Instantaneous Packet Delay Variation
ipdv

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1) INTRODUCTION

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- Reference to a given Transfer Delay
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About definitions

Being a Variation, some different definitions are possible, according to what the variation is measured against. Four possibilities have been considered.

1) - Variation of Inter Arrival time with respect an expexted one
similar to the 1-point CDV defined for ATM cells (ITU-T Rec. I.356)

2) - Delay Variation referred to a reference value for those Sec and Dst
similar to the 2-point CVD defined for ATM cells (ITU-T Rec. I.356)

3) - Delay Variation with respect a mean value of the delay

4) - Delay Variation with respect the last preceding packet (ipdv)

One or Two point measurements

The 1-point measurement includes the behavior of the source and the network. It has been considered more appropriate for characterizing a traffic profile at a given point than to analyze the behavior of a path between two points.

Even if 1-point measurements are performed at the same time at the beginning and at the end of a path, and then the results are compared, it is difficult to derive the behavior of the path from statistics.

The choice was to focus on a 2-point PDV measurement, that seems the more natural way for obtaining useful information on the behavior of the path.

At the same time the need was considered of having a metric that described those variations in dealy affecting real-time services, and as much as possible independent from synchronization problems.

Reference to a given Transfer Delay

For a given <Src, Dst, path> triad a Reference Transfer Delay "R" is given and the PDV value of the packet "n" having a transfer delay of "Dn" is given by:

PDVn = Dn - R

Some problems with this definition:

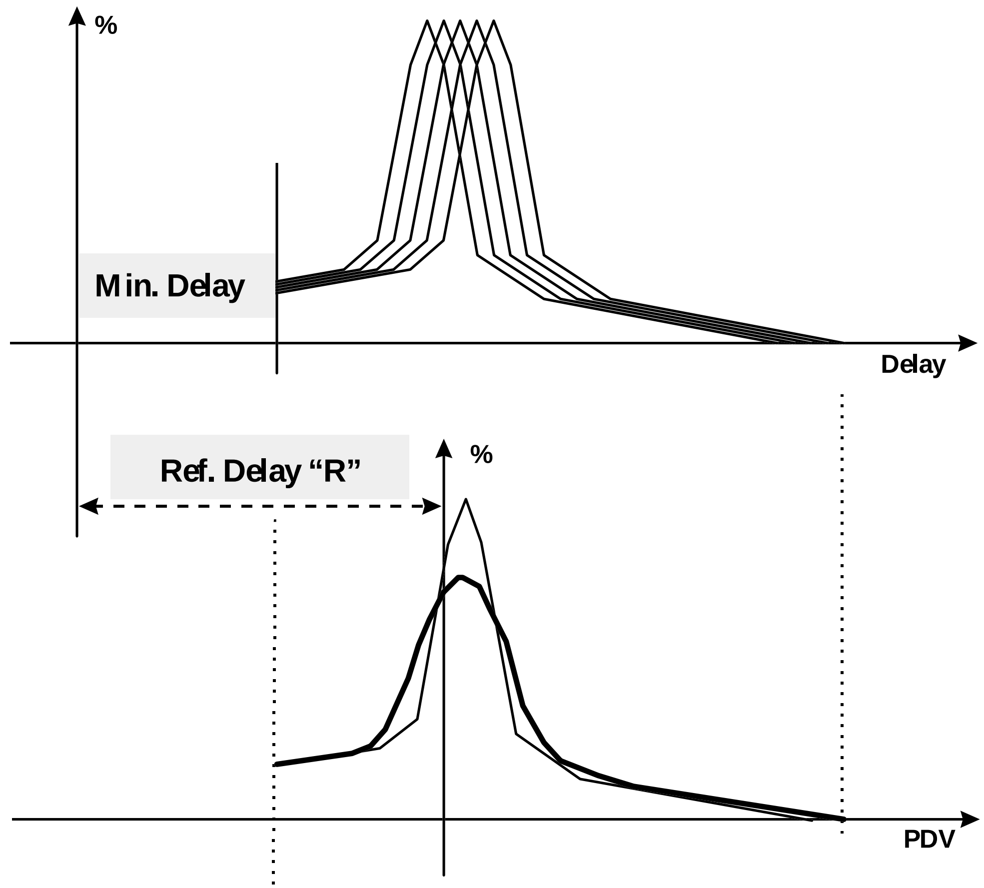
1) - It does not contain a strong idea of variation, being a Delay minus a fixed offset

2) - It does not describe the time in which the variation takes place

3) - If the Delay is different from R but it does not change, values of PDV are anyway high

4) - A Reference Delay "R" should be defined for each possible path

5) - The distribution of values is distorted by changing conditions of the path



Errors depend on duration of the measurement

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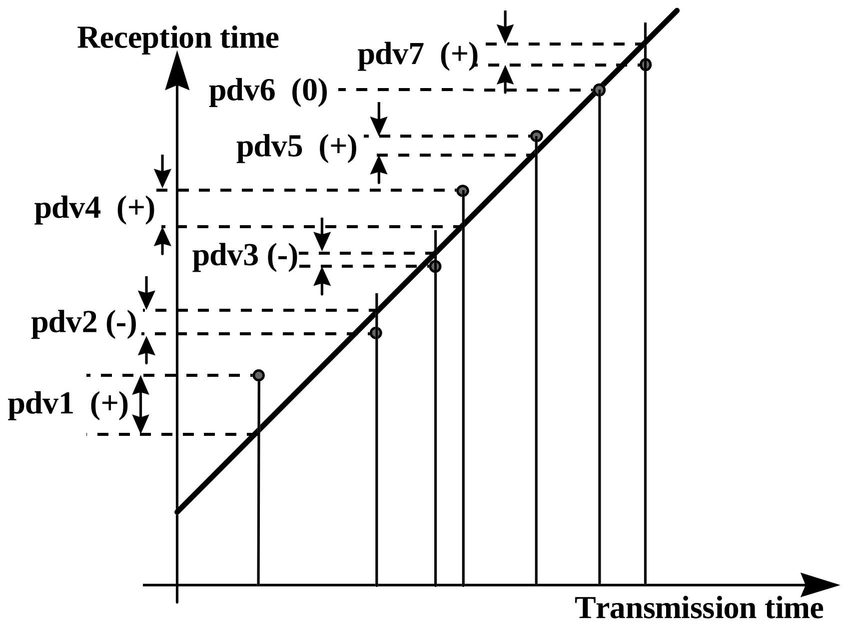
Reference to the Mean Value of Delay

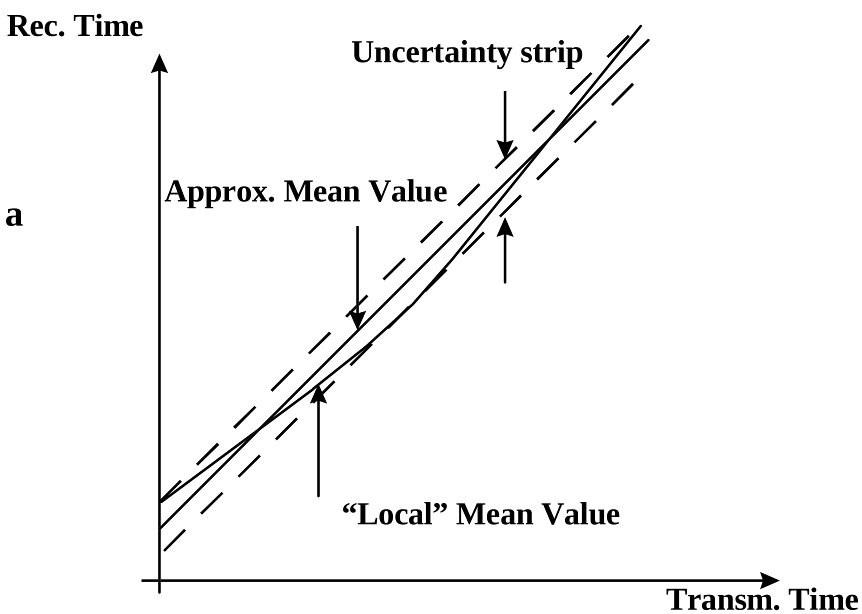


Each circle indicates a packet as characterized by a Tx time and a Rx time.

The red straight line can be computed as the one minimizing the vertical distances between circles and line

If there exist an offset between clocks, line and points are traslated up or down, the distances are unchanged

If there exist a skew between clocks the slope of the straight line is higher or lower than 1.



The method is derived from the preceding definition, and is a way of chosing the best refernce value.

A straight line can be a not good approximation in case of variation of the mean value along the time

Also in this case the strip of uncertainty can increase in width according to the duration of the measuremet

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Instantaneous Packet Delay Variation (1)

Definition

For a given stream of packets, flowing from a Src to a Dsr the Instantaneous Packet Delay Variation (ipdv) of a packet is the difference between the Transfer Delay of the packet and the Transfer Delay of the preceeding packet.
If D(i) is the Transfer Delay of the i-th packet, its ipdv (ipdv(i)) is:

$$ipdv(i) = D(i) - D(i - 1)$$

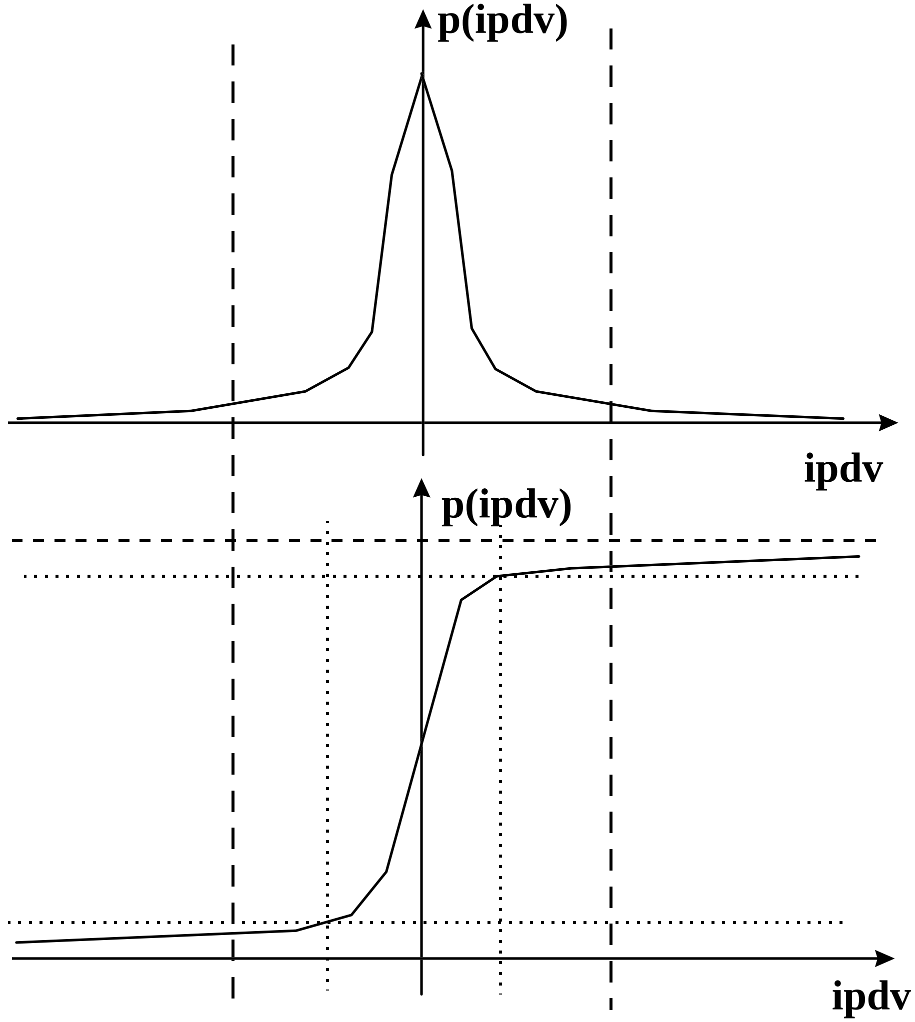
The ipdv(0) of the first packet is not defined

The Measurement Points MP1 at Src and MP2 at Dst are virtually located at the first and, respectively, last point of the intreface with the transport network, at which it is (virtually) possible to observe the packets at wire-time.
Practical measurement points will be the first and the last ones at which it is possible to deal with time-stamps (host-time). For referring the measurement to MP1 and MP2 it is necessary to know the diffe-rence (host-time vs wire-time) related to each packet. Otherwise that difference will be part of the measurement error.

According to its definition, ipdv is only affecred by the variable part of this difference.

Instantaneous Packet Delay Variation (2)

Distributions



Probability (frequency) distribution

- The theoretical mead value should tend to ZERO

- Number of values exceeding given thresholds indicate how can be supported a given service

- Standard Deviation is an indicator of the Quality

- For better describing the behavior, SD can be also calculated over the sub-set of values inside the threshold limits.

Cumulative curve

- Evidentiates the performance parameter "Percentile"

- Evidentiates the performance parameter "Inverse Percentile"

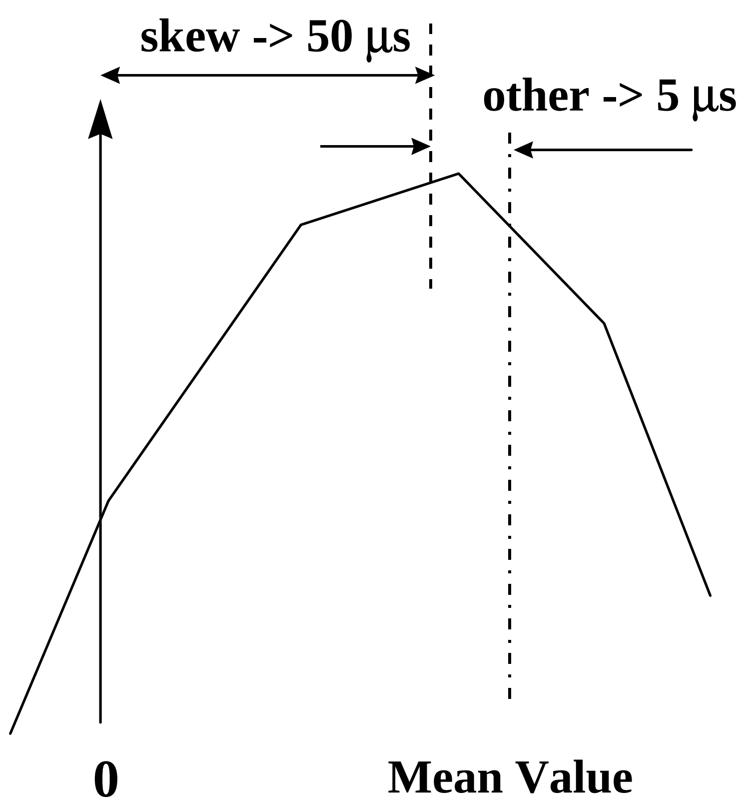
In principle, results are not affected by the duration of the measurement

Instantaneous Packet Delay Variation (3)

The Mean Value

For example (typical):

120000 packets
Average of intervals = 0.75 sec



Reasnons that can produce a non ZERO value

1) - Effect "Last Value" in short measurements
E(ipdv) = [D(last) - D(first)] / N

2) - Monotone variation of Average Delay inside limited periods

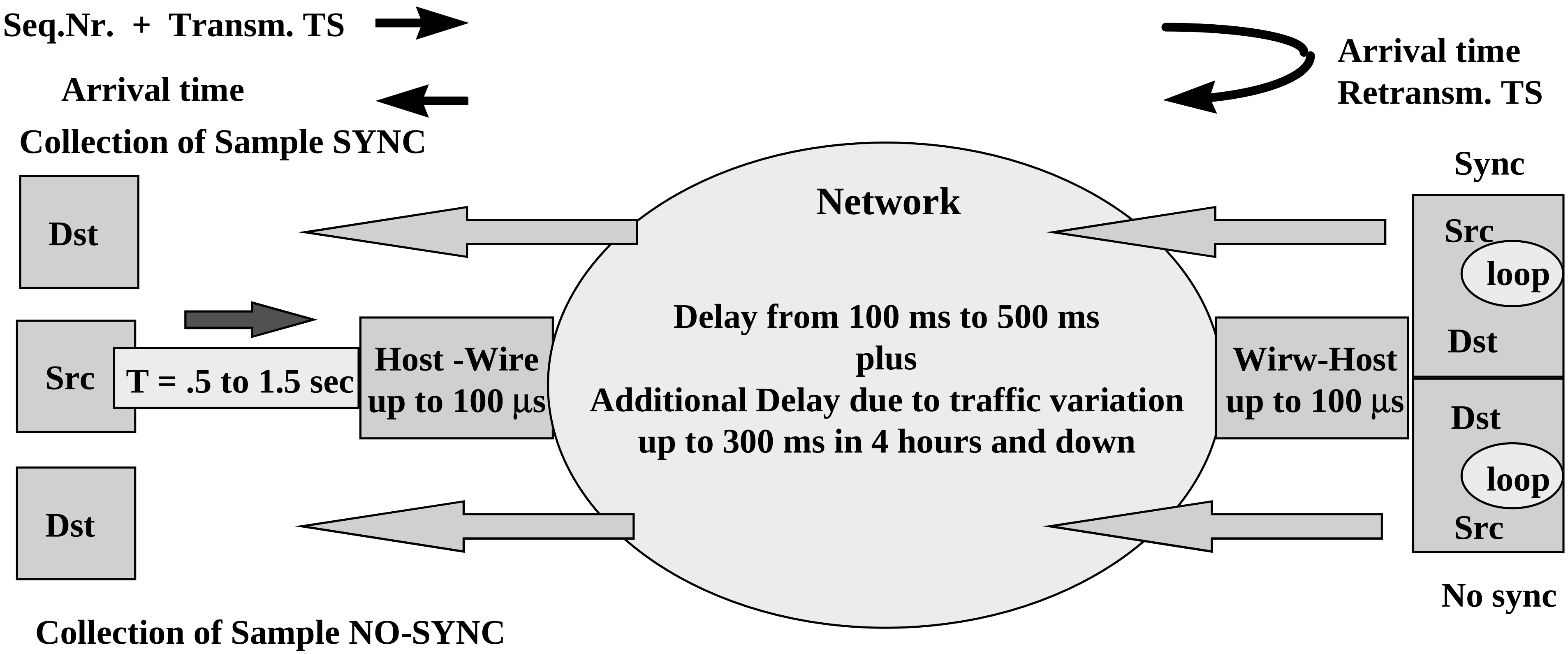
3) - Skew of the clocks (fixed)

4) - Drift of the clocks (limited by a max. skew that can be reached)

2) to 4) variation effects are limited to IAT of the packets.

Measurement with simulated traffic

Simulator



The post-processing tool calculates:

For each direction : Mean ipdv value, Values exceeding +/- LIM, Standard Deviation (total)

St. Dev. over subset {-LIM < x < LIM}, Distributions.

The same is provided for Time intervals into which the measurement can be subdivided.

Measurement with simulated traffic results

Conditions:

Duration : 24 hours
Emission Interval (average) : 1 sec
H-W time uncert. and vice versa : 100 µs
Delay : 100 ms to 500 ms
Delay variation for traffic variation in 4 hours : + or - 300 ms
Packet Loss Ratio : 5 E-3
Skew of not sync. host : 50 ppm
Drift of not sync. host in 6 hours : 50 ppm

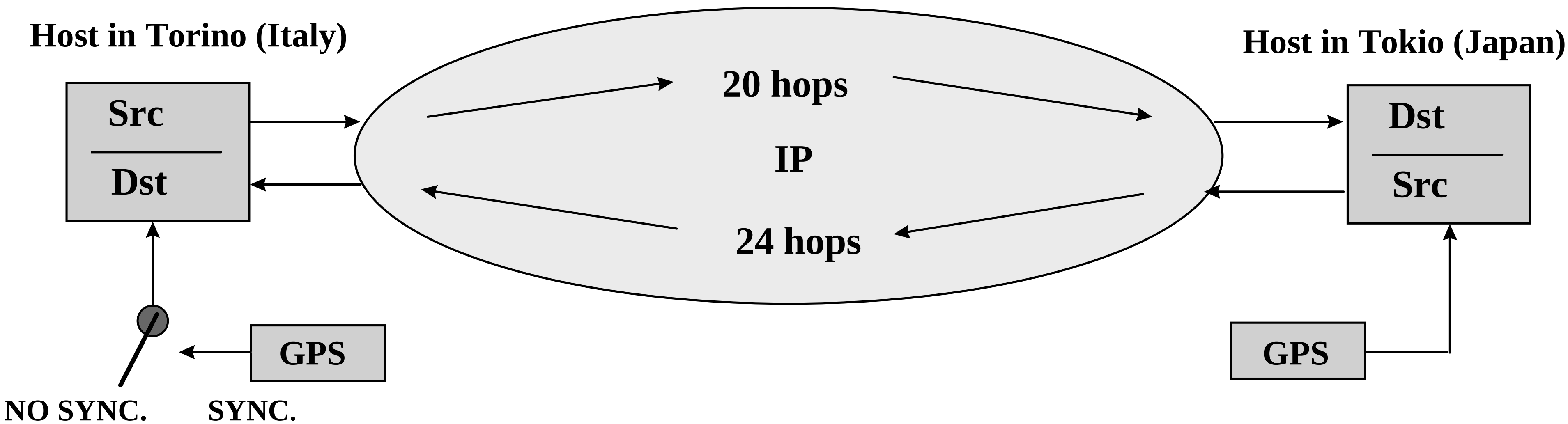
RESULTS:	W-E Sync	E-Wsync.	W-Enot-sync	E-Wnot-sync
Mean ipdv	1.159 µs	1.926 µs	55.578 µs	52.572 µs
values <-100ms	20158	20217	20157	20200
values > 100ms	20193	20236	20170	20222
S.D total	160.3701 ms	160.6403 ms	160.3767 ms	160.5712 ms

Measurements of ipdv

layout

- Independent Measurements were performed at the same time in the two directions

- Data were recorded and then post-processed



Two measuremests of 24 hours:

- The first with Synchronized Clocks (from 3pm of 3rd March to 3pm of 4th March)

-The second with NOT Synchronized clocks (from 3pm of 5th March to 3pm of 6th March)

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Measurement with Synchronized Clocks (1)

Type of Packets used :	**UDP**			
Emission Interval :	**pseudo-random Poisson process**			
T average =	**0,764 sec**	**W-E**	**0.764 sec**	**E-W**
Tmin =	**14.5 ms**	**W-E**	**17 ms**	**E-W**
T max =	**8.999 sec**	**W-E**	**8.989 ms**	**E-W**
Duration :	**24h 00m 11s**	**W-E**	**24h 00m 17s**	**E-W**
Number of generated packets :	**113045**	**W-E**	**113079**	**E-W**
Detected conditions				
Packets Lost :	**794 (0.7%)**	**W-E**	**4609 (4.08%)**	**E-W**
Out of sequence :	**2**	**W-E**	**3**	**E-W**
Replicated packets :	**0**	**W-E**	**0**	**E-W**
Mean One-way-Delay :	**279.9 ms**	**W-E**	**384.6 ms**	**E-W**

Measurement with Synchronized Clocks (2)

RESULTS East to West (over 24 hours) :

Mean ipdv value :	**0.27 [μs]**
Nr. of ipdv values < - 100 ms :	**1421**
Nr. of ipdv values > 100 ms :	**1429**
Nr. of ipdv values < - 1 s :	**3**
Nr. of ipdv values > 1 s :	**3**
Total Standard Deviation :	**44.3 [ms]**
S.D. of subset {-100ms < x <100ms}	**31.8 [ms]**
S.D. of subset {1s<x<1s}	**43.5 [ms]**

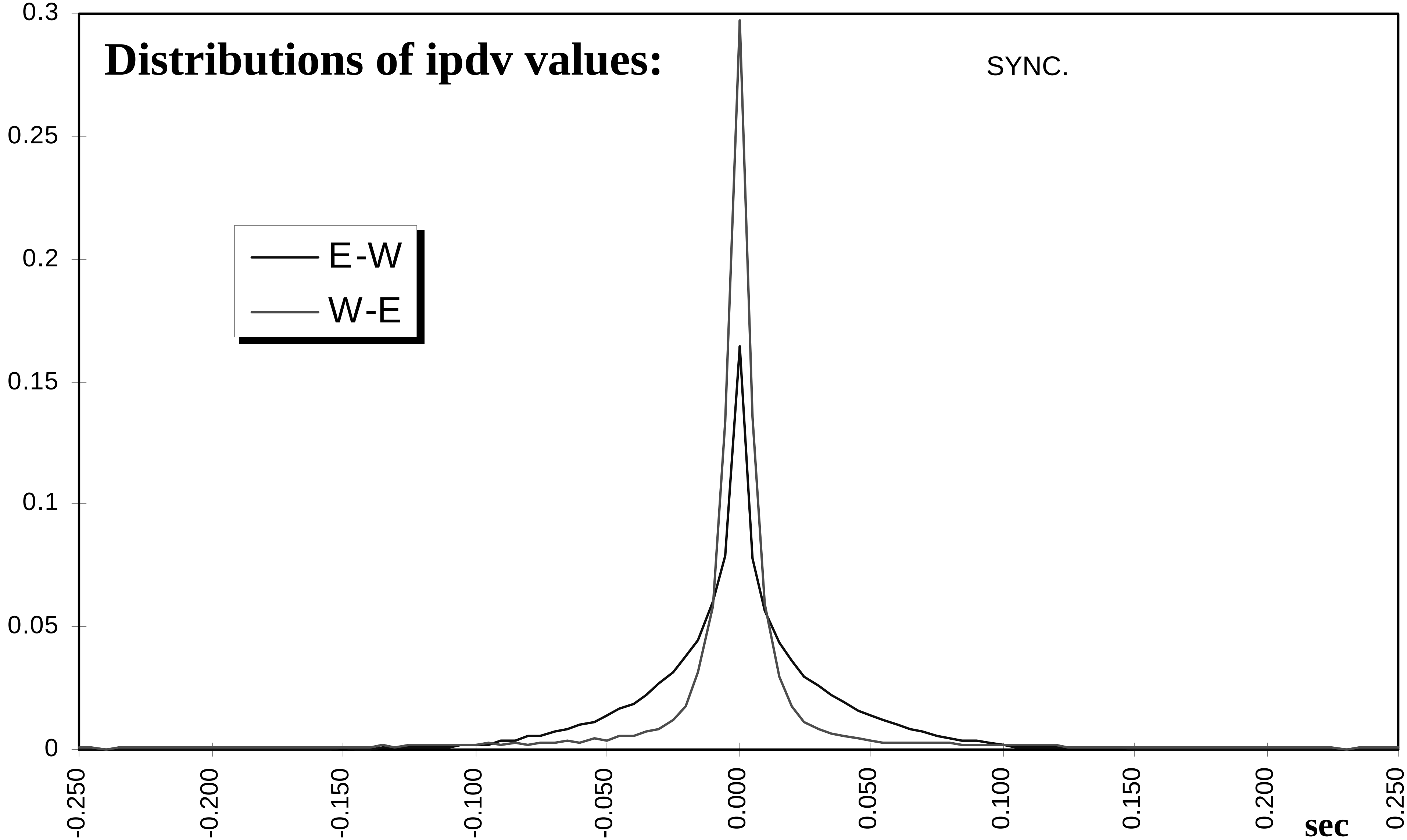
GPS equipment indicated a correction of about 77,7 μs / sec

Measurement with Synchronized Clocks (2)

RESULTS West to East (over 24 hours) :

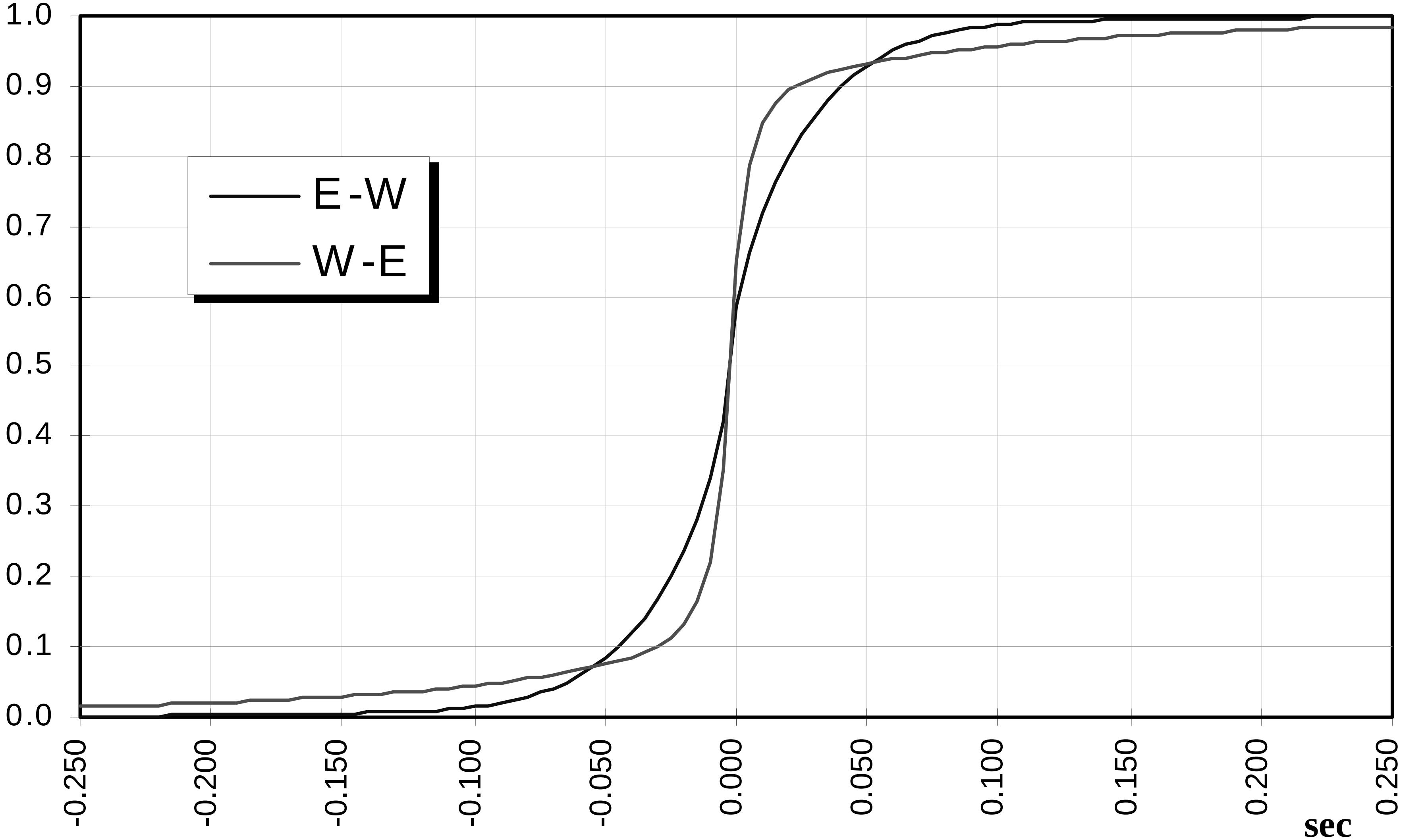
Mean ipdv value :	**0.02 [µs]**
Nr. of ipdv values < - 100 ms :	**4961**
Nr. of ipdv values > 100 ms :	**4861**
Nr. of ipdv values < - 1 s :	**25**
Nr. of ipdv values > 1 s :	**57**
Total Standard Deviation :	**97.37 [ms]**
S.D. of subset {-100ms < x <100ms}	**21.86 [ms]**
S.D. of subset {1s<x<1s}	**91.53 [ms]**

Measurement with Synchronized Clocks (3)



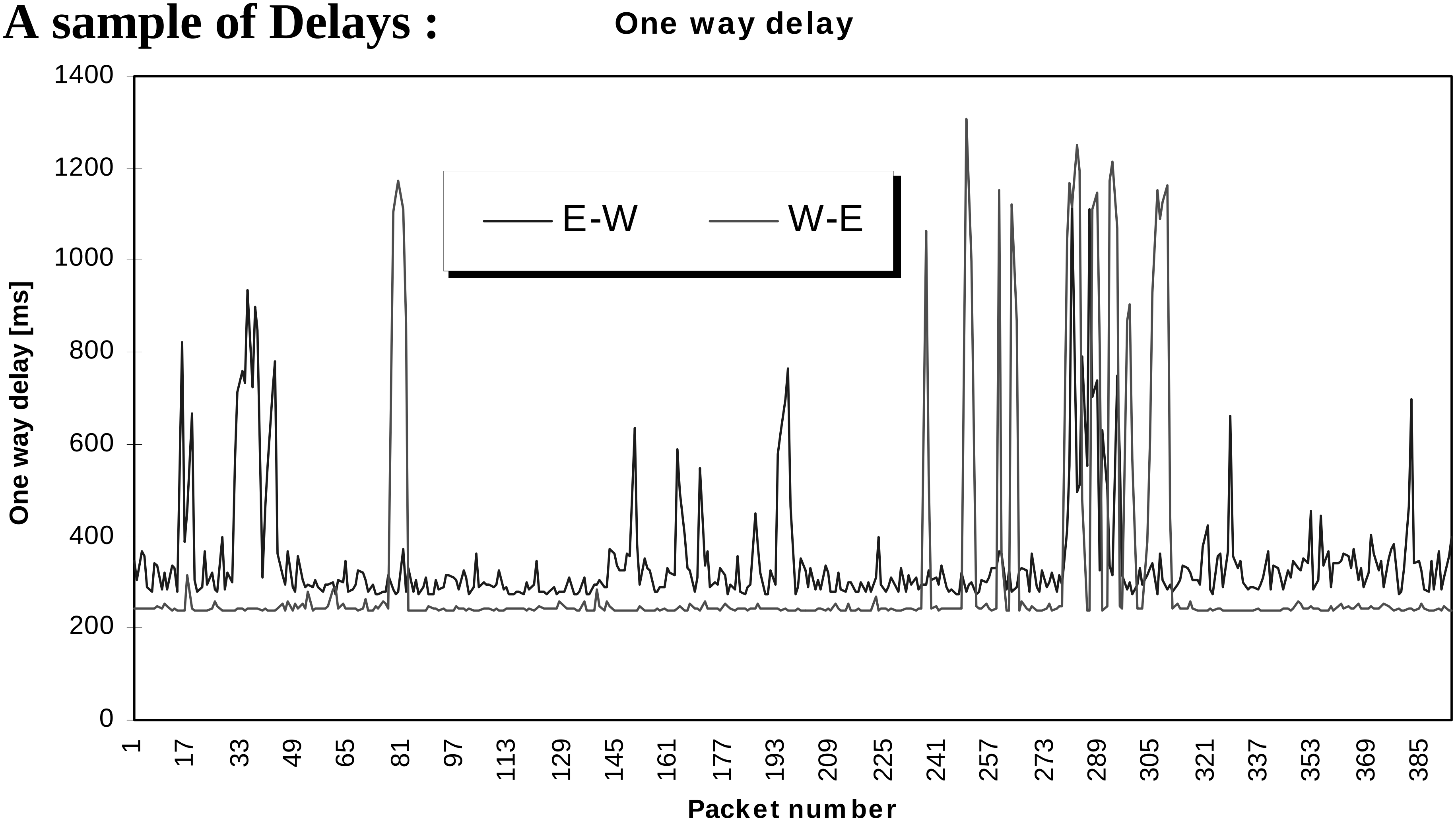
Measurement with Synchronized Clocks (3)

Cumulative distributions :



Measurement with Synchronized Clocks (3)

A sample of Delays :



Measurement with NOT Synchronized Clocks (1)

Type of Packets used :	**UDP**			
Emission Interval :	**pseudo-random Poisson process**			
T average =	**0.764 sec**	**W-E**	**0.764 sec**	**E-W**
Tmin =	**10 ms**	**W-E**	**18 ms**	**E-W**
T max =	**9.36 ms**	**W-E**	**8.99 ms**	**E-W**
Duration :	**23h 48m 50s**	**W-E**	**24h 03m 48s**	**E-W**
Number of generated packets :	**112131**	**W-E**	**113361**	**E-W**
Detected conditions				
Packets Lost :	**1154 (1.03%)**	**W-E**	**4075 (3.59%)**	**E-W**
Out of sequence :	**3**	**W-E**	**10**	**E-W**
Replicated packets :	**0**	**W-E**	**0**	**E-W**
Mean One-way-Delay :	**Not measurable in these conditions**			

Measurement with NOT Synchronized Clocks (2)

RESULTS West to East (over 24 hours) :

Mean ipdv value :	**56.64 [μs]**
Nr. of ipdv values < - 100 ms :	**4730**
Nr. of ipdv values > 100 ms :	**4656**
Nr. of ipdv values < - 1 s :	**18**
Nr. of ipdv values > 1 s :	**26**
Total Standard Deviation :	**87.35 [ms]**
S.D. of subset {-100ms < x <100ms}	**20.75 [ms]**
S.D. of subset {1s<x<1s}	**83.78 [ms]**

Being the mean emmission interval of 0.764 sec
this means a clock skew of 56.64/0.764 = 74.136 ppm

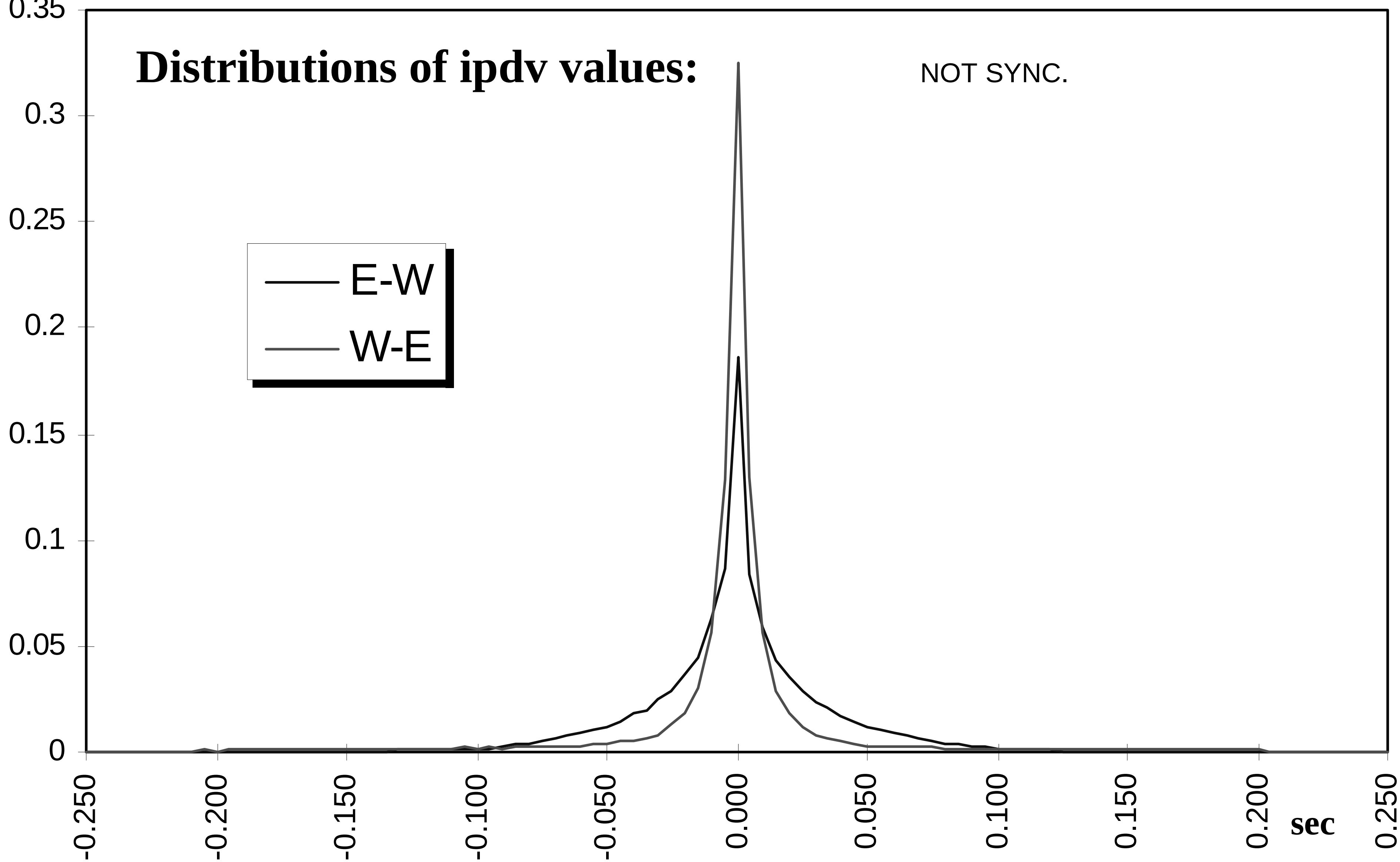
Measurement with NOT Synchronized Clocks (2)

RESULTS East to West (over 24 hours) :

Mean ipdv value :	**-59.36 [µs]**
Nr. of ipdv values < - 100 ms :	**1280**
Nr. of ipdv values > 100 ms :	**1286**
Nr. of ipdv values < - 1 s :	**1**
Nr. of ipdv values > 1 s :	**2**
Total Standard Deviation :	**40.23 [ms]**
S.D. of subset {-100ms < x <100ms}	**29.98 [ms]**
S.D. of subset {1s<x<1s}	**39.81 [ms]**

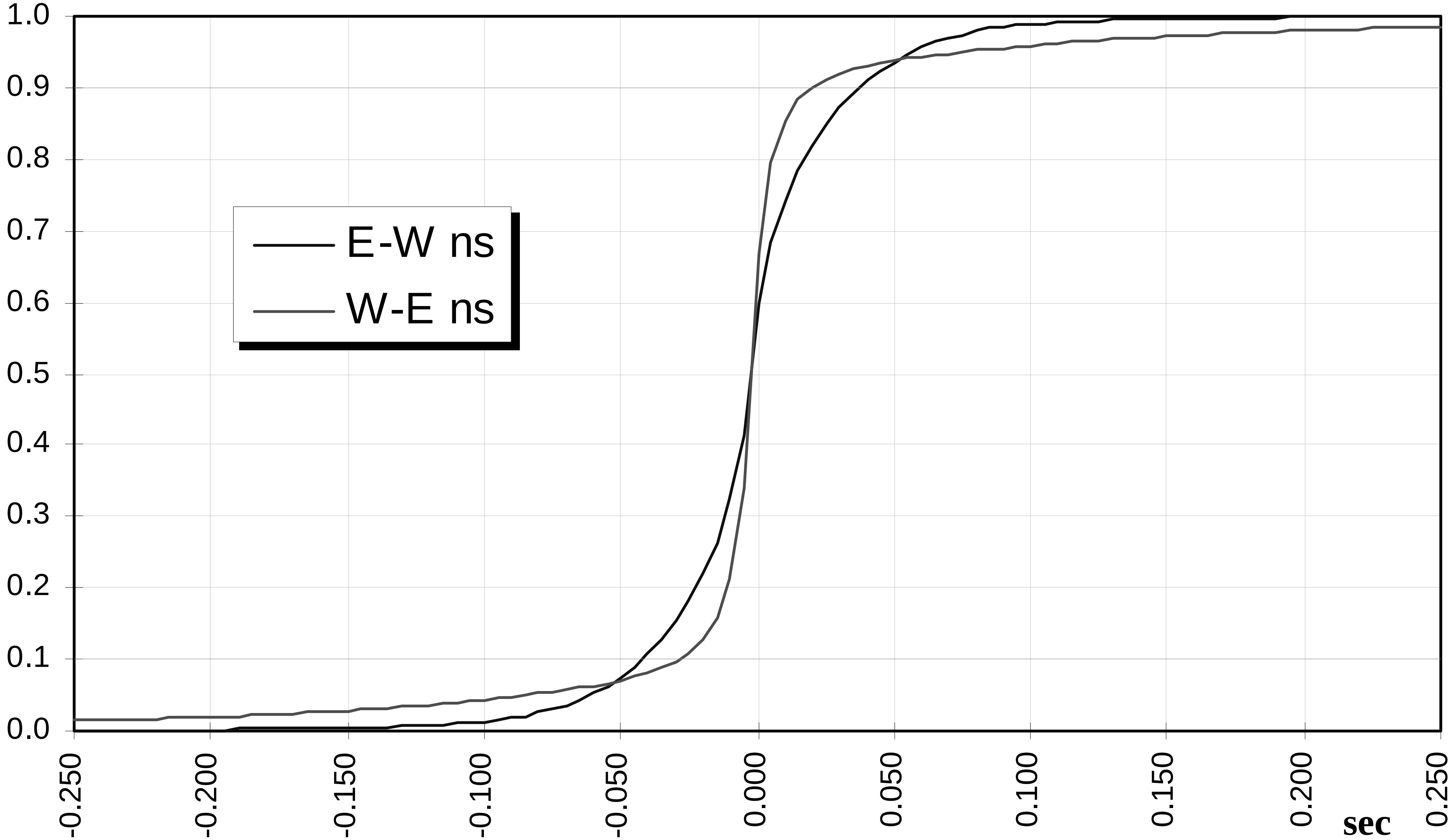
Being the mean emmission interval of 0.764 sec
this means a clock skew of -59.36 / 0.764 = -77.69 ppm

Measurement with NOT Synchronized Clocks (3)

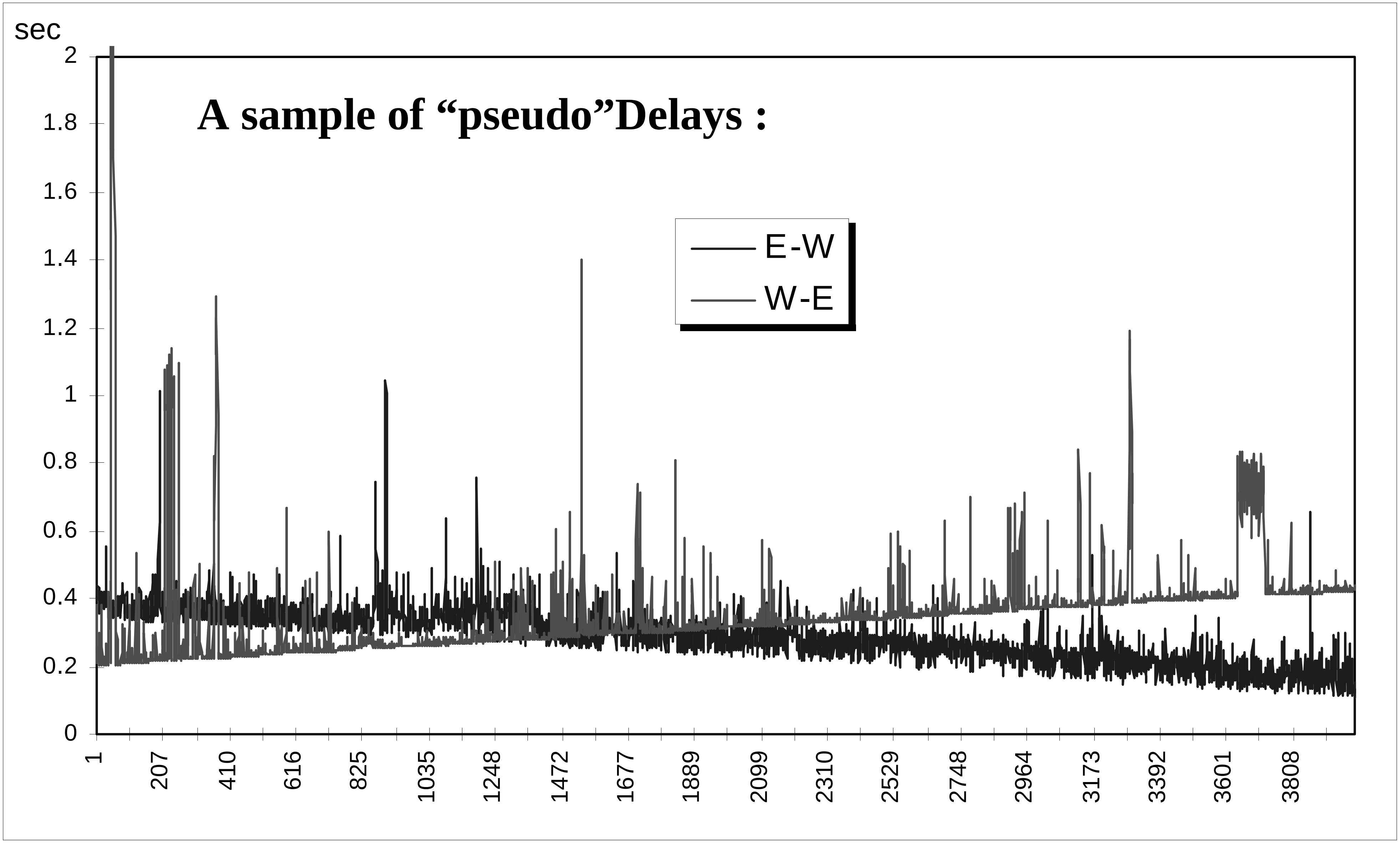


Measurement with NOT Synchronized Clocks (3)

Cumulative distributions :



Measurement with NOT Synchronized Clocks (3)



Further points for study (1)

Some points that could be further explored are:

1) - Measurements with looped packets (measurements of Round trip delay at the same time)
2) - Detection and characterization of bursts produced by the network
3) - Measurements with separate pairs of thest pachets instead of using a continuous stream
4) - Possibility of measurements interleaving with user traffic.
5) - Unique tool for measuring:
- **Round Trip Delay**
- **ipdv on both directions**
- **Packet Loss Ratio**
- **Out of sequence Ratio**
- **Replicated Packets Ratio**

Further points for study (2)
Example

Detection of bursts generated by network