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RESEARCH TITLE:
CLOCK SKEW MEASUREMENT METHOD FOR LOW TIME RESOLUTIONS

RESEARCH TEAM

KOMANG OKA SAPUTRA, ST., MT., PH.D. (0004048106)

YOGA DIVAYANA, PH.D. (0007108204)

STUDY PROGRAM OF ELECTRICAL ENGINEERING

FACULTY OF ENGINEERING

UDAYANA UNIVERSITY

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HALAMAN PENGESAHAN
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Judul	: Clock Skew Measurement Method for Low Time Resolutions
Peneliti / Pelaksana	
Nama lengkap	: Komang Oka Saputra, S.T., M.T., Ph.D.
NIP/NIDN	: 198104042008011009 / 0004048106
Jabatan Fungsional/Stuktural	: Asisten Ahli / Tidak ada
Program Studi	: Sarjana Teknik Elektro
Nomor HP	: 628123660060
Alamat Surel (e-mail)	: okasaputra@unud.ac.id
Anggota 1	
Nama Lengkap	: Yoga Divayana, Ph.D
NIDN	: 0007108204
Perguruan Tinggi	: Sarjana Teknik Elektro
Institusi Mitra (jika ada)	
Nama Institusi Mitra	: National Taiwan University of Science and Technology
Alamat	: No. 43, Section 4, Keelung Rd, Da'an District, Taipei City, Taiwan 106
Penanggung Jawab	: Prof. Wei-Chung Teng
Tahun Pelaksanaan	: Tahun ke-1 dari rencana 3 tahun
Biaya Diusulkan	: Rp. 145.000.000
Biaya Disetujui	: Rp. 150.000.000

Mengetahui
Dekan/Direktur Fakultas Teknik

(Prof. Ir. Ngakan Putu Gede Suardana, MT, Ph.D.)
NIP:196409171989031002

Denpasar, 30 Oktober 2018
Ketua Tim Pelaksana

(Komang Oka Saputra, S.T., M.T., Ph.D.)
NIP:198104042008011009

Menyetujui,
Ketua Lembaga Penelitian dan Pengabdian kepada Masyarakat
Universitas Udayana

(Prof. Dr. Ir. I Gede Rai Maya Temaja, MP.)
NIP:196210091988031002

ABSTRACT

In the world of INTERNET OF THINGS (IoT), more and more devices connected to network. One most importance issue is how to identify the validity of devices. Current methods such as cookies and mac address are known to be vulnerable of being hijacked or duplicated. Currently, an entity of hardware called clock skew, the different in speed of a clock to an ideal one, has been introduced. As clock skew is unduplicated, it is highly suitable to be used as device ID. By using clock skew device identification to become more robust.

Beside of its strong for device identification, clock skew is hard to measure as its value is affected by several factors. Network delay, client behavior, operating system, and time resolution are factors that can degrade clock skew, which in accordance can affect the identification process as well. Current clock skew measurement methods focus on handling network delay and client behavior issues. When these methods are applied in conditions with low time resolution the measurement values are highly deviated from the real clock skew value. Therefore, this research aims to develop new method for clock skew measurement for the condition of low time resolution.

The long-term purpose of this research is to develop new method than can adaptively measure clock skew for all conditions. Specifically, to obtain that purpose, there are several issues to be done first: 1) deep analysis about the low time resolution, 2) how to model the clock skew in low time resolution mode, 3) methods to measure clock skew for each level of time resolution, and 4) combining all methods to become one method for measuring skew in all conditions.

On this first year research, we have obtained data of clock skew from low time resolution and analysis of how the data formed have been conducted. A new method for grouping data from low time resolutions namely dotted line grouping method has been successfully developed.

Index terms: ***Clock skew, device identification, and time resolution***

TABLE OF CONTENT

CHAPTER I

INTRODUCTION

1.1 Background

The clock skew of a digital clock is the difference in the ticking frequency of the built-in crystal oscillator compared to the time. When two devices communicate over a network, the relative clock skew between them may cause problems for applications that demand accurate time. In communication delay measurement and time synchronization processes, for example, clock skew is highly undesirable, and must thus be eliminated in order to achieve precise time (moon et al, 1998). However, clock skew can be used to identify devices according to the unique properties of clock skew: the measured skews are stable in ppm (parts per million) precision over time, and the skews of different devices are generally distinguishable in ppm precision (Huang et al, 2012).

Linear regression is the fastest and simplest method of deriving the relative skew from a collected offset-set. However, this method is vulnerable to outliers. Alternatively, the linear programming algorithm (LPA) developed by (Moon et al, 1998) is known to be robust in obtaining an accurate clock skew, which is the slope of a line that lies below all the offsets, but passes through as many offsets as possible. Since LPA uses offsets of minimal delay, which are in fact low outliers, to determine the line, it requires a large amount of time to collect enough low outliers in order to stabilize its estimation. Recently, Oka et al. proposed the Hough transform (HT)-based method, which uses the gradient of the ROM's lower boundary line as the estimated clock skew (Oka et al, 2015). The HT-based approach provides the same level of precision as the LPA, but as the ROM becomes stable with only a few hundred offsets, the measurement time can be reduced to less than 10 minutes.

As the widespread use of clock skew now ranges from cases of notebooks communicating inside a WLAN (Jana et al, 2012) to smart phone applications accessing cloud services (Huang et al, 2012), there is significant demand for an approach able to provide accurate estimations even to device with low clock

resolution. The higher the clock resolution the more precise the reported time as well. However, it is known also that high clock resolutions can harm battery life, waste power, or even slow the computer. These facts make lower clock resolutions are also a proper option. When the aforementioned methods applied to offset-set from device with low time resolution, the estimation results are highly degraded. As devices with low clock resolution are frequently used, therefore, this research aims to develop new method for clock skew measurement for the condition of low time resolution.

Through collaboration between Udayana University and National Taiwan University of Science and Technology (NTUST), we have conducted several experiments to gain data related to clock skew in low time resolutions. As the data are analyzedon both parties, to this point we have been able to determine how the anomaly on low-time resolutions data is formed. Finally, we have conducted a new method namely dotted line grouping method.

1.2 State of Problem

Through the aforementioned introduction, several problems that have to be solved are:

1. How to have experiments data containing low time resolution.
2. How to analyze the effect of low time resolution.
3. How to have pattern of data that containing low time resolution.
4. How to obtain patterns that deeply dig from several points of view, for instance the period, the number of dots per time interval, the value of clock skew per interval, etc.
5. How to developing method for measuring clock skew for each low time resolution.

1.3 Research Purpose

To develop new methods for measuring clock skew accurately in low time resolution mode.

1.4 Potential results

Throughout the planned research, here are some output that can be produced:

1. Experimental data related low time resolution.
   Scenario of experiments, analytical results of the experimental data, and clock skew variations in each schema of experiment can be abstracted into papers for conference proceeding.
2. Pattern of offset-set in each low time resolution.
   New findings in the area of clock skew is going to be launched when we finish to model the pattern of offset-set in low time resolution. As this issue is new in the research of clock skew, we can push the publication into high rank journals.
3. New methods in clock skew measurement for low-time resolution.
   New method is always hot issue in publication. Therefore, another journal can be reached through the developed method for measuring clock skew for low-time resolution.
4. Lecturing materials
   Clock skew-based device identification is part of network security. In some departments like Electrical and Computer Engineering, Information Engineering, or Informatics, network security is one of fundamental course. However, mostly used teaching material in these courses are material with basic knowledge of network security. Therefore, teaching material related clock skew will fulfill material of those courses with applicated materials that are not generally used in university

CHAPTER II

LITERATURE REVIEW

2.1 State of the art

All digital devices have an embedded internal digital clock. Since there exists an error in the manufactured frequency to the ideal one, the clocks tick slightly faster or slower than physical time. This error of ticking rate is known as the clock skew, and the ticking rate difference between two digital clocks is called the relative clock skew. In this chapter, the current state of the study in the field of clock skew and clock skew measurements are firstly provided. Several issues that downgrade the current clock skew measurements are then summarized. In the end, motivation and contributions of this dissertation are introduced.

Earlier work, focused on eliminating the clock skew effect that caused inaccurate delay measurement between the sender and the receiver. Afterwards, two properties of clock skew were identified: the stability over time and the ability to distinguish between any two devices. These properties make clock skew a potential candidate for physical device fingerprinting and identification. For example, a pioneering work used clock skew as a tool for fingerprinting computers in a general network. Other work utilized clock skew in revealing a hidden service behind the onion router (TOR) network. Likewise, some studies exploited clock skew to secure time synchronization among sensor nodes in a wireless sensor network (WSN). Recently, usage of clock skew has been extended as an attack or defense instrument in various advanced technologies: wireless local area network (WLAN); cloud environments; mobile hand-held devices; and smartphones. Due to the importance of clock skew in many areas, it is crucial to pursue the accuracy of clock skew measurements.

It is worth noting that various methods have been deployed to measure clock skew. For instance, some scholars proposed outlier filtering methods by selecting the minimum offsets of the collected offsets. In the process, Paxson finalized the

outlier filter using the median line procedure, Aoki used the linear regression to calculate the slope of the accumulated minimum offsets selected from several minimum windows, and Huang used the quick piecewise minimum algorithm (QPM) to calculate the slope only from the minimum offsets in the first segment and the last segment of the collected offsets. However, the most widely adopted method is linear programming algorithm (LPA), as its result is not significantly affected by outliers. Moon et al. are the pioneers of clock skew measurement by LPA, and determine clock skew from the gradient of a line that lies below all the offsets.

All the above methods focused on achieving an accurate clock skew on a classical offsets distribution. In this research problem that has to be answered is how to develop new clock skew measurement method for condition where devices or server is using low time resolution. This condition is yet to be solved by previous method.

2.2 Previous study

There are several preliminary studies related to clock skew that we have published:

1. Study of delay and its relation to clock skew in Bluetooth

Our first research studies a special case of transmission delay when two devices communicate by Bluetooth technology. Transmission delays of packets are usually distributed randomly over some range, or the delay jitter, in wireless or wired communication. However, it is observed that under certain conditions, the transmission delays of consecutive packets may form into parallel dotted lines, and the intervals between a line and its next one are almost the same. The characteristics of the dotted-line delays, like the lifetime of one dotted line, are deduced to help develop an algorithm for detecting the period of this phenomenon. Experiments are further conducted to reveal how factors like operating system, packet sending period, and Bluetooth chips may affect the pattern of regular transmission delays.

This study has been published in: **“Komang Oka Saputra, Wei-Chung Teng, Pin-Yen Chou, and Tien-Ruey Hsiang, “A Study of Regular**

Transmission Delay in Bluetooth Communications." Proceedings of the 3rd International Conference on Intelligent Technologies and Engineering Systems (ICITES 2014)".

2. Replication attack detection method based on timestamps

In this study, we first demonstrate how an attacker can forge any clock skew by manipulating their timestamps to match the target skew. It is than explained in detail how to detect altered timestamps by detecting regular jumps when the system time resolution of the attacker be 1 ms or lower. Finally, experiments are conducted to verify that the proposed method is effective.

This research has been published in: **"Komang Oka Saputra, Wei-Chung Teng, and Yi-Hou Cou, "A Clock Skew Replication Attack Detection Approach Utilizing the Resolution of System Time." Proceedings of the 2015 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-AT 2015)"**.

3. Hough Transform(HT)-based Clock Skew Measurement over Network

In this study, we contribute into two issues. First, it introduces a new method based on the Hough transform: a method that combines the concept of clock skew and the Hough transform voting process. The goal of this method is to identify the parallelogram-like region that encloses the cluster of offsets, enabling the skew estimation to be derived from offsets that are undisrupted by the low outliers as well as the outliers. Second,

the proposed method is used to improve the clock skew measurement when the lower bound is unstable due to the presence of the low outliers.

This research has been published in: **"Komang Oka Saputra, Wei-Chung Teng, dan Tsung-Han Chen, "Hough Transform-Based Clock Skew Measurement Over Network." IEEE Transactions on Instrumentation and Measurement Volume 64 Number 12 2015"**.

4. Improvement of the HT-based method

The main contribution of this work is a new method called dynamic region of offset majority locating (DROML) for estimating the skews of multi-segment offset-sets. DROML uses the HT-based method both to determine the range and to estimate the skew of each segment. When the current ROM no longer enfolds the offset majority, i.e. a jump is detected, DROML dynamically relocates its ROM to fit the offset majority of the next segment. It then merges the clock skews of all segments into a reasonable estimation. Finally, DROML is designed to adaptively estimate the global skew such that it is able to provide real-time estimation. As the second contribution, the original HT-based method is also improved in order to locate the most representative ROM for a given number-of-bounded-offsets threshold. The improved version, wrapped as a function called LocateROM(), is able to provide more precise estimation than LPA and the original HT based method.

This research has been published in: **"Komang Oka Saputra, Wei-Chung Teng, dan Takaaki Nara, "Hough transform-based clock skew measurement by dinamically locating the region of offsets majority." IEICE Transactions on Information and System Volume E99-D Number 8 2016".**

Based on these preliminary studies we have done, we found that some issues like effect of low time resolution and how to measure clock skew in low time resolution are yet to be studied. Therefore, in this study, contributions that can be produced:

1. Analytical data related effects of low time resolution to clock skew
2. New methods to measure clock skew on low time resolution conditions

To conclude, Figure 2.1 is the roadmap of my research. In this diagram, all my previous studies from 2013 are shown as well as the plans for the next three years.

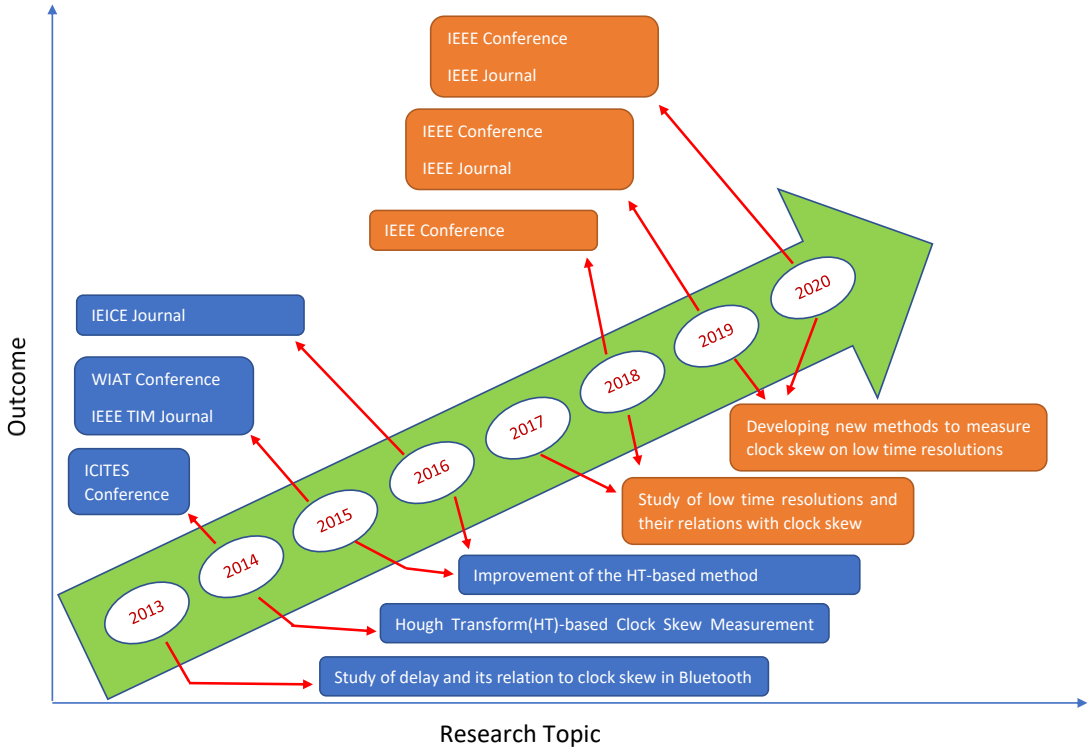

Figure 2.1 Roadmap of our research in clock skew

CHAPTER 3

METODOLOGY

3.1 General description

A clock skew measurement is initialized by collecting timestamps sent from a device. The measurer can actively send ICMP requests to the device and collect timestamps from the response packets. Alternatively, the measurer can provide a service (e.g., Web application) by which devices communicate with it and send their timestamps through AJAX packets or TCP timestamp options in TCP packets like it is shown in Fig 3.1.

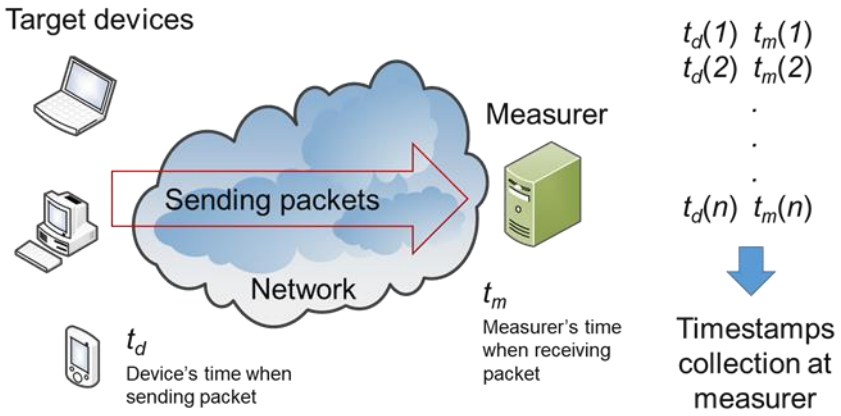

Figure 3.1 Basic concept of clock skew measurement

After the measurer collected the client time and measurer time, the timestamps collection can be shown like in Figure 3.2a. In this scatter diagram, each point represents one received timestamp, and the offset of each point is calculated by subtracting the devices timestamp from the measurer's receiving time. After this, a line-fitting method such as linear regression, or a more advance methods, like linear programming method or HT-based method can be used to estimate the slope or the clock skew of the whole collection. However, when data is collected from client/server with low time resolution, the timestamps collection to become a pattern like in Figure 3.2b. This collection degrade the accuracy of all methods,

especially in short-time calculation. Therefore it is required new method to measure collection like in Figure 3.2B.

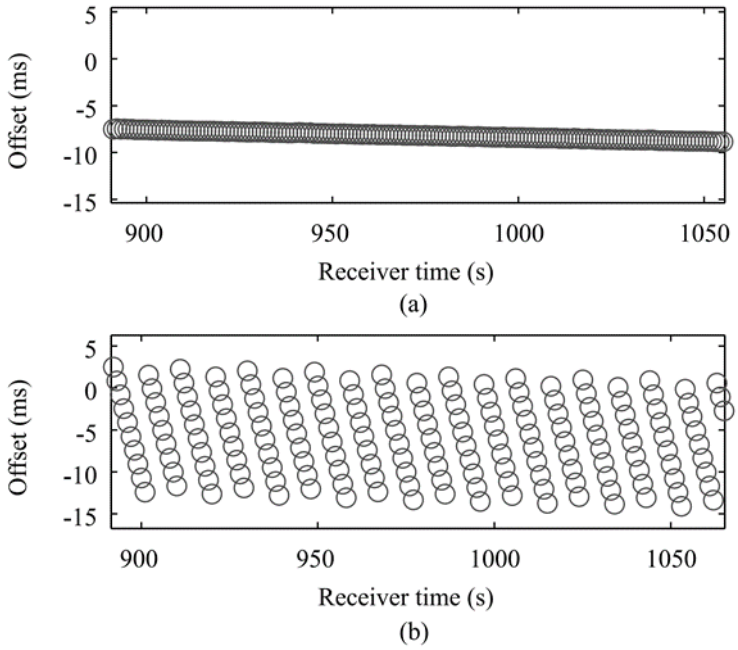

Figure 3.2. a) Normal timestamps collection. b) Timestamps collection from low-time resolution

3.2 Method

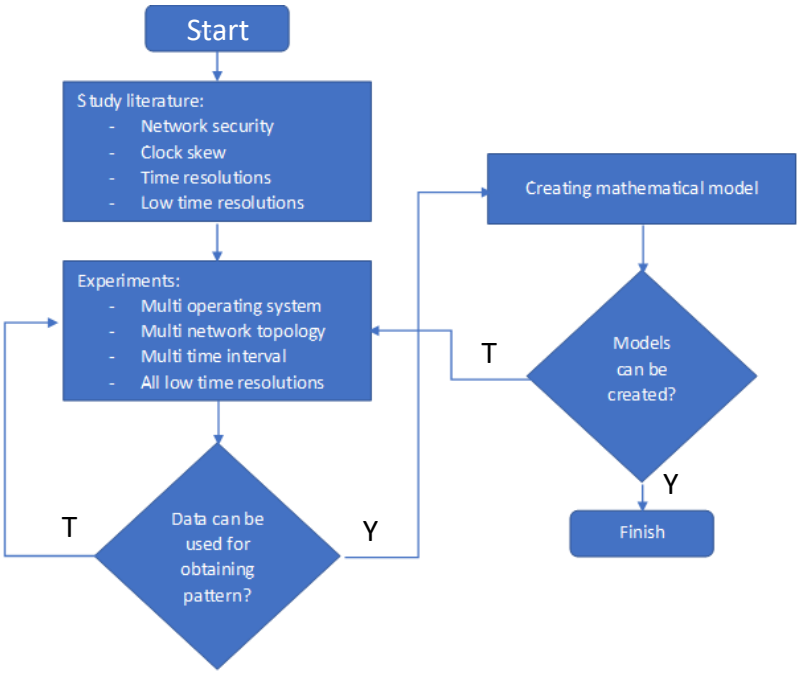

Figure 3.3 Flow chart of the first year of research.

In order to obtain models on data with low time resolution, we have conduct several experiments. Aferwards, data must be selected to obtain mathematical model. As mathematical model is related to the purity of the data, experiments can be repeated for several time to obtain correct data and correct models. This process is detailed in Figure 3.3.

CHAPTER 4

RESULTS

4.1 Data

Among several experiments we have down, Figure 4.1 is one of experimental data that can be used to define pattern.

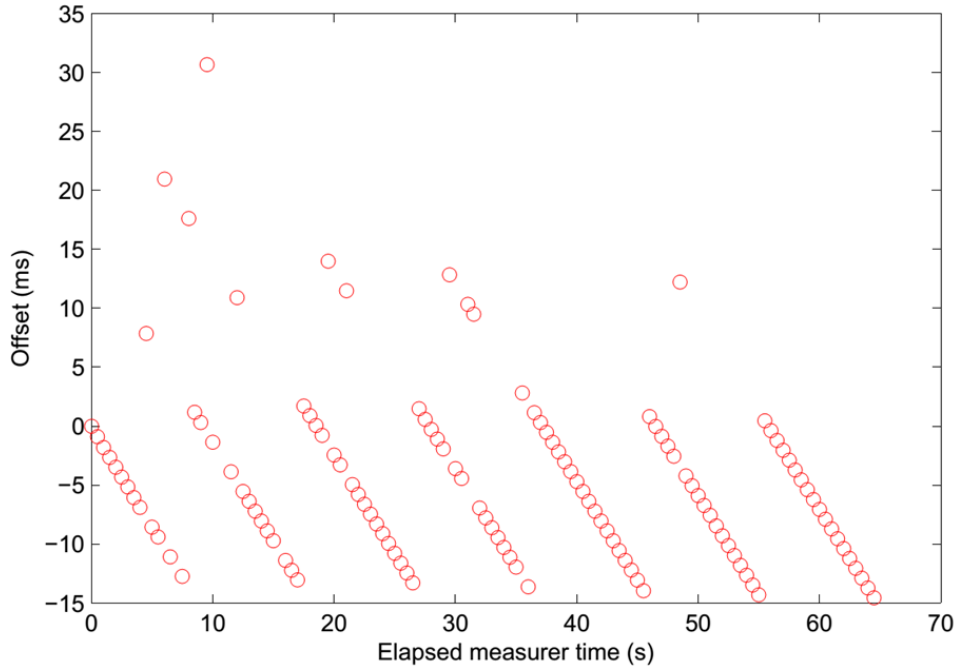

Figure 4.1 Sample of data from low time resolution

Data from Figure 4.1 is obtained from a client that send to a measurer with sending interval of 500 ms. Detail of communication between client and measurer is shown in Table 4.1.

Table 4.1. Data between client and measurer

No	Measurer time (us)	Client time (us)	Offset (us)	Offset interval (us)
1	0	0	0	
2	499201	500095	-894	-894
3	998402	1000212	-1810	-916
4	1497603	1500249	-2646	-836
5	1996803	2000285	-3482	-836
6	2496004	2500320	-4316	-834
7	2995205	3000359	-5154	-838
8	3494406	3500466	-6060	-906
9	3993607	4000503	-6896	-836
10	4508408	4500539	7869	14765
11	4992009	5000573	-8564	-16433
12	5491210	5500608	-9398	-834
13	6021610	6000649	20961	30359
14	6489611	6500686	-11075	-32036
15	7488013	7500756	-12743	-1668
16	8018414	8000791	17623	30366
17	8502015	8500828	1187	-16436
18	9001216	9000908	308	-879
19	9531617	9500946	30671	30363
20	9999617	10000982	-1365	-32036

From “Measurer Time” column we can see that the measurer receiving time is formed by the 15600 ms resolution (n x 15600). Based on our team discussion, this fact can be used to find the dotted line pattern o data with low timeresolution.

4.2 Developed method

Based on Table 4.1, we can modify it into Table 4.2.

Table 4.2. Data between client and measurer

No	Measurer time (us)	Client time (us)	Measurer num. tick	Num. tick interval
1	0	0	0	
2	499201	500095	32	32
3	998402	1000212	64	32
4	1497603	1500249	96	32
5	1996803	2000285	128	32
6	2496004	2500320	160	32
7	2995205	3000359	192	32
8	3494406	3500466	224	32
9	3993607	4000503	256	32
10	4508408	4500539	289	33
11	4992009	5000573	320	31
12	5491210	5500608	352	32
13	6021610	6000649	386	34
14	6489611	6500686	416	30
15	7488013	7500756	480	64
16	8018414	8000791	514	34
17	8502015	8500828	545	31
18	9001216	9000908	577	32
19	9531617	9500946	611	34
20	9999617	10000982	641	30

In this table, column “Measurer num. tick” is obtained by using the following formula:

$$Number\ of\ tick = \frac{Measurer\ time}{15600}$$

Afterward, a term of base tick is created by using the following formula:

$$base_{tick} = \left\lfloor \frac{seding\ interval}{15600} \right\rfloor$$

To this point, a new formula can be develop:

$$Normalized\ Tick(i) = \left\lfloor \frac{measurer\ time\ (i) - (i-1) * base_{tick} * 15600}{15600} \right\rfloor$$

Finally, we can find all Normalized Tick value of each data, and then we can draw it into scatter diagram as it described in Figure 4.2.

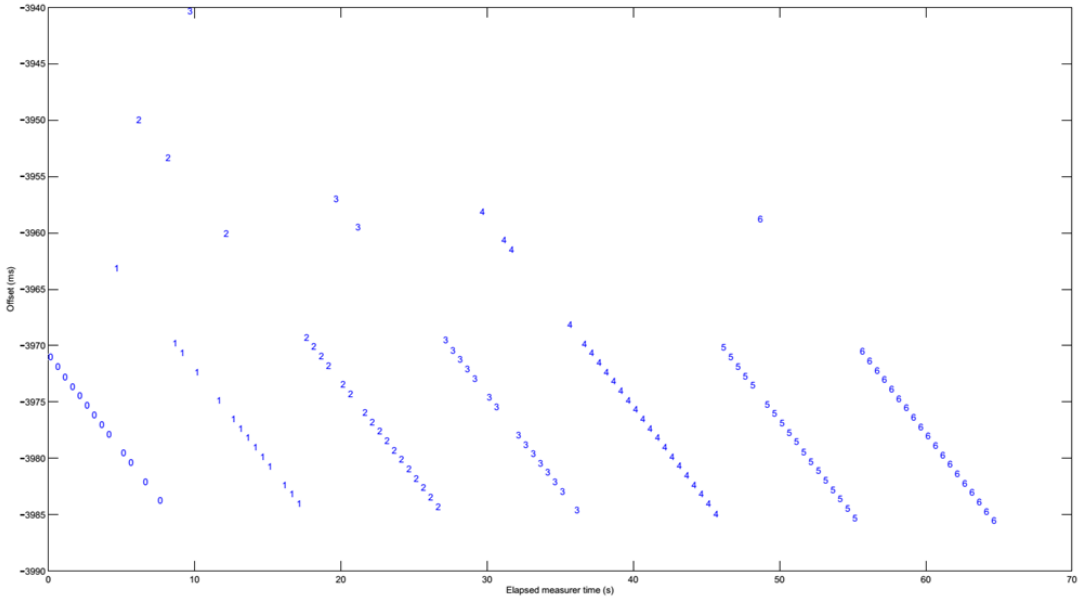

Figure 4.2 Tick view of the Figure 4.1

Logically, data in Figure 4.2 can be grouped as detailed in Table 4.3.

Table 4.3. Logical view of Figure 4.2

Norm. tick	Dots member (arrival sequence at the receiver)
0	1,2,3,4,5,6,7,8,9,11,12,14,15
1	10, 17, 18, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31
2	13, 16, 22, 32, 33, 34, 35, 37, 38, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50
3	19, 36, 39, 51, 52, 53, 54, 55, 57, 58, 61, 62, 63, 64, 65, 66, 67, 69
4	…
5	…
6	…

To finalize the above findings we have develop a new method shown in Figure 4.3.

Algorithm 1 Dotted lines grouping method

Require: $RecT$, $PackL$, $SenT$, int

$DotL$ = $null$
$PackL$ = $null$
j = 0
for $i = 1$; $i < RecT$.length; i++ **do**
  if $i > 1$ **then**
    $loss$ = floor(($SenT(i) - SenT(i-1)$)/int)
    if $loss > 0$ **then**
      Create a new row in $PackL$
      Add i to $PackL$($PackL$.rowlength - 1)
      Add $loss$ to $PackL$($PackL$.rowlength - 1)
      $j = j + loss$
    end if
  end if
  $dtick$ = floor(($RecT(i)$ − j*floor((int/15.6)*15.6))/15.6)
  if $DotL == null$ **or** $DotL$.rowlength $\leq dtick$ **then**
    Create ($dtick - DotL$.rowlength $- 1$) new row in $DotL$
    Add i to $DotL$($DotL$.rowlength $- 1$)
  else
    Add i to $DotL(dtick)$
  end if
  j = j + 1
end for

Figure 4.3 New developed method

We have tested this method by using data in Figure 4.4.

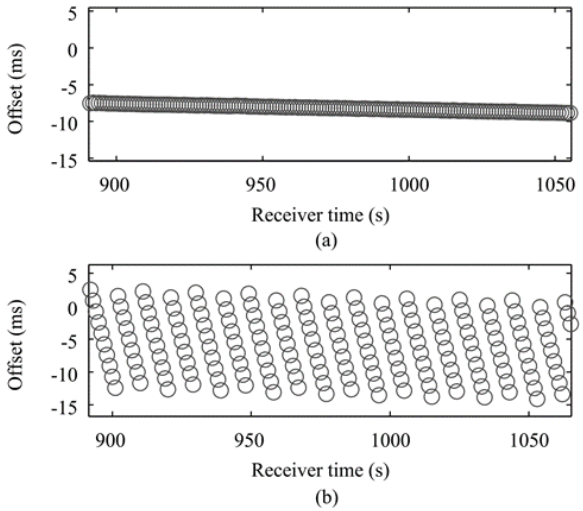

Figure 4.4 Parts of 3000 pairs of timestamps of a Linux notebook and a Windows PC. (a) Classicall case. (b) dotted-line case

Results of the implementation of Algorithm 1 to the data in Figure 4.4 are detailed in Table 4.4.

Table 4.4. Calculation results

Number of offset	3000
Number of line	309
Sample #1 (line number 9)	
Number of dot	10 (78—87)
Line skew	-1.6207 ms/s
Sample #2 (line number 71)	
Number of dot	9 (679--687)
Line skew	-1.6190ms/s
Sample #2 (line number 71)	
Number of dot	10 (2190--2199)
Line skew	-1.6187 ms/s
Average of all line skews	-1.6581 ms/s
Min value of all line skews	-1.6181 ms/s
Max value of all line skews	-1.6516 ms/s
Max – Min	0.0335 ms/s

Calculation results of the proposed method shown consistent value with only 0.0335 ppm skew deviation.

CHAPTER 5

CONCLUSION

Experiments for low time resolutions have been conducted. From several data with low time resolutions, pattern of how the dotted line happened can be derived. Finally, a novel method namely dotted line grouping method have been developed.

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APPENDIX 1 EXPENSE JUSTIFICATION

Month	Day	Date	Name	Number	Price	Qty	Total	Tax (PPH)	Tax (PPN)
MEI	Saturday	5/5/2018	Snack for May team meeting		20000	10	200000	6000	
			Lunch box for May team meeting		48000	10	480000	14400	
			Transport fee for team member		150000	10	1500000		
	Saturday	12/5/2018	Snack for FGD team meeting		20000	20	400000	12000	
			Lunch box for FGD team meeting		48000	20	960000	28800	
			Transport fee for team member		150000	10	1500000		
	Monday	14-5-2018	Copy and print for FGD material		20000	30	600000	24000	
	Saturday	19-5-2018	Snack for FGD		20000	30	600000	18000	
			Lunch box for FGD		48000	30	1440000	43200	
			Transport fee for team member		150000	10	1500000		
			Rent for projector and screen		900000	1	900000	36000	
	Monday	21-5-2018	Document translation		900000	1	900000	36000	
			Document proofreading		900000	1	900000	36000	
	Tuesday	22-5-2018	Purcase of clock skew modul part 1		4000000	1	4000000	5454545.455	363636.3636
	Wednesday	23-5-2018	Purcase of paper		100000	5	500000		
			Purcase of notebook		40000	5	200000		

			Purcase of ballpoint		40000	5	200000		
			Purcase of tissue		25000	14	350000		
			Purcase of coffe		100000	6	600000		
JUNI	Saturday	2/6/2018	Rent of 10 notebooks for 7 days	7	200000	10	14000000	330000	2000000
			Rent of network equipment (switch, router, access point) for 7 days	7	1000000	1	7000000		
			Rent of server for 7 days	7	1000000	1	1000000		
	Saturday	2/6/2018	Snack for June team meeting		20000	10	200000	6000	
			Lunch box for June team meeting		48000	10	480000	14400	
			Transport fee for team member		150000	10	1500000		
	Sunday	3/6/2018	Snack box for conducting experiments day 1	3	20000	15	900000	27000	
			Lunch box for conducting experiments day 1		48000	15	720000	21600	
	Monday	4/6/2018	Snack box for conducting experiments day 2	3	20000	15	900000	27000	
			Lunch box for conducting experiments day 2		48000	15	720000	21600	
	Tuesday	5/6/2018	Snack box for conducting experiments day 3	3	20000	15	900000	27000	
			Lunch box for conducting experiments day 3		48000	15	720000	21600	
	Wednesday	6/6/2018	Snack box for conducting experiments day 4	3	20000	15	900000	27000	
			Lunch box for conducting experiments day 4		48000	15	720000	21600	

	Thursday	7/6/2018	Snack box for conducting experiments day 5	3	20000	15	900000	27000	
			Lunch box for conducting experiments day 5		48000	15	720000	21600	
	Friday	8/6/2018	Snack box for conducting experiments day 6	3	20000	15	900000	27000	
			Lunch box for conducting experiments day 6		48000	15	720000	21600	
	Saturday	23/6/2018	Snack for FGD team meeting		20000	15	300000	9000	
			Lunch box for FGD team meeting		48000	15	720000	21600	
			Transport fee for team member		150000	10	1500000		
	Monday	25/6/2018	Copy and print for FGD material		15000	40	600000	24000	
	Saturday	30/6/2018	Snack for FGD		20000	40	800000	24000	
			Lunch box for FGD		48000	40	1920000	57600	
			Transport fee for team member		150000	10	1500000		
	Saturday	30/6/2018	Document translation		900000	1	900000	36000	
			Document proofreading		900000	1	900000	36000	
			Rent for projector and screen		900000	1	900000	36000	
	Saturday	30/6/2018	Purcase of clock skew modul part 2		4000000	1	4000000	54545.45455	363636.3636
JULI	Saturday	7/7/2018	Snack for July team meeting		20000	10	200000	6000	
			Lunch box for July team meeting		48000	10	480000	14400	
			Transport fee for team member		150000	10	1500000		
	Saturday	14/7/2018	Snack for FGD team meeting		20000	20	400000	12000	

			Lunch box for FGD team meeting		48000	20	960000	28800	
			Transport fee for team member		150000	10	1500000		
	Monday	16/7/2018	Copy and print for FGD material		15000	50	750000	30000	
	Saturday	21/7/2018	Snack for FGD		20000	50	1000000	30000	
			Lunch box for FGD		48000	50	2400000	72000	
			Transport fee for team member		150000	10	1500000		
			Rent for projector and screen		900000	1	900000	36000	
	Monday	23/6/2018	Document translation		900000	1	900000	36000	
			Document proofreading		900000	1	900000	36000	
AGUSTUS	Wednesday	1/8/2018	honor head of software engineer (Suta)	5	21000	12	1260000		
			honor head of hardware engineer (Nola)	5	21000	12	1260000		
			honor software team member (Nanda)	5	20000	12	1200000		
			honor software team member (bima)	4	20000	12	960000		
			honor hardware team member (cindi)	5	20000	12	1200000		
			honor hardware team member (veda)	4	20000	12	960000		
			honor first secretary (meutia)	5	15000	12	900000		
			honor second secretary (mudsir)	4	15000	12	720000		
			honor data analitycal (dharma)	5	12500	12	750000		
	Friday	2/8/2018	Purcase of clock skew modul part 3		4000000	1	4000000	5454545.455	363636.3636

	Saturday	4/8/2018	Snack for August team meeting		20000	10	200000	6000	
			Lunch box for August team meeting		48000	10	480000	14400	
			Transport fee for team member		150000	10	1500000		
	Saturday	11/8/2018	Snack for MONEV preparation meeting		20000	20	400000	12000	
			Lunch box for MONEV preparation meeting		48000	20	960000	28800	
			Transport fee for team member		150000	10	1500000		
	Sunday	18/8/2018	Snack for MONEV preparation meeting		20000	20	400000	12000	
			Lunch box for MONEV preparation meeting		48000	20	960000	28800	
			Transport fee for team member		150000	10	1500000		
	Thursday	6/8/2018	Document translation		900000	1	900000	36000	
			Document proofreading		900000	1	900000	36000	
	Thursday	6/8/2018	SENASTEK payment		975000	1	975000		
SEPTEMBER	Saturday	1/9/2018	Snack for September team meeting		20000	10	200000	6000	
			Lunch box for September team meeting		48000	10	480000	14400	
			Transport fee for team member		150000	10	1500000		
	Sunday	2/9/2018	Snack box for conducting experiments part 2 day 1	3	20000	15	900000	27000	
			Lunch box for conducting experiments part 2 day 1		48000	15	720000	21600	
	Monday	3/9/2018	Snack box for conducting experiments part 2 day 2	3	20000	15	900000	27000	
			Lunch box for conducting experiments part 2 day 2		48000	15	720000	21600	

	Tuesday	4/9/2018	Snack box for conducting experiments part 2 day 3	3	20000	15	900000	27000	
			Lunch box for conducting experiments part 2 day 3		48000	15	720000	21600	
	Wednesday	5/9/2018	Snack box for conducting experiments part 2 day 4	3	20000	15	900000	27000	
			Lunch box for conducting experiments part 2 day 4		48000	15	720000	21600	
	Thursday	6/9/2018	Snack box for conducting experiments part 2 day 5	3	20000	15	900000	27000	
			Lunch box for conducting experiments part 2 day 5		48000	15	720000	21600	
	Friday	7/9/2018	Snack box for conducting experiments part 2 day 6	3	20000	15	900000	27000	
			Lunch box for conducting experiments part 2 day 6		48000	15	720000	21600	
	Friday	14/9/2018	Document translation		900000	1	900000	36000	
			Document proofreading		900000	1	900000	36000	
OCTOBER	Saturday	6/10/2018	Snack for Oktober team meeting		20000	10	200000	6000	
			Lunch box for october team meeting		48000	10	480000	14400	
			Transport fee for team member		150000	10	1500000		
	Monday	8/10/2018	Document translation		900000	1	900000	36000	
			Document proofreading		900000	1	900000	36000	
	Wednesday	24/10/2018	Snack box for collaboration meeting between team and Prof. Teng		20000	10	200000	6000	
			Lunch box for collaboration meeting between team and Prof. Teng		48000	10	480000	14400	
			Transport fee for team member		150000	10	1500000		

	Thursday	25/10/2018	Snack box for FGD		20000	50	1000000	30000	
			Lunch box for FGD		48000	50	2400000	72000	
			Transport fee for team member		150000	10	1500000		
	Friday	26/10/2018	Snack box for guest lecturer Prof. Teng		20000	53	1060000	31800	
			Lunch box for guest lecturer Prof. Teng		48000	53	2544000	76320	
			Transport fee for team member		150000	10	1500000		
	Monday	27/8/2018	Air fare ticket TPE-DPS and DPS-TPE		7625000	1	7625000		
			Hotel accomodation		4000000	1	4000000		
		TOTAL					144434000	2486356.364	3090909.091
		TOTAL + TAX					150011265.5		

APPENDIX 2 SUPPORTING INFRASTRUCTURE

1. Computer Laboratory, at Study Program of Electrical Engineering, Faculty of Engineering Udayana UNiversity
2. Cybernetics and Network Security Laboratory, at the Department of Computer Science and Information Engineering, National Taiwan University of Science and Technology.

APPENDIX 3 TEAM MEMBER AND JOB DESCRIPTION

No.	Name	Department	Field of research	Time allocation (hour/week)	Job description
1	Komang Oka Saputra, S.T., M.T., Ph.D.	Electrical Engineering	Informatics and Telecommunication	16	All parts of research
2	Yoga Divayana, PhD	Electrical Engineering	Electronics	10	Analyzing data
3	KETUT DHARMA YASA (1605541104)	Student of Electrical Engineering	Power system	8	Experiments
4	Nola Verli Herlian (1404405087)	Student of Electrical Engineering	Telecommunication	8	Experiments

APPENDIX 4 LETTER OF AGREEMENT

LETTER OF AGREEMENT (LOA)

TO COLLABORATE IN CONDUCTING RESEARCH AND INTERNATIONAL PUBLICATION

BETWEEN

Prof. Wei-Chung Teng

NATIONAL TAIWAN UNIVERSITY OF SCIENCE AND TECHNOLOGY – DEPARTMENT OF COMPUTER SCIENCE AND INFORMATION ENGINEERING

AND

Komang Oka Saputra, ST., MT., PhD

UDAYANA UNIVERSITY - DEPARTMENT OF ELECTRICAL ENGINEERING

This letter is to confirm that Prof. Wei-Chung Teng from the National Taiwan University of Science and Technology, Taipei, Taiwan and Komang Oka Saputra, ST., MT., PhD from the Department of Electrical Engineering, Udayana University, Bali, Indonesia have agreed to:

- Develop a research network between Udayana University and National Taiwan University of Science and Technology.
- Collaborate in conducting research study on the area of "Clock skew measurement method"
- Conduct the proposed research which is planned to be completed in three years period.
- Share the use of available resources in order to complete the proposed research activities.
- Disseminate research finding at international forums.
- Publish research finding internationally.
- Communicate and publish (orally and verbally) in English

For the aforementioned agreed activities, the responsible parties will be the team leader of the research team of the Department of Computer Science and Information Engineering, National Taiwan University of Science and Technology, and the team leader of the research team of the Department of Electrical Engineering, Udayana University.

For
The National Taiwan University of Science and Technology

Wei-chung Teng

Prof. Wei-Chung Teng
Department of Computer Science and Information Engineering
Date: 12th February 2018

For
The Udayana University

Komang Oka Saputra, ST., MT., PhD
Department of Electrical Engineering
Date: 12th February 2018

APPENDIX 5 CURICULUME VITAE

HEAD OF RESEARCHER

A. Personal information

1	Full name with title	Komang Oka Saputra, ST, MT L/~~P~~
2	Academic rank	Tenaga pengajar
3	Structural position	-
4	NIP/NIK	198104042008011009/5106040404810010
5	NIDN	0004048106
6	Birth date	Kintamani, 4 April 1981
7	Home address	Desa Katung Kintamani Bangli
8	Phone	+628123660060
9	Office address	Jurusan Teknik Elektro – Universitas Udayana Jl. Kampus Bukit Jimbaran, Badung Bali
10	Phone	+62-361-703315
11	Email	okasaputra@unud.ac.id;
12	Lulusan yang telah dihasilkan	3
13	Mata Kuliah yg Diampu	Agen cerdas
		Bahasa Inggris
		Dasar Pemrograman Komputer
		Soft Computing
		Decission Suport System
		Telekomunikasi Ramah Lingkungan

B. Education

Program	Bachelor	Master	PhD
Name	Universitas Brawijaya	Universitas Indonesia	National Taiwan University of Science and Technology
Research field	Jurusan Teknik Elektro, Telekomunikasi	Jurusan Teknik Elektro, Telekomunikasi	Computer Science and Information Engineering
Start-End	1999-2004	2004-2006	2013-2016
Research title	Jaringan Hybrid Fiber Coax (HFC) dengan Medium Access Control Protocol	Sequential Rotation Array untuk Meningkatkan Circular Polarization Bandwidth	Hough Transform-Based Clock Skew Measurement over Networks
Advisor	Ir. Endah Budi Purnomowati MT	Prof. Eko Tjipto Rahardjo	Prof. Wei-Chung Teng

C. Research

No.	Year	Title	Expense	
			Source	Grant

1	2017	Analisa penerapan e-quiz dengan soal non-formal pada pengetahuan umum mahasiswa bidang Teknik elektro dan komputer	PNBP	25000000

D. Community service

No.	Year	Title	Expense	
			Source	Grant
1	2017	Implementasi E-Exam dengan soal non-formal pada kegiatan asah terampil gapoktan budhi luhur desa katung	PNBP	10000000

E. Journals

No.	Title	Vol./No./Year	IOurnal
1.	Hough Transform-Based Clock Skew Measurement Over Network	64/12/2015	IEEE Transactions on Instrumentation and Measurement
2.	Hough transform-based clock skew measurement by dynamically locating the region of offsets majority	E99-D/8/2016	IEICE Transactions on Information and Systems

F. Conferences

No.	Year	Title	Conference name
1	2014	*A Study of Regular Transmission Delay in Bluetooth Communications*	*The 3rd International Conference on Intelligent Technologies and Engineering Systems (ICITES)*

2	2015	*A Clock Skew Replication Attack Detection Approach Utilizing the Resolution of System Time*	*International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT)*

Denpasar, 12th February 2018

Komang Oka Saputra, ST, MT, PhD

RESEARCHER MEMBER

Yoga Divayana, PhD

NIP: 19821007 201012 1 001

Pangkat dan Golongan: IIIc

Jurusan Teknik Elektro, Fakultas Teknik

Kampus Bukit Jimbaran, Universitas Udayana, Bali Indonesia

yoga@unud.ac.id; yogadivayana@gmail.com

+6282145959144

Research Interests

Organic light-emitting diode (OLED); hybrid quantum-dots organic LED; solid-state LED; photovoltaic; thin-film transistor; light-emitting transistor; surface plasmon polariton; quantum field theory; hydrodynamics.

Work Experience

Juni 2011- Sekarang	Lecturer in Department of Electrical Engineering Universitas Udayana, Bali, Indonesia
Juli 2010 – Mei 2011	Senior Research Fellow Nanyang Technological University
Agus 2008 - Jul 2010	Research Fellow Nanyang Technological University Post-Doctoral Research Fellow Singapore Millennium Foundation Fellowship
Des 2007 - Jul 2008	Project Officer, Nanyang Technological University

Education

Nov 2004- Nov 2007	S3 PhD, Electrical and Electronic Eng. Thesis: *Optimizing electroluminescence processes in organic light-emitting diodes* Nanyang Technological University, Singapore

Jul 2000-Jul 2004 S1 Bachelor of Engineering *First Class Honors*

- Scholarship: Nanyang Scholarship
- *University Medal (Thales Gold Medal* for the highest aggregate grade in Photonics Specialization)
  Nanyang Technological University, Singapore

Teachings

Opto-electronika; Elektronika; Teknologi Flat-Panel Display; Nano-teknologi; Teknik Akusisi Data, Material Teknik Elektro, Teknik Kendali Fuzzy

Awards and Honors

2017 Akademi Ilmuan Muda Indonesia (ALMI), Indonesian Academy of Young Scientist

2008 Singapore Millennium Foundation Fellowship

2008 IEEE-LEOS Graduate Student Fellowship (hanya 12 mahasiswa S3 didunia)

2004 PhD Scholarship, Photonics Research Center

2004 University Medal (Thales Gold Medal) for highest aggregate in Photonic Subjects

2004 Professional engineers board gold medal (Nominated)

2001 Dean's Lists, Nanyang Technological University, Singapore

2000 Nanyang Scholarship, Nanyang Technological University, Singapore

2000 Bronze Medal in XXXI International Physics Olympiad in United Kingdom

Professional Services

Reviewer for the journal of Applied Physics Letters, Organic Electronics, Journal of Applied Physics, Optics Letters, Thin Solid Films, Journal of Luminescence, Journal of Vacuum Science and Technology.

Professional Memberships

Anggota dari the IEEE and IEEE-Photonic Society

Journal Publications

Physical Review Letters (Impact Factor 8,462), Applied Physics Letters (Impact Factor 3,4), Organic Electronics (Impact Factor 3,4), Journal of Applied Physics (Impact Factor 2,06), Chemistry-A European Journal (Impact Factor 5,73), Journal of Materials Chemistry (Impact Factor 6,62), Optics Express (Impact Factor 3,48), and others.

Total Citations : 651*

H-Index : 14*/12[+]

*** source google scholar**

[+] source scopus

2014

1. Y Zhao, J Zhang, S Liu, Y Gao, X Yang, KS Leck, AP Abiyasa, **Y Divayana**, E Mutlugun, ST Tan, Q Xiong, HV Demir, XW Sun, "Transition metal oxides on organic semiconductors" *Organic Electronics* 15 (4), 871-877(2014)

2013

2. Y Zhao, R Chen, Y Gao, KS Leck, X Yang, S Liu, AP Abiyasa, **Y Divayana**, E Mutlugun, ST Tan, H Sun, HV Demir, XW Sun, "AC-driven, color-and brightness-tunable organic light-emitting diodes constructed from an electron only device" *Organic Electronics* 14 (12), 3195-3200 (2013)

3. KS Leck, **Y Divayana**, D Zhao, X Yang, AP Abiyasa, E Mutlugun, Y Gao, S Liu, ST Tan, XW Sun, HV Demir, "Quantum dot light-emitting diode with quantum dots inside the hole transporting layers" *ACS applied materials & interfaces* 5 (14) (2013)

4. Liu SW, Wang JX, **Divayana Y**, Dev K, Tan ST, Demir HV, Sun XW, "An Efficient Non-Lambertian Organic Light-Emitting Diode Using Imprinted Submicron-size Zinc Oxide Pillar Arrays," *Applied Physics Letters* 102, 053305 (2013).

a.

b.

c.

2012

5. Yang XY, **Divayana Y**, Zhao DW, Leck KS, Lu F, Tan ST, Abiyasa AP, Zhao YB, Demir, HV and Sun XW, "A Bright Cadmium-Free, Hybrid Organic/Quantum Dot White Light-Emitting Diode," *Applied Physics Letters* 101, 233110 (2012).
6. Liu SW, **Divayana Y,** Abiyasa AP, Tan ST, Demir HV and Sun XW, "On the Triplet Distribution and its Effect on an Improved Phosphorescent Organic Light-Emitting Diode," *Applied Physics Letters* 101, 093301 (2012).

7. Li G, Abiyasa AP, Gao J, **Divayana Y**, Chen W, Zhao Y, Sun XW and Zhang QC, "Synthesis and Properties of a Diazopentacene Analogue," *Asian Journal of Organic Chemistry* 4 (**Cover**), 285 (2012).

2011

8. Liu SW, **Divayana Y**, Sun XW, Wang Y, Leck KS and Demir HV, "Improved performance of organic light-emitting diodes with MoO_3 interlayer by oblique angle deposition " *Optics Express* 19, 4513, 2011.
9. **Divayana Y**, Liu SW, Kyaw AKK and Sun XW, "Efficient extraction of singlet-triplet excitons for high-efficient white organic light-emitting diode with a multilayer emission region," *Organic Electronics* 12, 1, 2011.

2010

10. Kyaw AKK, Sun XW, Zhao DW, Tan ST, **Divayana Y** and Demir HV, "Improved Inverted Organic Solar Cells With a Sol-Gel Derived Indium-Doped Zinc Oxide Buffer Layer ", *IEEE Journal Of Selected Topics In Quantum Electronics*, 16, 1700 (2010).
11. Xiao JC, **Divayana Y**, Zhang QC, Doung HM, Zhang H, Boey F, Sun XW, Wudl F, "Synthesis, structure, and optoelectronic properties of a new twistacene 1,2,3,4,6,13-hexaphenyl-7: 8,11: 12-bisbenzo-pentacene", *Journal of Materials Chemistry* 20, 8167, 2010.
12. Zhang QC, **Divayana Y**, Wang ZJ, Tiekink ERT, Doung HM, Xiao JC, Zhang H, Boey F, Sun XW and Wudl F, "Synthesis, Characterization, and Bipolar Transporting Behavior of a New Twisted Polycyclic Aromatic Hydrocarbon: 1',4'-Diphenyl-naphtho-(2'.3':1.2)-pyrene-6'-nitro-7'-methyl Carboxylate", *Chemistry-A European Journal* 16, 7422 (2010).
13. Ling B, Zhao JL, Sun XW, Tan ST, Kyaw AKK, **Divayana Y**, Dong ZL, "Color tunable light-emitting diodes based on p(+)-Si/p-CuAlO2/n-ZnO nanorod array heterojunctions", *Applied Physics Letters* 97, 013101, Jul 2010.
14. **Divayana Y** and Sun XW, "Existence of optimum intermolecular-spacing for maximum exciton diffusion in tris(2-phenylpyridine) iridium(III)", *Organic Electronics* 11, 67, Jan 2010.

2009

15. **Divayana Y** and Sun XW, "An efficient bis(2-phenylquinoline) (acetylacetonate) iridium(III)-based red organic light-emitting diode with alternating guest:host emitting layers", *Organic Electronics* 10, 320, Apr 2009.

2008

16. Chen BJ, **Divayana Y**, Sun XW, and Sarma KR, "Improved performance of organic light-emitting devices with ultra-thin hole-blocking layers", *Journal of the Society for Information Display* 16, 603, May 2008.
17. **Divayana Y** and Sun XW, "Sequentially doped blue electrofluorescent organic light-emitting diodes" *Organic Electronics* 9, 136-142 (2008).

2007

18. **Divayana Y**, Sun XW, Chen BJ, Lo GQ, Jiang CY, Kwong DL and Sarma KR, "Bandgap engineering in Alq_3-and NPB-based organic light-emitting diodes for efficient green, blue and white emission " *Solid-State Electronics* 51, 1618-1623, Nov 2007.
19. **Divayana Y** and Sun XW, "Observation of excitonic quenching by long-range dipole-dipole interaction in sequentially doped organic phosphorescent host-guest system", *Physical Review Letters* 99, 143003, Oct 5 2007. Also selected for the October 15, 2007 issue of *Virtual Journal of Biological Physics Research.*
20. **Divayana Y**, Sun XW, Chen BJ, Lo GQ, Jiang CY, Kwong DL and Sarma KR, "Undoped White Organic Light-Emitting Diodes Utilizing Two Sources of Excitons" *Japanese Journal of Applied Physics* 46 (8A), 5164, Aug 6 2007.
21. **Divayana Y** and Sun XW, "Efficient electrofluorescent organic light-emitting diodes by sequential doping", *Applied Physics Letters* 90 (20), 203509, May 14 (2007).
22. **Divayana Y**, Sun XW, Chen BJ, and Sarma KR, "Improved organic light-emitting device with tris-(8-hydroxyquinoline) aluminium inserted between hole-injection layer and hole-transporting layer", *Journal of Physics D: Applied Physics* 40 (1): 183-186, Jan 7 2007.

2006

23. **Divayana Y**, Sun XW, Chen BJ, Lo GQ, Jiang CY, and Sarma KR, "Efficient blue organic light-emitting device based on N,N '-di(naphth-2-yl)-N,N '-diphenyl-benzidine with an exciton-confining structure" *Applied Physics Letters* 89 (17), 173511, Oct 23 2006.
24. **Divayana Y**, Chen BJ, and Sun XW, "Comment on "Singlet-singlet and singlet-heat annihilations in fluorescence-based organic light-emitting diodes under steady-state high current density" [Applied Physics Letters 86, 213506 (2005)]", *Applied Physics Letters* 88 (9), 096101, Feb 27 2006.
25. **Divayana Y**, Chen BJ, Sun XW, and Sarma KR, "Organic light-emitting devices with a hole-blocking layer inserted between the hole-injection layer and hole-transporting layer" *Applied Physics Letters* 88 (8), 083508, Feb 20 2006.
26. Divayana Y, Chen BJ, Sun XW, Wong TKS, Sarma KR, and Hu X, "Hole injection or blocking? The role of CuPc in Alq(3)-based organic light-emitting devices ", *Journal of Crystal Growth* 288 (1), 105-109, Feb 2 2006.

2005

27. Chen BJ, Sun XW, **Divayana Y**, and Tay BK, "Improving organic light-emitting devices by modifying indium tin oxide anode with an ultrathin tetrahedral amorphous carbon film", *Journal of Applied Physics* 98 (4), 046107, Aug 15 2005.

Book

1. **Divayana Y** and Sun XW, "Electroluminescence in Organic Light-Emitting Diodes: Basics, Processes, and Optimizations" (VDM Verlag Dr. Muller Aktiengesellschaft & Co. KG, Saarbrucken, Germany, October 2, 2009). ISBN: 978-3639177909

Invited Speaker

1. **Divayana Y**, "The Förster-type exciton quenching mechanism and its impact to the quantum efficiency and exciton diffusion in organic semiconductor", *Research Frontiers of Solid State Lighting Workshop*, Photonics Research Center, School of EEE, Nanyang Technological University, Society for Information Display, IEEE Photonics Society, Dec 2009.
2. **Divayana Y**, "Organic Electronics", Seminar Nasional Fisika, Universitas Negeri Jakarta, Jakarta Indonesia, June 2012
3. Workshop Pelatihan Penulisan Jurnal Internasional, Fakultas Teknik Universitas Udayana, September 2017.
4. Narasumber Seminar Nasional Sains dan Teknologi IV , "The Rise of Plastic Electronics," Universitas Udayana, Desember 2017.

International Conference

1. **Divayana Y**, Sun XW, and Chen BJ, "Multilayer Approach for Efficient Multicolor Organic Light-emitting Diodes", in *Proceedings of the 10th Asian Symposium on Information Display*, Singapore, Aug 2007.
2. **Divayana Y** and Sun XW, "Highly efficient electrophosphorescent and electrofluorescent organic light-emitting diodes by sequential doping", in *Proceedings of the International Conference on Materials for Advanced Technologies 2007*, Singapore, Jul 2007.
3. **Divayana Y**, Sun XW, Chen BJ, Lo GQ, Jiang CY, Kwong DL and Sarma KR, "Optimizing the interference effect for high-efficient undoped white organic light-emitting diodes", in *Proceedings of the Asia Display 2007*, Shanghai, China, Mar 2007.
4. **Divayana Y**, Sun XW, Chen BJ, Lo GQ, and Sarma KR, "Improved organic light-emitting devices with tunable IV by inserting a hole-blocking layer between hole-injecting layer and hole-transporting layer", in *Proceedings of the 36th European Sold-State Device Research Conference*, Montreux, Switzerland, Sept 2006.
5. Divayana Y, Chen BJ, Sun XW, Wong TKS, Sarma KR, and Hu X, "The role of CuPc in organic light-emitting diodes", in *Proceedings of the International Conference on Materials for Advanced Technologies 2005*, Singapore, Jul 2005.

STUDENTS

No	Category	Detail
1	Name	KETUT DHARMA YASA
2	Birth place	Denpasar
3	Birth date	04-02-1998
4	Email	dharmayasaketut@yahoo.co.id
5	Address	Desa Depeha Kecamatan Kubutambahan
6	Phone	081999048012
7	Student number	1605541104
8	Department	Electrical Engineering
9	Research interest	Robotic, Electronic, Power system

No	Category	Detail
1	Name	Nola Verli Herlian
2	Birth place	Denpasar
3	Birth date	03-11-1995
4	Email	nola.herlian@yahoo.com
5	Address	Jl. Subur Gg. Mirah Hati II No 9A
6	Phone	081236222204
7	Student number	1404405087
8	Department	Electrical Engineering
9	Research interest	Telecommunication

APPENDIX 6 STATEMENT LETTER

KEMENTERIAN RISET, TEKNOLOGI DAN PENDIDIKAN TINGGI
UNIVERSITAS UDAYANA
LEMBAGA PENELITIAN DAN PENGABDIAN KEPADA MASYARAKAT

Kampus Bukit Jimbaran. Telp. (Fax) (0361) 703367: 704622.
E-Mail: info-lppm@unud.ac.id Http://lppm.unud.ac.id

STATEMENT LETTER

I am who signed this document:

Full Name	: Komang Oka Saputra, ST., MT., PhD
NIP/NIDN	: 198104042008011009/0004048106
Academic rank	: Penata Muda Tk. I/IIIb, Asisten Ahli
Department/Faculty	: Electrical Engineering/Fakulty of Engineering

State that this proposal entitled:
Clock Skew Measurement Method for Low Time Resolutions, which is proposed in the UDAYANA INTERNATIONAL RESEARCH COLLABORATION SCHEME for the funding year of 2018 is created together with the researcher team and it is original and never be funded before.

Later, if there is any mismatch with this statement, I am ready to be judged and processed in accordance with the law, and I am ready to return all grant to BLU.

Jimbaran, 8-2-2018
Principal researcher,

Komang Oka Saputra, ST., MT., PhD
NIP. 19810404 200801 1 009

Approved
Head of Research Institution,

Prof. Dr. Ir. I Gede Rai Maya Temaja, MP.
NIP. 19621009 198803 1 002