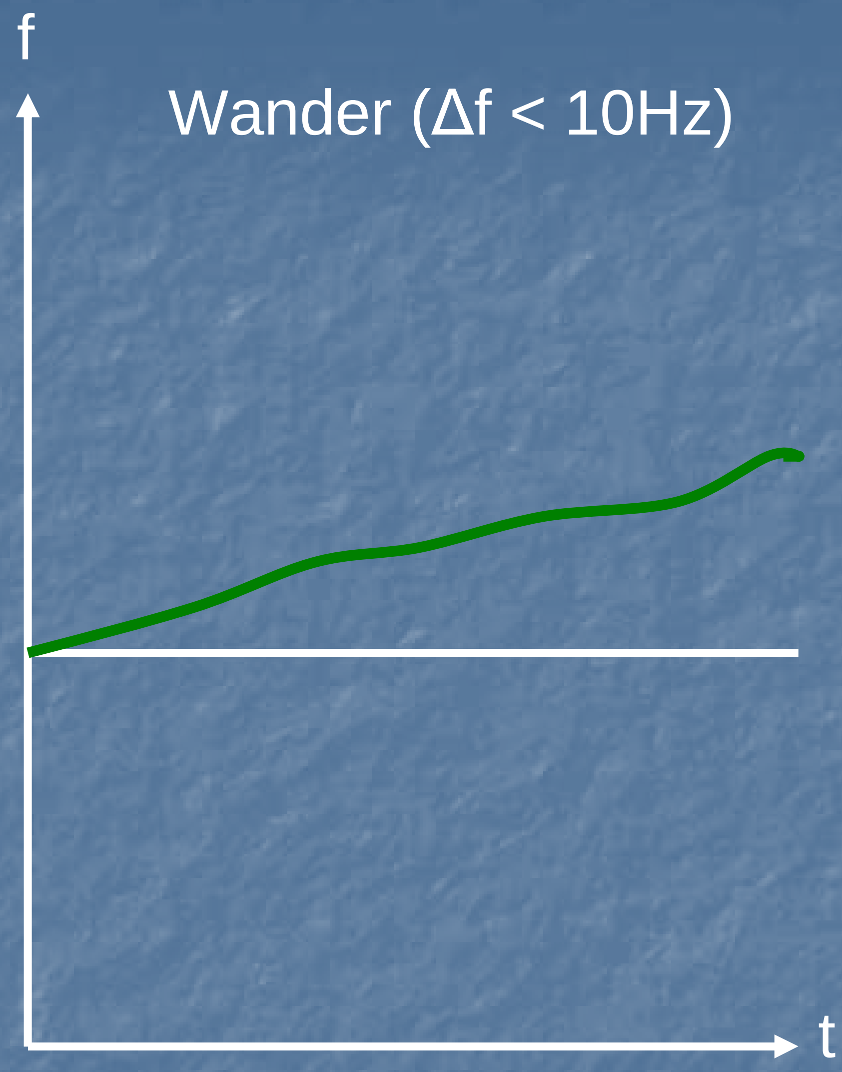
Background (1)

- Wireless communication systems require precise frequency synchronization: Utilization of cheap oscillators, handovers, inter-cell interference, Doppler shift, multicast transmissions
- Standards define the maximum tolerable frequency offset for base stations:
  - 2G&3G: 50 ns (2,1 GHz -> max.freq.offset = 105 Hz)
  - WiMAX: 8 µs (3,5 GHz -> max.freq.offset = 28 kHz)
  - WLAN: 20 µs (2,4 GHz -> max.freq.offset = 48 kHz)
- Migration towards packet switched core networks: Traditionally it has been relatively easy to recover frequency synchronization for mobile phone networks from circuit switched core network. Operators are now looking for the possibility to shift towards packet switched backhaul networks.

Background (2)

- Fully packet switched wireless communication systems: There is no need for circuit switched backhaul anymore which doesn’t utilize capacity as well as packet switched network. (circuit switched reserves resources)
- Time synchronization is not required yet but in the future it might be: Time Division Duplexing (TDD), Sensor Networks, Frequency Hopping (FH), broadcasting
- Generally in communication systems time synchronization is needed for effective log keeping, banking services, traffic engineering etc.
- At the moment WiMAX networks are generally synchronized by using GPS and mobile phone networks via SDH backhaul. However, it would be an attractive possibility to exploit packet switched backbone networks (Ethernet) to distribute synchronization information cost effectively, safely and precisely.


f
Jitter (Δf > 10Hz)
t


f
Wander (Δf < 10Hz)
t

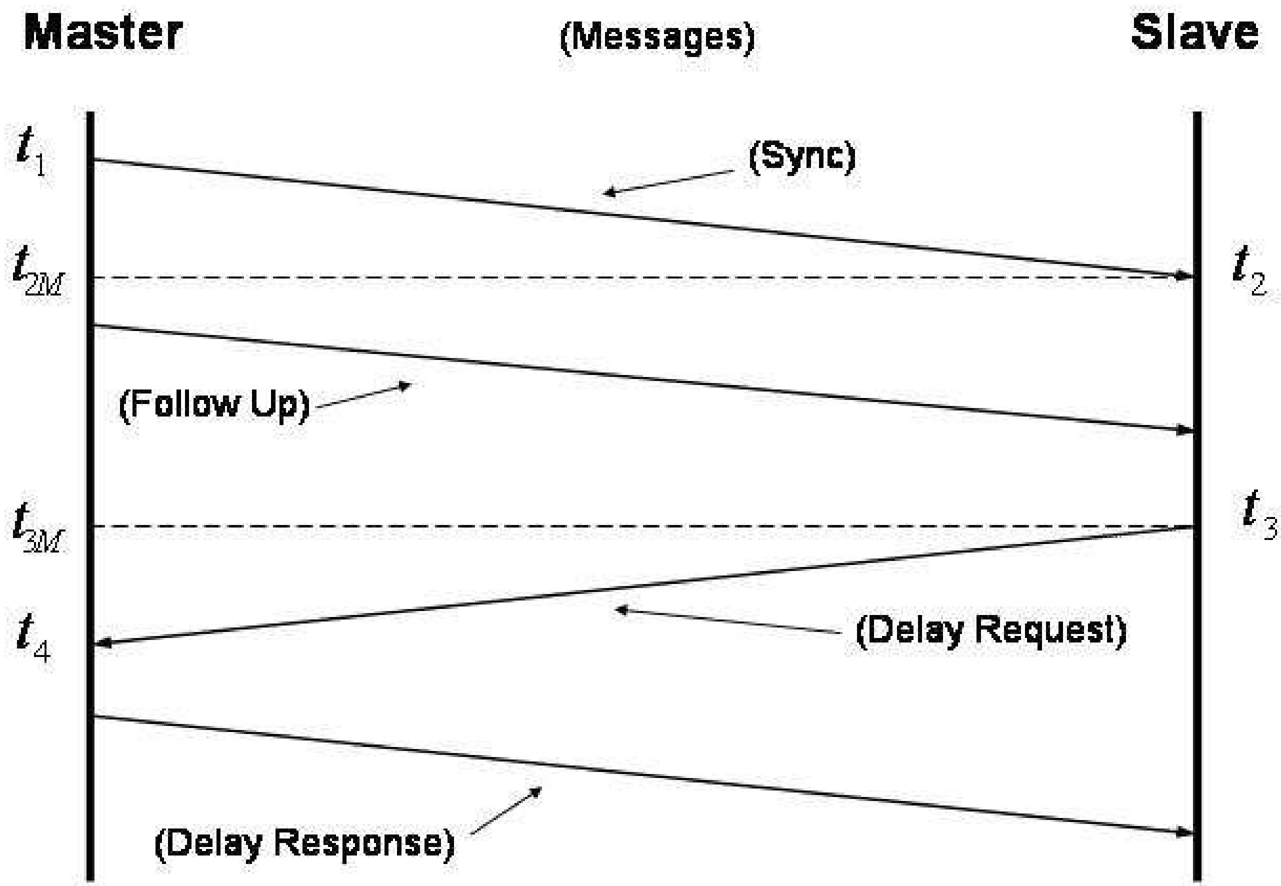
Options

- Global Positioning System (GPS): Highly accurate, both frequency and time synchronization, Selective Availability (SA), vulnerability to jamming, under control of US, need for hardware (receiver), not cost effective, wide area, need for radio connection
- Synchronous Digital Hierarchy (SDH): Circuit switched, the distribution of frequency synchronization natural because the system itself is synchronized, no time synchronization, migration towards packet switched core networks, high synchronization precision
- Network Time Protocol (NTP): Internet, utilization of packet network, not vulnerable to jamming, achievable accuracies are not enough for wireless systems (about milliseconds), congestion of the network may be a problem, no specific hardware needed, wide area, cost effective

Precision Time Protocol (PTP)

- Distribution of synchronization information in small, local area networks (10/100 BaseT-Ethernet). Submicroseconds accuracies in Ethernet promised, not vulnerable to jamming, utilization of packet switched network, hardware required for highest precision, increment in network traffic, congestion of a network may be a problem
- Hardware time stamping: Time stamps are taken straight at the hardware level in order to cancel variable processing delays of higher protocol layers
- Follow Up -messages: After Sync -message, another message is sent which contains the accurate time stamp of the Sync -message.
- Originally designed to provide synchronization for measurement, control and automation networks. However, the next version will also include several improvements considering synchronization in telecommunication networks (Transparent clock, safety, wireless implementations, Gigabit Ethernet, shorter frames and sync interval)

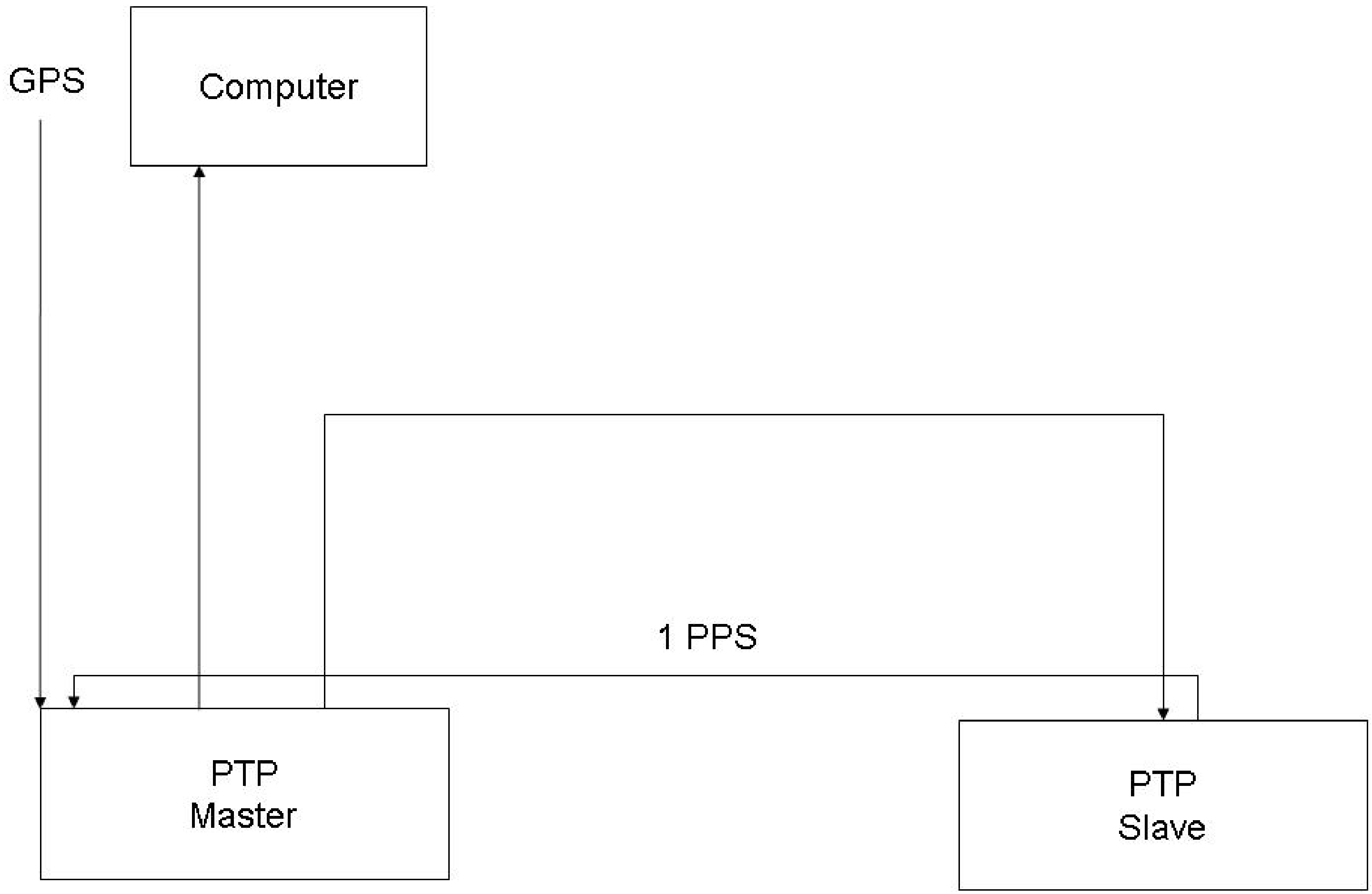
PTP -messaging



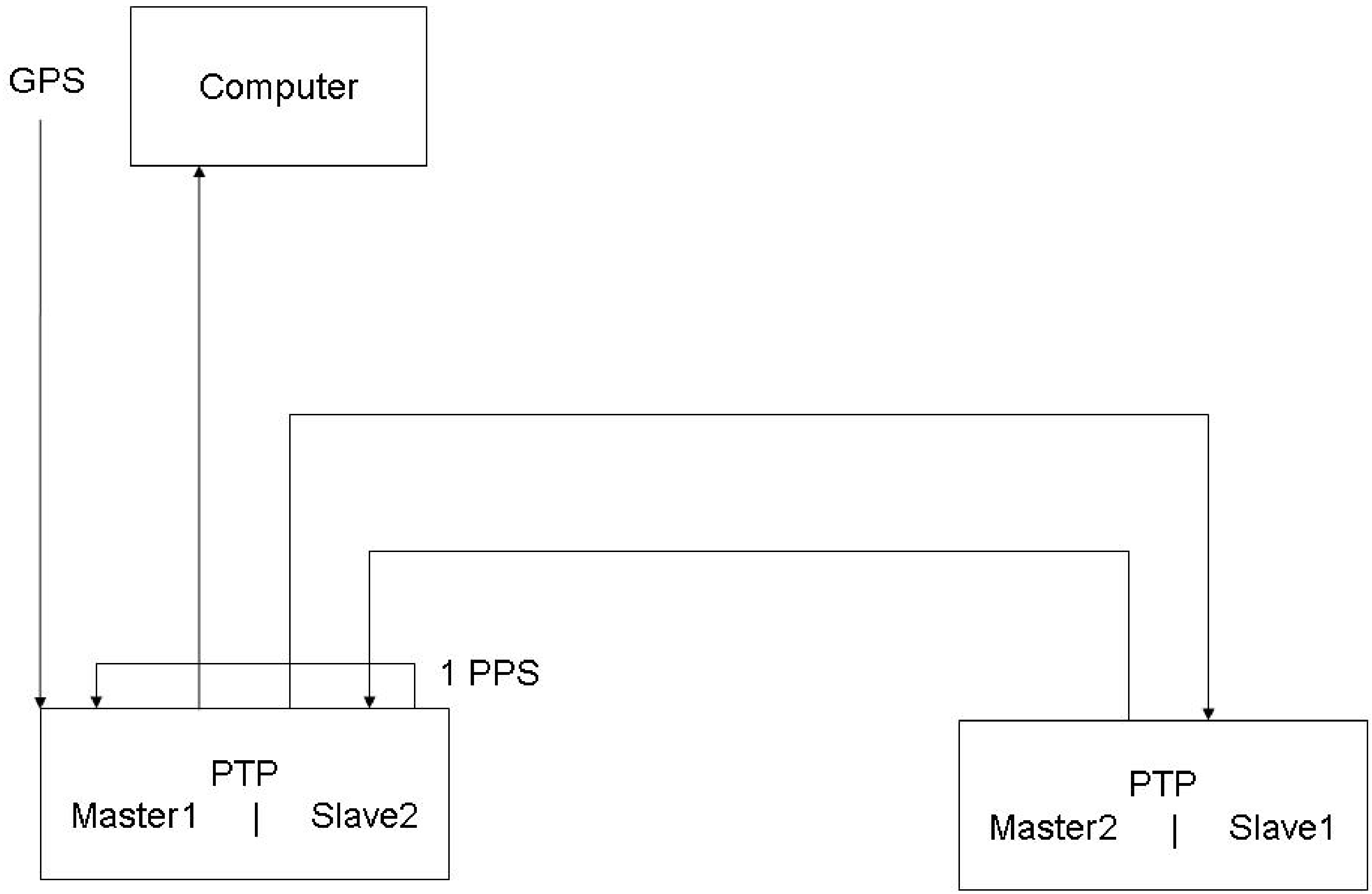
Measurement Parameters

- The main problems in synchronization of telecommunication networks are related to jitter, wander and stability. In order to be able to evaluate and compare these characteristics of synchronization systems, ITU has specified 5 different parameters which determine the quality of a synchronization system. (ITU-T G.810)
- In this Thesis only Maximum Time Interval Error (MTIE) and Time Deviation (TDEV)
- MTIE: ” The maximum peak-to-peak delay variation of a given timing signal with respect to an ideal timing signal within an observation time (t=*n*t0) for all observation times of that length within the measurement period (*T*)”
- TDEV: ”A measure of the expected time variation of a signal as a function of integration time. TDEV can also provide information about the spectral content of the phase (or time) noise of a signal.”

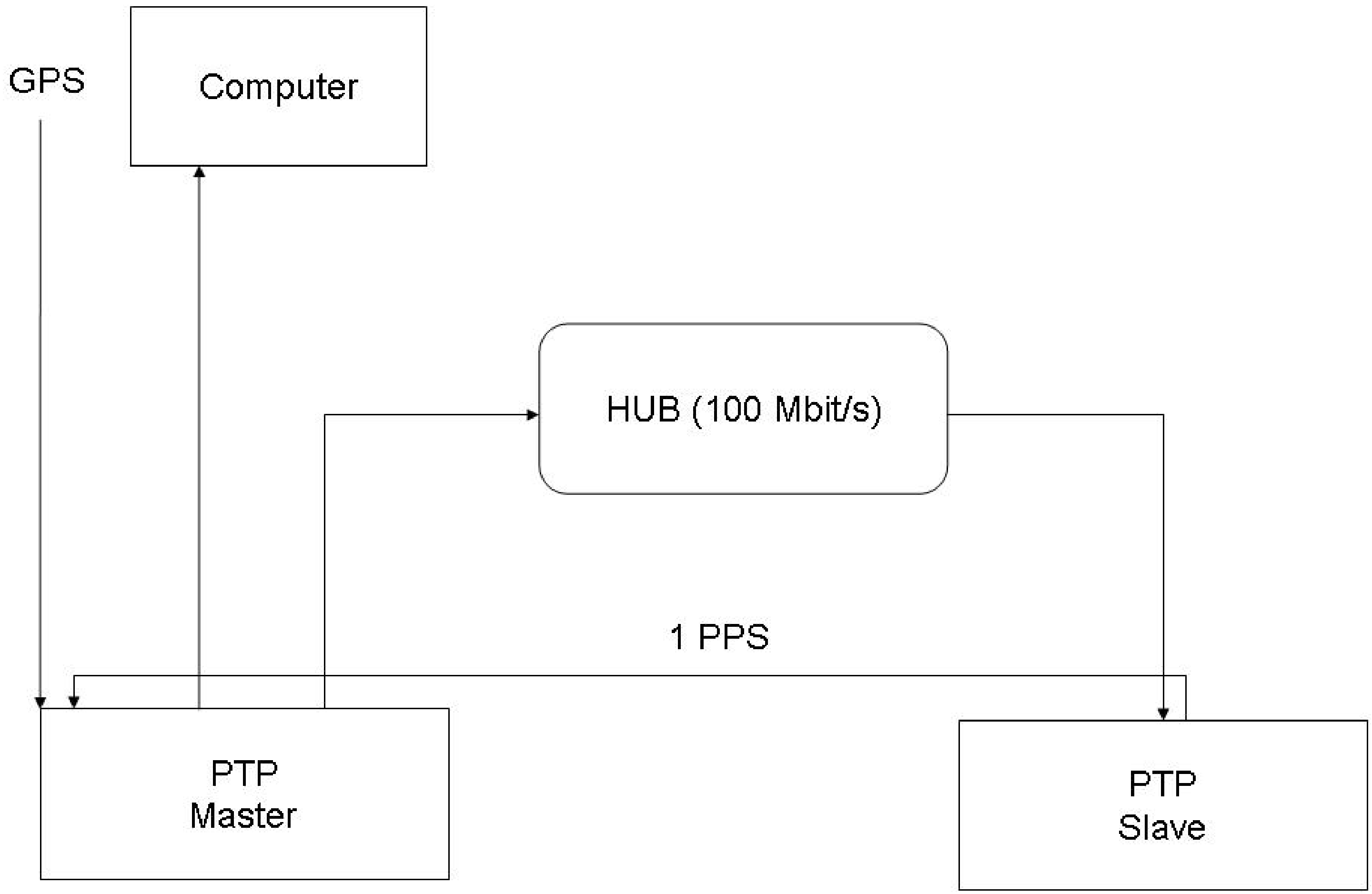
Measurement Setup#1



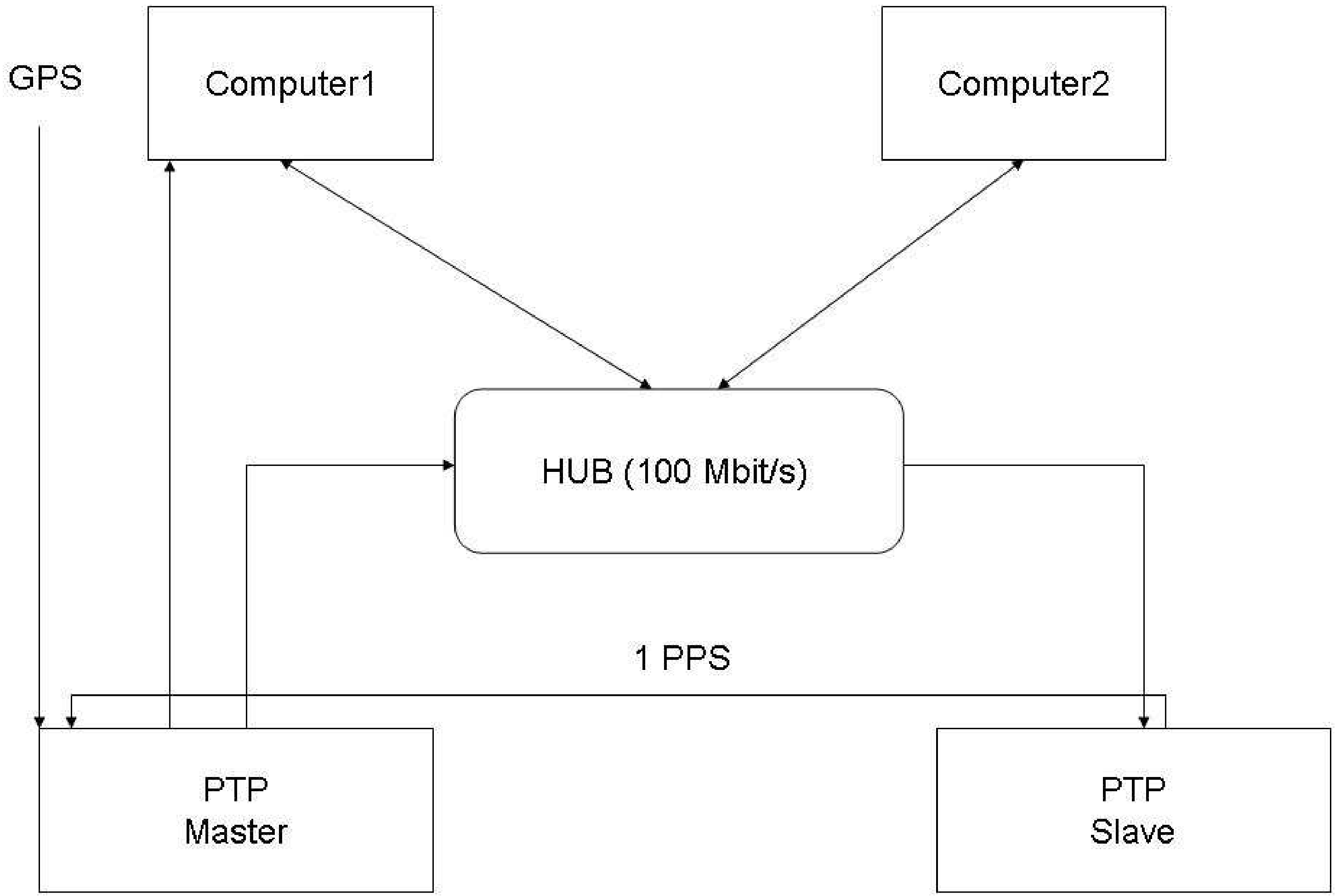
Measurement Setup#2



Measurement Setup#3



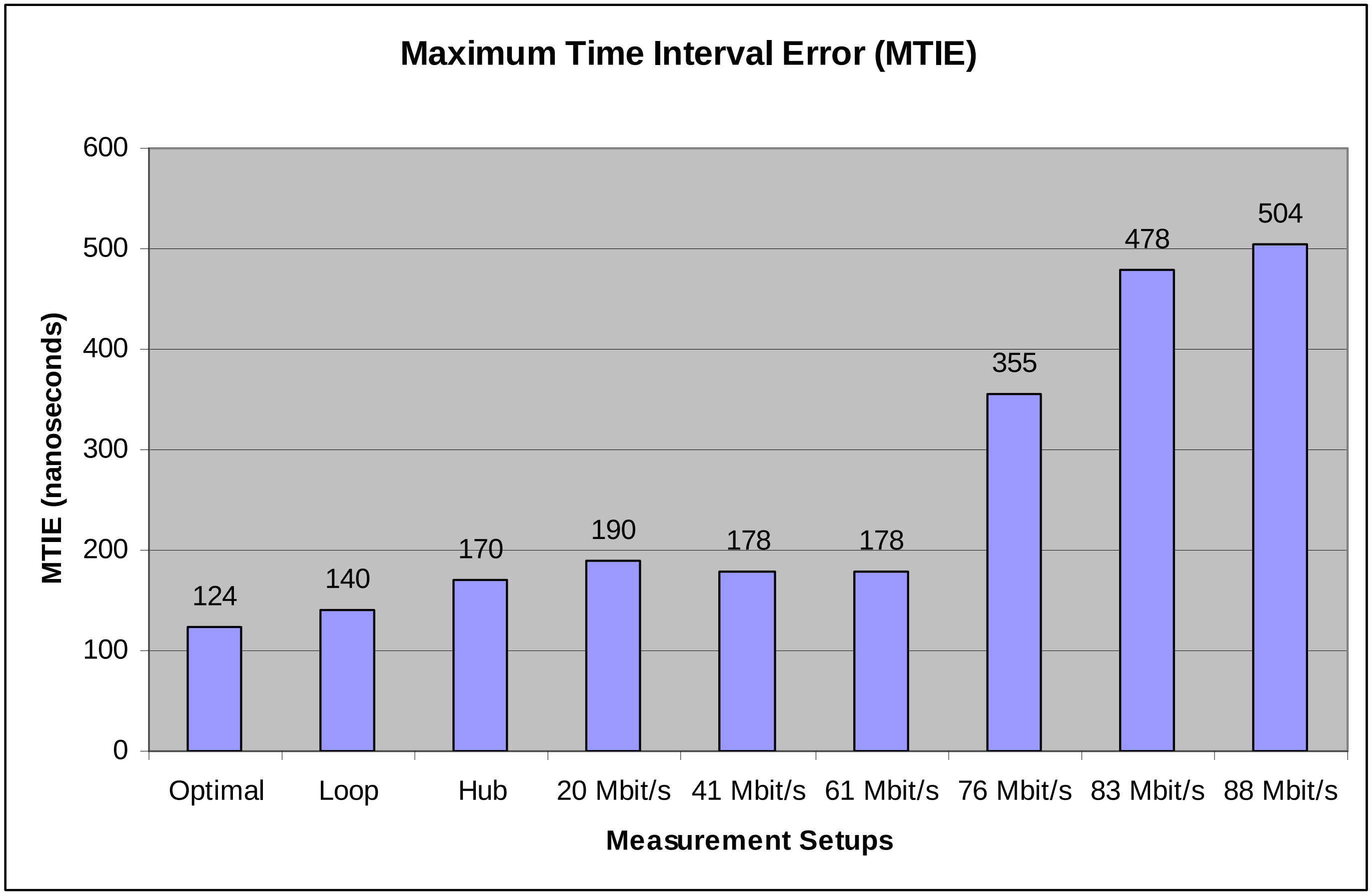
Measurement Setup#4



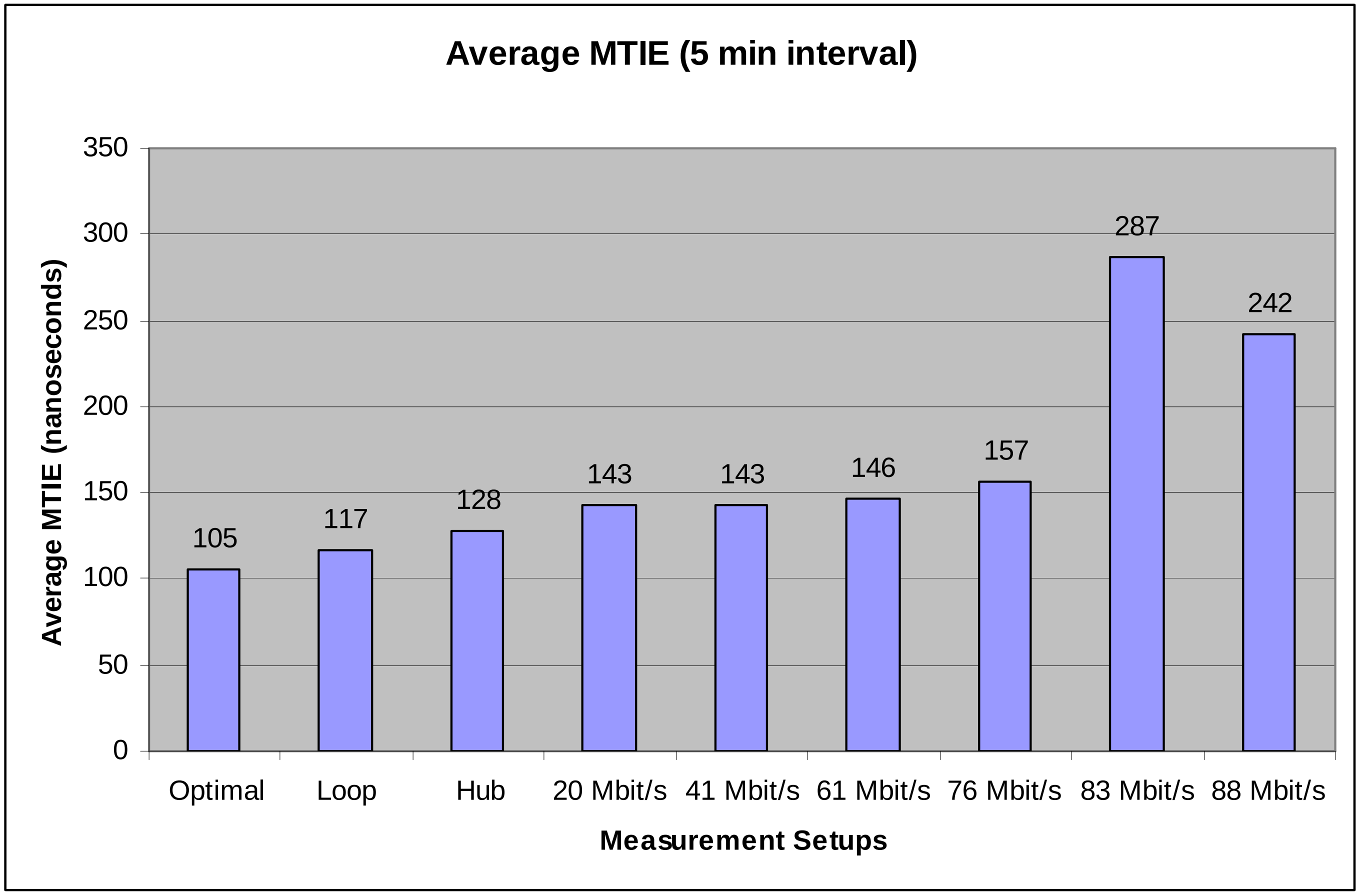
Measurement Results

- PTP performance in optimal conditions approximately 100 nanoseconds.
- Devices in the middle of the synchronization chain cause impairments and therefore it seems that the concatenation of devices will decrease synchronization accuracy. (According to these results, a non-PTP device will deteriorate performance more than a device which supports PTP)
- Congestion of the network affects to the precision of the synchronization. However, PTP seems to be working quite well even with high network loads. (MTIE approximately 500 nanoseconds)
- These results indicate that the performance of PTP protocol is quite stable regardless of traffic in the network. TDEV values seem to be random which could indicate that with high network loads, PTP still can perform well on average. However, the congestion of the network seems to cause some rapid and large fluctuations in synchronization accuracy.

Maximum Time Interval Error (MTIE)



Average MTIE (5 min interval)



Time Deviation (TDEV)