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Jengnan Juang
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Chapter 40
A Study of Regular Transmission Delay in Bluetooth Communications

Komang Oka Saputra, Wei-Chung Teng, Pin-Yen Chou, and Tien-Ruey Hsiang

Abstract This chapter 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.

Keywords Transmission delay • Bluetooth • Raining

40.1 Introduction

Transmission delays are essential, or at least useful, information to many applications including time synchronization, network traffic analysis, and device fingerprinting [1], to name but a few. Taking device fingerprinting as an example, it may be implemented by measuring the clock skews of the neighboring sensor motes in wireless sensor networks (WSN) [2], the clients device as a cloud service [3], or the other hosts inside the same wireless local area network (WLAN) [4]. A recent research even implemented clock skew-based Bluetooth device identification in personal area network (PAN) [5].

As Bluetooth is one of the most commonly used wireless communication technologies for many years, the communication performance and theoretical delay are studied [6, 7]. However, most of these researches studied Bluetooth's network behaviors on MAC layer instead of network layer. In the aforementioned

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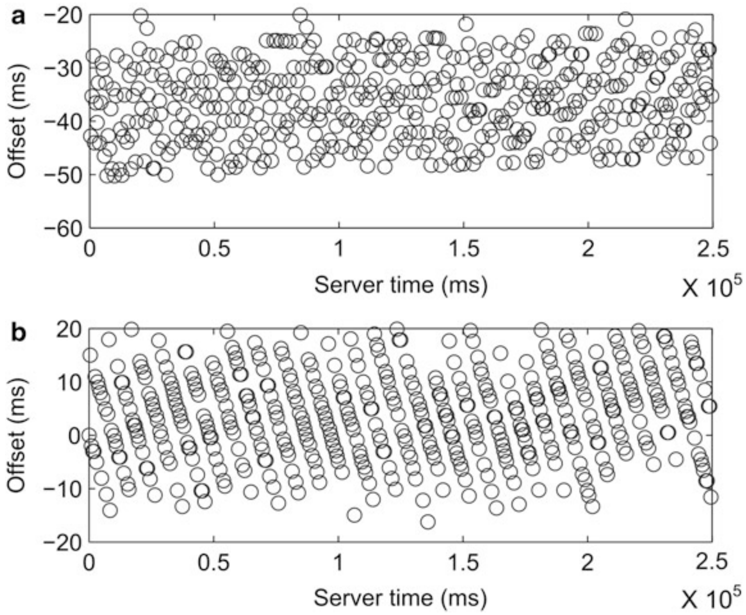

Fig. 40.1 Preliminary results. (**a**) Normal collection. (**b**) Collection with *dotted lines*

research [5], Huang et al. also implemented their BlueID technology based on the temporal feature of Bluetooth frequency hopping. This chapter presents a study of smart devices' time-stamping by transmitting the network layer timestamps to a measurer via Bluetooth communication. Nevertheless, during the experiments, it is found that there exist two types of communication delay patterns. In a normal collection, the offsets (difference between sending time of the smart device and the receiving time of the measurer) distributed randomly over some range, as shown in Fig. 40.1a. Yet in some 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 (Fig. 40.1b). To the best of our knowledge, this *raining* phenomenon is not studied before.

To identify the presence of the dotted lines, a mechanism based on the patterns and the slopes of the dotted lines is developed. Furthermore, experiments covering variables of operating systems, server software languages, Bluetooth chips, and packet sending intervals are conducted to discover which combinations would the dotted lines would occur.

40.2 System Setup and Preliminary Results

The experiment system to perform device time-stamping collection is composed by several components:

Client: currently two mobile phones, HTC OneX and Samsung Galaxy Note3, are measured by their built-in Bluetooth chips.

Server: an ASUS K42JP notebook with 4GB RAM is used as server. The built-in AW-BT270 Bluetooth chip and an external BCM20702 Bluetooth chip are used to communicate with clients in the experiments.

Client application: an Android-based application which is developed to get the timestamps of the client device. The application reads the client's system time, and directly sends it to the server. The sending interval of the timestamps is adjustable from 0.5 s to few seconds.

Server application: an application that records the measurer's timestamp each time a packet contains the client's timestamp is received. For offsets like Fig. 40.1a, it is easy to estimate the clock skew of client device by using linear regression [8] or linear programming algorithm (LPA).

40.3 Dotted-Lines Detection Method

The preliminary experiments showed that the slopes of the dotted lines ranging from −1,850 to −1,350 ppm. Meanwhile, when the dotted line occurs, up to 90% of all offsets belong to the dotted lines. Due to these facts, a detection algorithm is developed as depicted in Fig. 40.2. It details how the detection starts from the first offset, the slope between offsets in the measured target are calculated. When the slope is detected to satisfy the threshold, the measured offset is then counted to be belonging to the dotted line. Otherwise, if the slope is out of range, then the offset is parked in a waiting area for later process. After the whole offsets have been processed, the dotted line is detected to happen if the number of offsets that belong to the dotted line is more that 90 % of all offsets.

40.4 Experiment Results

Four controlled variables are selected to study the behavior of the raining phenomenon. The values of these variables include: two types of server operating system, Ubuntu 14.0 (denoted as L) and Windows 7 Ultimate (W); three types of programming language, JAVA (J), C# (C), and Python (P); two types of Bluetooth chip from the onboard AW-BT270 chip (X) and the USB BCM20702 chip (Y); two devices: an HTC OneX (A) and a Samsung Galaxy Note3 (B); and three different clients sending intervals: 0.5, 1, and 2 s.

Table 40.1 summarizes if the dotted lines happen in the result offsets of all combination. As depicted in Table 40.1, the detection algorithm produced results that the dotted lines happen as long as the OS is Windows operating system. The statistic of the detection method is depicted in Table 40.2, which shows the average points in each dotted line for each combination and sending interval. The results

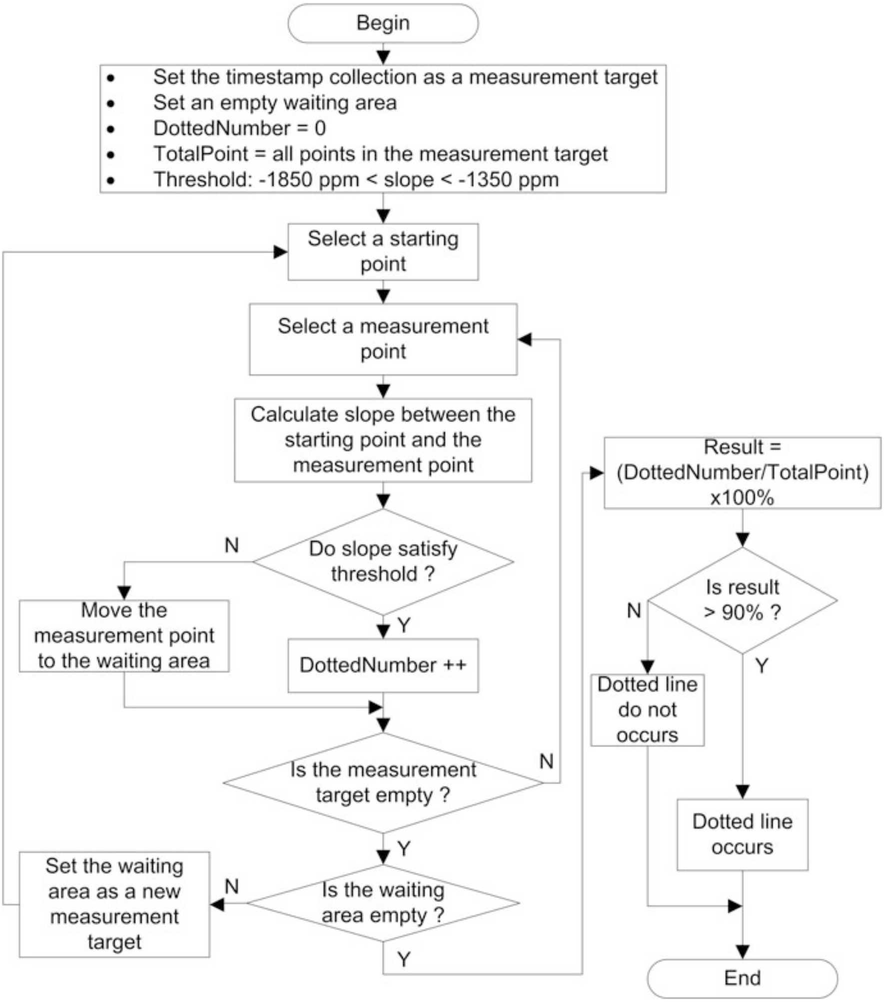

Fig. 40.2 *Dotted line* detection method

Table 40.1 The results if the raining phenomenon happens in various conditions

		W			L	
		C	J	P	J	P
X	A	Yes	No	Yes	No	No
	B	Yes	No	Yes	No	No
Y	A	Yes	No	Yes	No	No
	B	Yes	No	Yes	No	No

show negative correlation between the number of points and the sending interval, i.e., the bigger the interval, the less the number of points in each line.

To quantify the correctness of the detection method, we calculate the clock skew of all the combinations. As we did not know the real clock skews of the two devices,

Table 40.2 Relation between sending interval and the number of points in one dotted line

	AWPY	BWPY	AWPZ	BWPZ	AWCY	BWCY	AWCZ	BWCZ
0.5 s	17.85	18.51	16.56	18.34	18.50	18.50	19.03	18.20
1 s	8.94	9.42	8.82	8.02	9.65	9.48	9.52	9.42
2 s	4.77	4.79	4.69	4.64	4.83	4.75	4.81	4.82

Table 40.3 Clock skew results of all combinations (unit: ppm)

	Minimum	Maximum	Average	$\lvert$Average − reference$\rvert$
AWCY	−11.84	−8.48	−10.43	0.01
AWJY	−34.88	−31.14	−33.01	22.57
AWPY	−10.81	−8.78	−9.95	0.49
ALJY	−12.04	−9.60	−10.62	0.18
ALPY	−12.27	−10.31	−11.22	0.78
AWCZ	28.60	38.23	32.29	42.73
AWJZ	14.77	17.55	15.85	26.29
AWPZ	30.02	37.21	32.87	43.31
ALJZ	−11.96	−9.51	−10.73	0.29
ALPZ	−13.53	−9.54	−11.53	1.09
BWCY	12.01	15.35	13.82	0.46
BWJY	−15.91	−13.03	−14.55	28.83
BWPY	13.03	14.27	13.78	0.50
BLJY	12.02	15.97	14.48	0.20
BLPY	11.24	15.48	13.31	0.97
BWCZ	27.56	36.68	33.28	19.00
BWJZ	16.52	19.02	17.88	3.60
BWPZ	32.34	40.21	37.58	23.30
BLJZ	11.46	15.05	13.17	1.11
BLPZ	11.46	15.10	13.68	0.60

we used our previous research [9] which uses WiFi network to calculate the clock skews between the two devices and the server, and use both results as references for the clock skews in Bluetooth network.

As detailed in Table 40.3, all the experiments when using Linux as the server operating system show a relatively close clock skews when compared with the references. These results confirmed the correctness of the detection method's results in Table 40.1. For the Windows operating system, meanwhile, relatively far results of AWCZ, AWPZ, BWCZ, and BWPZ when compared with the references, confirmed that dotted line occurs in Windows when combined with C# and Python. However, we also discovered results which are inconsistent with the results in Table 40.1. AWJY, AWJZ, and BWJY, are three combinations that should produce a relatively close result to the reference, and BWPY which should produce a relatively far result. Since we use LPA as the estimator, LPA is known to find a slope of all observed data by creating a line that lies below all data (lower bound), there might be other factors that affect the lower bound of the observed device. For instance, even though AWJY is uncontaminated by the dotted line, the lower bound of AWJY's data could be not in a stable condition which caused the skew highly fluctuated.

40.5 Conclusions

This chapter verified the device time-stamping through Bluetooth network. A normal timestamp collection was obtained when using Linux as the server operating system combined with Java and Python, and when Windows combined with Java. The normal collection can be directly used to fabricate the clock skew, and the results were confirmed to be acceptable as they are close to clock skew references. For the dotted line, we detected its existence in Windows when combined with C# and Python. The clock skew results are relatively far when compared with the references, which shows the dotted line interferes with the clock skew measurement. We also observed that several clock skews are inconsistent with the results of the detection method, which might be caused by other factors that influence the lower bound of the collected data. As this work is a part of an ongoing research, our further work would include improving the precision of the Bluetooth device time-stamping and also to handle the problem of the lower bound instability.

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