

Estimation of Network Type Based on The Response Delay Property

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Abstract—The large number of Internet of things (IoT) terminals increases the cost and difficulty of IoT network management such as network scan. Some wireless IoT networks that have low transmission data rate especially require low overhead for network management to avoid interruption. Hence, it is important to make automatic identification of network type for effective network management. In this study, we at first carry out laboratory experiments of network scan to wireless terminals in wireless LAN (WLAN), Long Term Evolution (LTE) and Low Power, Wide Area (LPWA) networks that include Wi-SUN and LoRa network. From the result of response delay obtained from each network in the experiments, we then examine the basic property of the response delay, especially about the minimum response delay. Finally, we propose a scheme of network-type estimation based on the property of the minimum delay in different networks. The performance of the proposed scheme of network-type estimation is evaluated regarding the network objects of WLAN, LTE and LPWA networks. The evaluation results show that the scan response delay is a useful factor for successfully identifying different types of IoT networks.

Keyword—Internet of things, response delay, network estimation

I. INTRODUCTION

With the advances in Internet of things (IoT) technologies, the number of IoT terminals is rapidly increasing. In addition to conventional communication networks, a number of IoT networks emerge in recent years to meet requirements of IoT use on energy efficiency, long-time operation, and large coverage. For instance, Low Power, Wide Area networks (LPWANs) provide wireless

communication with large coverage with low power consumption. In LPWANs, there are diverse network types, includes Wi-SUN and LoRa, each of which has its specification in communication [1], [2]. In this paper, the term of IoT networks refers to the broad scope networks that involve conventional networks and LPWANs because both networks are employed for operating IoT applications.

For the large number of networked IoT terminals, efficient network management is important for reliable and safe communication. Network scan, including TCP port scan and ping-based scan using Internet Control Message Protocol (ICMP), is an important way to detect the network connection status and vulnerable terminals [3–6]. In a scan event, a scanner probes the target network terminals to acquire information such as the port usage state as well as the response delay. Those kinds of information is helpful for network administrator to monitor network congestion status and to detect the vulnerable IoT terminals.

Due to the large population of IoT terminals, the network management employing network scan may incur large traffic overhead that causes the interruption on IoT networks and operation of IoT terminals. The impact of network scan traffic on IoT networks differs according to the types of IoT networks that have different amounts of available communication resources, transmission data rates, and allowable energy consumption.

Hence, automatic identification of IoT network type is a key technology to realize the successful network scan. Identification of the network type assists the scheduling of scan and to alleviate interruption to the IoT networks. It also helps the estimation of the underlying causes of network malfunctions and failure of scan events [7].

The studies of identification of IoT devices have been introduced in reference in [8–9]. The methods include classifying the IoT devices based on TCP port status or network traffic from the devices. On the other hand, these studies have not addressed how to identify the network type of IoT devices. In reference [5], we introduced a preliminary study about the estimation of network types. However, the paper focuses on examining only the object networks of LPWAN and wired LAN. Moreover, the network estimation method is limited to use the information of the average response delay of the known IoT networks.

This paper is an extended version of the reference [6]. From the reference [6], we extend the network objects for examination by including Long Term Evolution (LTE) network in addition to WLAN and LPWA networks. First,

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the properties of the network LTE network are measured and added to the set of delay properties regarding minimum delay of each network type. Furthermore, due to the increase of the number of objects to estimate, the evaluation of network estimation is re-conducted according to the new configuration of the set of minimum delay at object networks. Consequently, in the evaluation results, we show the performance of network-type estimation from the response-delay sample for WLAN, LTE, Wi-SUN and LoRa network.

In this paper, to enable network type estimation, we at first examine the response delay property of IoT networks that include wireless LAN (WLAN), LTE, and LPWAN with laboratory experiment. We propose a network estimation method utilizing the minimum response delay of each IoT network. We also carry out the comparison with the average delay based method [5] regarding the correctness of network type judgement. The evaluation results show that the proposed method is able to successfully identify the network type from the response delay of scan events.

The rest of this paper is organized as follows. Section II introduces the system model. Section III describes the property of response delay in IoT networks. Section IV describes the proposed method of network-type estimation and evaluation results. Section V concludes this article.

II. SYSTEM OVERVIEW

The network scan system utilizes a network scanner to measure the status of various IoT terminals. An example of the scan system is illustrated in Fig. 1. We consider several target wireless networks such as WLAN, LTE and LPWANs including Wi-SUN and LoRa network. To assess the status of IoT terminals, the scanner probes the IoT network by issuing a series of scan events to the IoT terminals. (In this paper, the terms of device and terminal have the same meaning.) A scan event in this paper refers to an ICMP ping operation. That is, in a scan event, the scanner issues a ping packet that traverses between the scanner and a target IoT terminal.

The network scan system measures the round trip time (RTT) spent in the target access network (ARTT) [5]. ARTT may have different properties according to the network type. Hence, the ARTT information will be used for network type estimation. In the following parts of this paper, the term of response delay refers to the ARTT in a scan event. The network estimation can be expressed as follows. Suppose that there are K network types to which the scanner monitors and performs network scan. The scan system tries to estimate the network type from the response delay data in terms of the ARTT.

The study of network type estimation introduced in this paper consists of two parts. (1) Preliminary investigation of the ARTT property with experimental measurement, especially with a focus on the minimum response delay of each network type. Measurement of the response delay in scan events is carried out by experiment on WLAN, LTE, and LPWA networks including Wi-SUN and LoRa network; we then investigate the characteristics of the response delay, especially the minimum response delay, from the results obtained through the experiments. (2) Estimation of the network type according to the response delay property of the minimum response delay in each network.

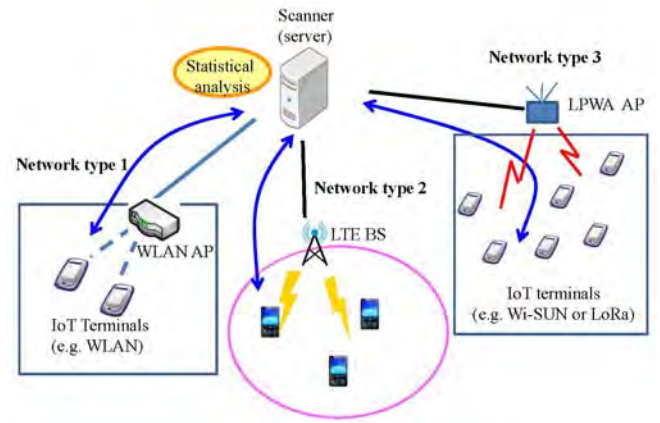


Fig. 1. An example of network scan system.

III. THE MEASUREMENT OF RESPONSE DELAY IN IOT NETWORKS

A. Measurement of Response Delay Property

We examine the properties of response delay of network scan in WLAN, LTE, Wi-SUN and LoRa network. These properties include the minimum, average and maximum of ARTTs, as well as the empirical probability distribution function (PDF) of ARTT result in each network type. Although the laboratory experiments on measurement of ARTT in different networks have constraints regarding to the scale of networks and diversity of environment, such basic experiments provide the basic properties of ARTT in each object networks.

The scenario of WLAN experiment setup is shown in Fig. 2. The network consists of a scanner, a WLAN access point (AP) and the terminal. The connection between the AP and the terminal is IEEE 802.11b/g/n WLAN in 2.4 GHz band. The connection between the scanner and the AP is by Ethernet.

The scenario of measurement in LTE simulator testbed is shown by Fig. 3. The experiment involves a scanner, an LTE BS simulator MD8475B and a LTE-handset terminal. The link between the scanner and the BS simulator is Ethernet. The link between the BS simulator and the terminal is LTE based wireless connection using Band 21 (1.5 GHz).

The scenario of experiments in Wi-SUN or LoRa network is shown by Fig. 4. The experiment involves a scanner, an LPWA access point (AP) and terminals of Wi-SUN and LoRa. The link between the scanner and the AP is Ethernet. The link between the AP and the terminal is wireless connection of Wi-SUN and LoRa network in a channel of 920 MHz band.

In the experiment, a series of scan events is issued to each network to measure the response delay. The interval between scan events in WLAN, LTE, and Wi-SUN is set to one second. While the interval between scan event in LoRa is set to 5 seconds due to the low data rate of LoRa. We measure response delay RTT, which is used as ARTT because the transmission delay in the wired network is much smaller than that in the wireless networks. Then, we construct the property database of each network type from the collected information of 500 samples of response delay in each network.

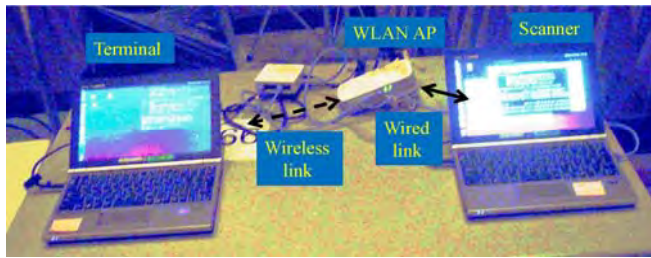


Fig. 2. Experimental scenario of WLAN.

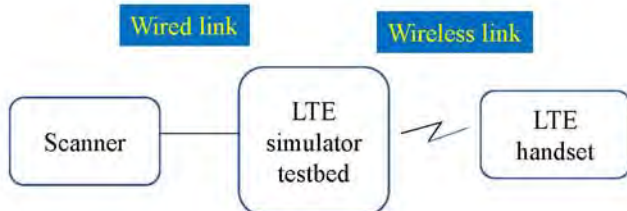


Fig. 3. Experimental scenario of LTE.

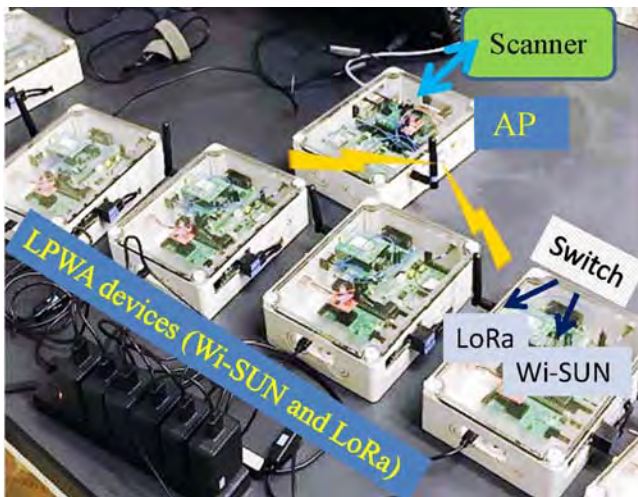


Fig. 4. Experimental scenario of LPWA network: Wi-SUN and LoRa network.

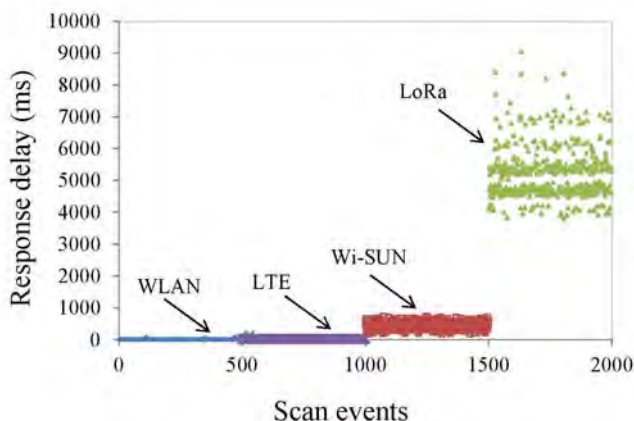


Fig. 5. Response delay in WLAN, LTE, Wi-SUN, and LoRa network.

B. Property of the Response Delay in Different Networks

Fig. 5 illustrates measured samples of response delay in the experiment of WLAN, LTE, Wi-SUN and LoRa network. The response delay in WLAN is distributed between 0 and 84 ms. The average delay of scan events in WLAN is 2.16 ms.

The response delay in LTE is distributed between 19.28 ms and 137.95 ms. The average delay of scan events in LTE is 24.48 ms. The response delay in Wi-SUN is distributed between 180 and 738 ms. The average delay in Wi-SUN is 460.4 ms, which is much larger than those in other networks. The response delay in the LoRa network is distributed between 3808 and 9047 ms. The average delay in the LoRa network is 5250 ms, which is much larger than those in WLAN, LTE and Wi-SUN.

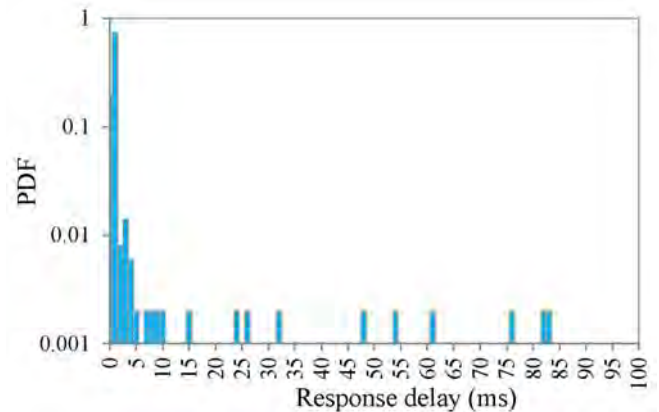


Fig. 6. The empirical PDF of response delay in WLAN.

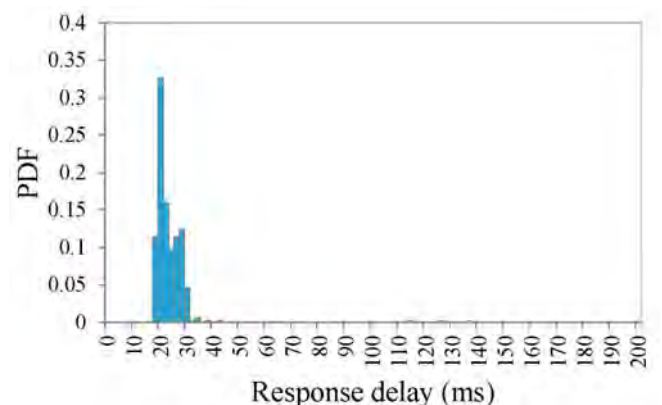


Fig. 7. The empirical PDF of response delay in LTE.

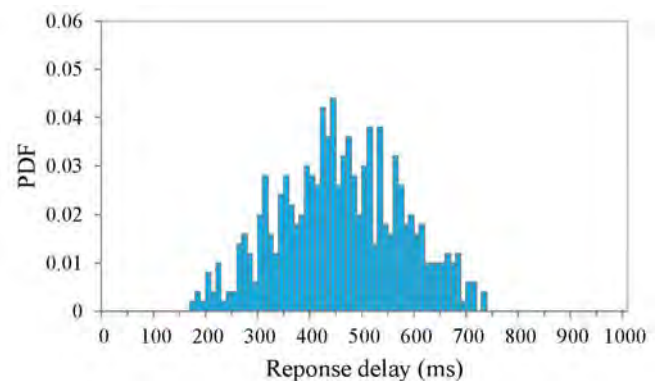


Fig. 8. The empirical PDF of response delay in Wi-SUN.

TABLE I
ESTIMATION RESULT FROM THE RESPONSE DELAY DATA OF WLAN, LTE, WI-SUN AND LORA ACCORDING TO THE MINIMUM DELAY PROPERTY OF EACH ETWORK TYPE. (FROM 200 OBSERVED SAMPLES FROM EACH NETWORK TYPES.)

Scan object network	The number of WLAN judgements	The number of LTE judgements	The number of Wi-SUN judgements	The number of LoRa judgements
WLAN	199	1	0	0
LTE	0	197	3	0
Wi-SUN	0	0	200	0
LoRa	0	0	0	200

TABLE II
ESTIMATION RESULT FROM THE RESPONSE DELAY DATA OF WLAN, LTE, WI-SUN AND LORA ACCORDING TO THE AVERAGE DELAY PROPERTY OF EACH ETWORK TYPE. (FROM 200 OBSERVED SAMPLES FROM EACH NETWORK TYPES.)

Scan object network	The number of WLAN judgements	The number of LTE judgements	The number of Wi-SUN judgements	The number of LoRa judgements
WLAN	199	1	0	0
LTE	0	200	0	0
Wi-SUN	0	7	193	0
LoRa	0	0	0	200

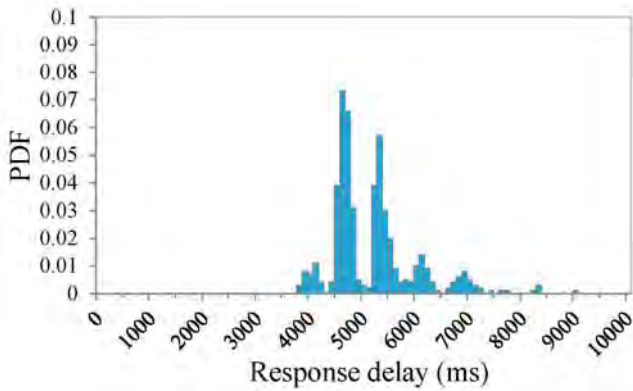


Fig. 9. The empirical PDF of response delay in LoRa network.

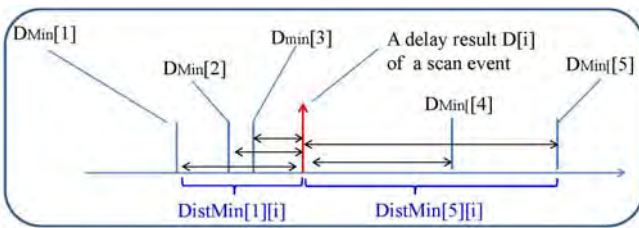


Fig. 10. Distance to the minimum response delay ($K = 5$).

IV. METHOD OF NETWORK-TYPE ESTIMATION BASED ON THE PROPERTY OF THE MINIMUM RESPONSE DELAY

A. Network Type Estimation Scheme

Suppose that there are K types of the object networks, to which the scan events are issued. We denote the set of object networks to be examined by $NA = \{N_1, N_2, \dots, N_K\}$. For an object network x in NA , the minimum response delay is denoted by $D_{Min}[x]$, where x is a member in NA . A set of minimum delays corresponding to all network types is denoted by $\{D_{Min}[N_1], \dots, D_{Min}[N_K]\}$. This minimum delay

information is obtained by the preliminary experimental measurement in each object IoT network. Let $DistMin[x][i]$ stand for the distance between a result of response delay $D[i]$ to $D_{Min}[x]$, as illustrated in Fig. 10 that assumes K is 5.

As shown in Algorithm 1, the proposed method estimates network type according to $DistMin[x][i]$. For each result of response delay regarding the i -th scan event, the scan system computes the $DistMin[x][i]$ corresponding to all network types in NA by $DistMin[x][i] = |D[i] - D_{Min}[x]|$, as shown in Fig. 10.

As a consequence, the scan system collects a set of $DistMin[x][i]$, x is a member in NA . Let Z be the network type that gives the least $DistMin[x][i]$; x is a member in NA . Then, Z is the result of network estimation. (For multiple networks that has the same least $DistMin[x][i]$, the estimation result can be set to unknown or either of the network types that gives the least $DistMin[X][i]$ for X in NA).

B. Evaluation of network estimation

We examine the effectiveness of the proposed method by utilizing the measurement results obtained from the experiment scenarios introduced in Section III. The minimum response delay of each object network is obtained

Algorithm 1: The proposed algorithm of network type estimation

Input: $D[i]$: the response delay of the i th scan event;
 $D_{Min}[x], x \in NA$: the minimum delay of each network type x .

Output: The result of estimated network type

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1 for  $x \leftarrow 1$  to  $x = k$  do
2    $DistAve[x][i] \leftarrow |D[i] - D_{Min}[x]|$ ;
3   if  $x = 1$  then
4      $DistLeast \leftarrow DistMin[x][i]$ ;
5      $Z \leftarrow x$ ;
6   if  $x > 1$  then
7     if  $DistLeast > DistMin[x][i]$  then
8        $DistLeast \leftarrow DistMin[x][i]$ ;
9        $Z \leftarrow x$ ;
10  $EstimatedNetwork \leftarrow Z$ ; return The estimated network type  $EstimatedNetwork$ 
    
```

from 500-sample data of scan events. Network type estimation is carried out from response delay results in 200 scan events in each object networks. These result data belong to the 500-sample data of scan events from which the minimum response delay is derived, while each of which are independent to each other. The results of network type estimation from the response delay information in WLAN, LTE, Wi-SUN and LoRa network are shown in Table I. The proposed method is able to successfully identify WLAN, LTE, Wi-SUN and LoRa in all judgements. We also carry out the network estimation based on the property of average response delay to make a comparison with the proposed method [5]. The result of network type estimation based on average delay property is shown in Table II.

We can find the proposed method have a higher success rate than that the method based on average delay property. The largest number of failed judgements in the proposed method is 3 in 200 judgements for LTE. While the method utilizing the average delay property fails 7 times in 200 estimation tests for Wi-SUN. We consider the reason why the proposed method shows better performance is the minimum response delay reflects the distinct network property much more than that of average response delay with respect to the distribution of response delay.

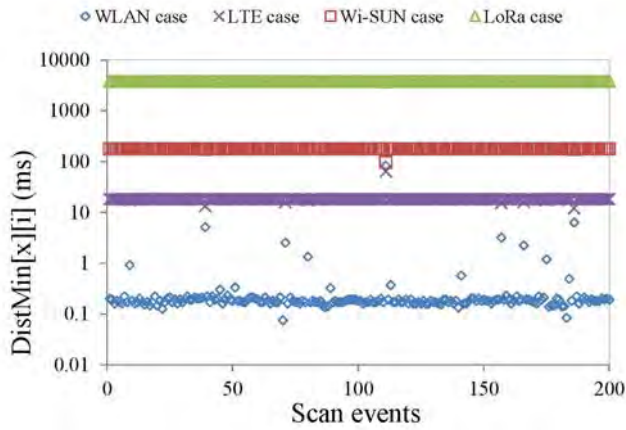


Fig. 11. WLAN case: distances between the response delay ($D[i]$) of each scan event in WLAN and the minimum response delay of each network type ($DMin[x]$).

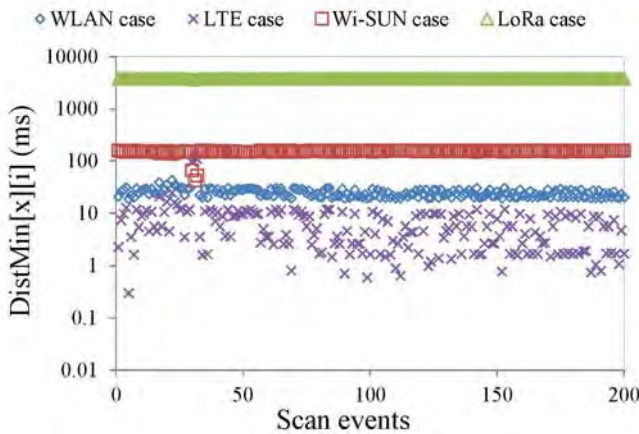


Fig. 12. LTE case: distances between the response delay ($D[i]$) of each scan event in LTE and the minimum response delay of each network type ($DMin[x]$).

Fig. 11, Fig. 12, Fig. 13, and Fig. 14 show the distances between the response delay ($D[i]$) of each scan event and the minimum response delay of each network type obtained in the learning ($DMin[x]$). Fig. 11 illustrates that the response delay in WLAN is closest to the minimum response delay of WLAN, with the distance ranging from 0.075 ms to 82.66 ms. Fig. 12 illustrates that the response delay in LTE is closest to the minimum response delay of LTE, with the distance ranging from 0.3 ms to 118.67 ms. Fig. 13 illustrates that the response delay in Wi-SUN is closest to the minimum response delay of Wi-SUN, with the distance ranging from 10 ms to 554 ms. Fig. 14 illustrates that the response delay in LoRa network is closest to the minimum response delay of LoRa network, with the distance ranging from 34 ms to 5239 ms.

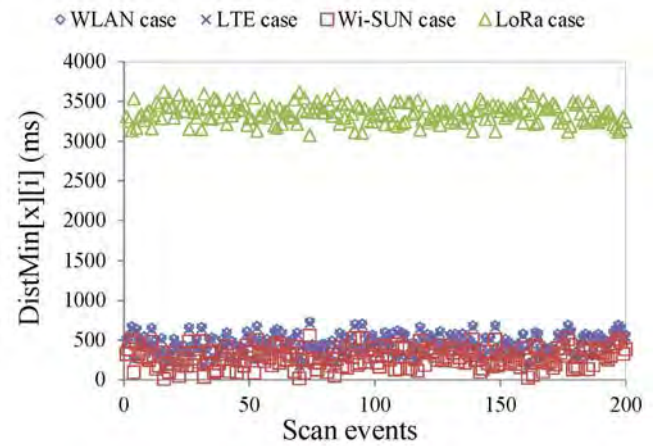


Fig. 13. Wi-SUN case: distances between the response delay ($D[i]$) of each scan event in Wi-SUN and the minimum response delay of each network type ($DMin[x]$).

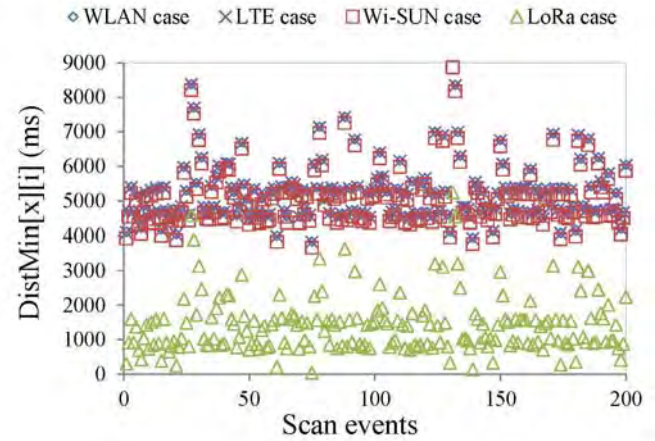


Fig. 14. LoRa network case: distances between the response delay ($D[i]$) of each scan event in LoRa network and the minimum response delay of each network type ($DMin[x]$).

V. CONCLUSION

In this paper, we investigated the basic properties of the minimum response delay in the network scan in WLAN, LTE, Wi-SUN and LoRa network. By laboratory experiments, we found that each network has quite different distribution of response delay. We then proposed a method to estimate network type from response delay. The proposed method determines the network type whose minimum response delay

is nearest to the instantaneous one of the target scan events. The effectiveness of proposed method was verified by using experimental results of response delay and the network property of the minimum response delay. The evaluation results of network estimation showed that the proposed method successfully identifies the three object networks of WLAN, LTE, Wi-SUN and LoRa network in scan events.

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