

Identification of IoT 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. Wireless IoT networks that have low data rate especially require low overhead for network management to avoid interruption. Hence, it is important to make an automatic identification of network type for effective network management. To successfully estimate the type of a network, in which IoT terminals are involved, this study examines the fundamental properties of the response delay of IoT terminals in scan events. We carry out indoor experiments of network scan to wireless terminals in wireless LAN (WLAN) and Low Power, Wide Area (LPWA) networks, including Wi-SUN and LoRa network. From the result of response delay obtained from 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 evaluation results show that the scan response delay is a useful factor for successfully identifying different types of IoT networks.

Index Terms—Internet of things, response delay, network estimation

I. INTRODUCTION

With the advances in IoT technologies, the number of IoT terminals is rapidly increasing. A number of IoT networks emerge in recent years to meet requirements of IoT use on energy efficiency, long-time operation, and large coverage. Low Power, Wide Area networks (LPWANs) provide wireless communication with large coverage with low power consumption. In LPWAN, there are diverse network types, includes WiSUN and LoRa, each of which has its specification in communication [1], [2].

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 [3–5]. 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 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, 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.

The studies of identification of IoT devices have been introduced in reference in [6–7]. 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. Reference [5] introduced a basic study of the property of response delay in IoT networks in LPWAN and LAN. A network estimation method is proposed by utilizing the property of the average response delay of the known IoT network type.

In this paper, we examine the response delay property of IoT networks that include wireless LAN (WLAN) and LPWAN with experimental measurement. 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.

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 and LPWANs including WiSUN and a 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

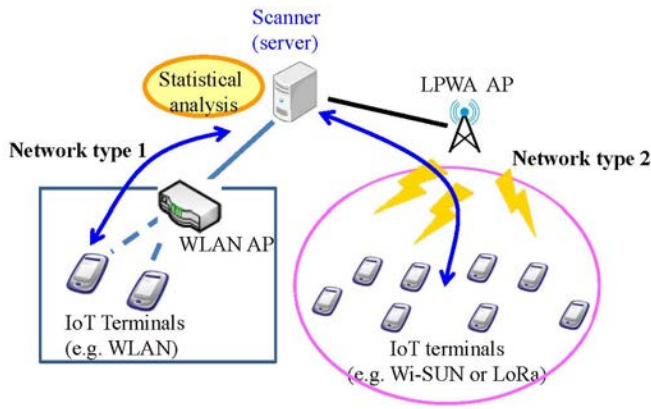


Fig. 1: An example of network scan system.

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 (A-RTT) [5]. A-RTT may have different properties according to the network type. Hence, the A-RTT information will be used for network type estimation. In the following parts of this paper, the term of response delay refers to the A-RTT in a scan event. The network estimation in a mathematical form is 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 A-RTT.

The study of network type estimation introduced in this paper consists of two parts. (1) Preliminary investigation of the A-RTT 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 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.

III. THE PROPERTY OF RESPONSE DELAY IN IoT NETWORKS

A. Measurement of Response Delay Property

We examine the properties of response delay of network scan in WLAN, Wi-SUN and LoRa network. The basic scenario of WLAN experiment setup is shown in Fig. 2. The network consists of a scanner, an WLAN access point (AP) and the terminal. The connection between the AP and the terminal is IEEE 802.11 WLAN in 2.4 GHz band. The connection between the scanner and the AP is by Ethernet.

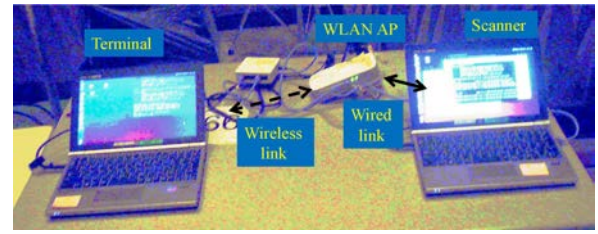


Fig. 2: Experimental scenario of WLAN.

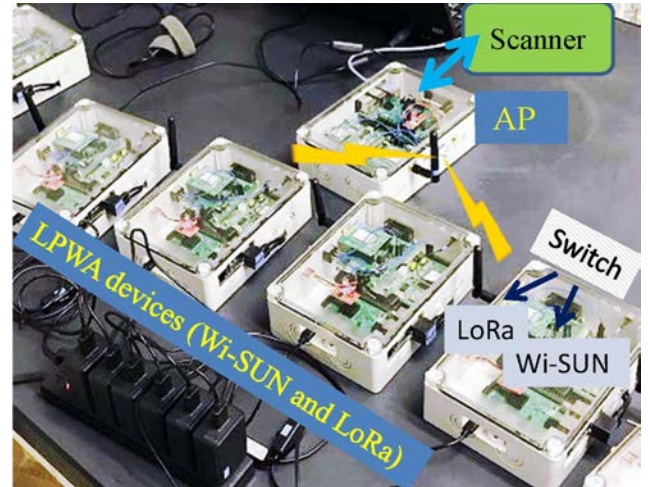


Fig. 3: Experimental scenario of LPWA network: Wi-SUN and LoRa network.

The basic scenario of experiments in Wi-SUN and LoRa network is shown by Fig. 3. 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 wired line. The link between the AP and the terminal is wireless connection of Wi-SUN and LoRa network in the 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 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 A-RTT because the transmission delay in the wired network is much smaller than that in the wireless network of LPWAN. Then, we construct the property database of each network type from the collected information of 500 samples of response delay in each network.

B. Property of the Response Delay in Different Networks

Figure 4 illustrates measured samples of response delay in the experimental scenarios of WLAN, 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 Wi-SUN is distributed between 180 and 738 ms. The average delay in Wi-SUN is 460.4 ms, which is much larger than that in WLAN. The response delay in the LoRa network is distributed between 3808 and 9047 ms.

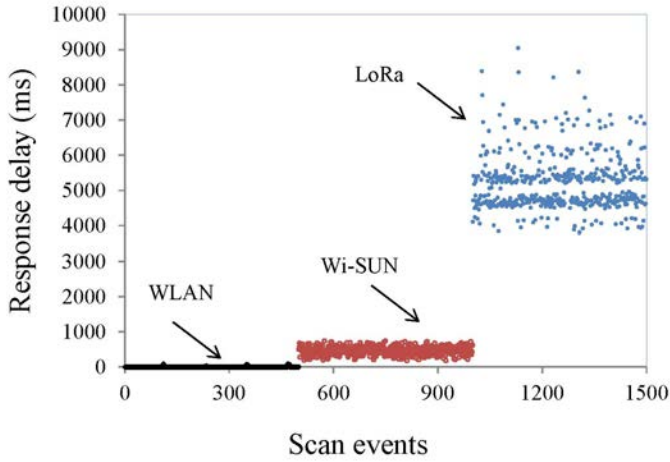


Fig. 4: Response delays in WLAN, Wi-SUN, and LoRa network (response delay here refers to the A-RTT in a scan event).

The average delay in the LoRa network is 5250 ms, which is much larger than those in WLAN and Wi-SUN.

Table I illustrates the minimum response delay from the 500 samples of response delay in each network. The minimum response delays of WLAN and Wi-SUN are 0.84 ms and 180 ms, respectively. The minimum delay in LoRa network is 3808 ms, which is much larger than those in WLAN and Wi-SUN.

TABLE I: Experimental data of the minimum response delays of different IoT networks.

Network types	Minimum response delay (ms)
WLAN	0.839
Wi-SUN	180
LoRa	3808

From the probability distribution function (PDF) of the response delay shown in Fig. 5, we find that the distribution probability in WLAN becomes the highest in the interval of 1 ms ~ 1.5 ms. From PDF of the response delay shown in Fig. 6, we find that the the distribution probability in Wi-SUN is the highest in the interval of 440 ms ~ 450 ms. From PDF of the response delay shown in Fig. 7, we find that the probability distribution in LoRa network is the highest in the interval of 4600 ms ~ 4800 ms.

IV. METHOD OF NETWORK-TYPE ESTIMATION

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 $N_A = N_1, N_2, \dots, N_K$. For an object network x in N_A , the minimum response delay is denoted by $D_{Min}[x], x \in N_A$. A set of minimum delays corresponding to all network types is denoted by $D_{Min}[N_1], \dots, D_{Min}[N_K]$. These minimum delay information is obtained by the preliminary experimental measurement in

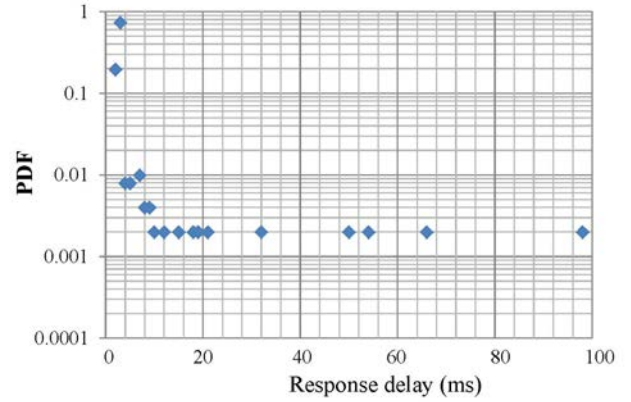


Fig. 5: PDF of response delays in WLAN.

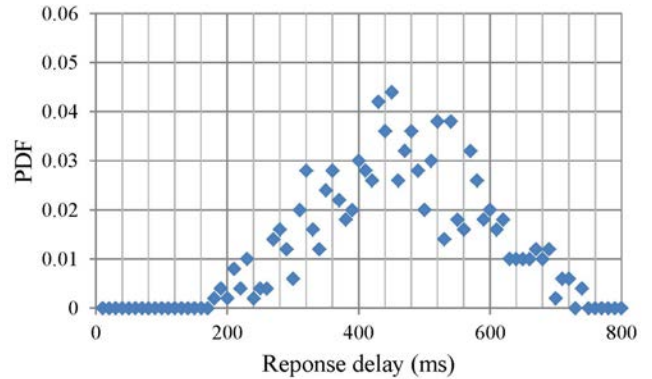


Fig. 6: PDF of response delays in Wi-SUN.

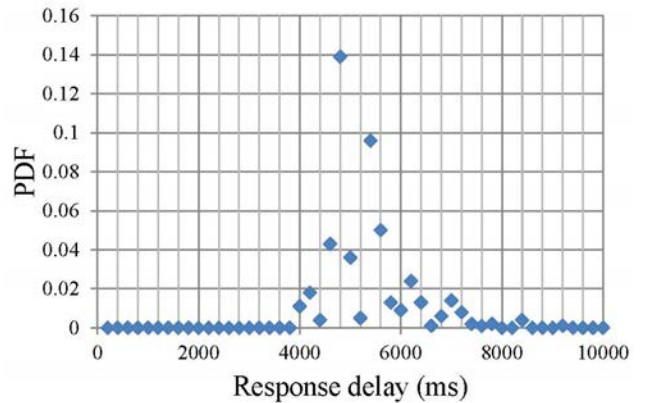
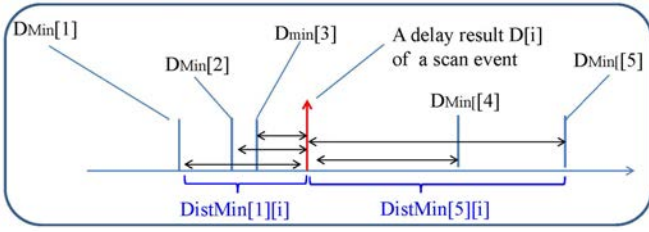


Fig. 7: PDF of response delays in LoRa network.

Fig. 8: Distance to the minimum response delay ($K = 5$).

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. 8 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 N_A by $DistMin[x][i] = |D[i] - D_{Min}[x]|$, as shown in Fig. 8.

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

Algorithm 1: The proposed algorithm of IoT network estimation

Input: $D[i]$: the response delay of the i th scan event;
 $D_{Min}[x]$, $x \in N_A$: 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  $EstimatedNetwork$ 

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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. Network type estimation is carried out from response delay results in 200 scan events in each object networks. The minimum response delay of each object network is obtained from 500-sample data of scan events.

The results of network type estimation from the response delay information in WLAN, Wi-SUN and LoRa network are

TABLE II: Estimation result from the response delay data of WLAN, Wi-SUN and LoRa according to the minimum delay property of each network type.

Object networks	Number of WLAN judgements	Number of Wi-SUN judgements	Number of LoRa judgements
Number of data for estimation: 200			
WLAN	200	0	0
LPWA (Wi-SUN)	0	200	0
LPWA (LoRa)	0	0	200

TABLE III: Estimation result from the response delay data of WLAN, Wi-SUN and LoRa according to the average delay property of each network type.

Object networks	Number of WLAN judgements	Number of Wi-SUN judgements	Number of LoRa judgements
Number of data for estimation: 200			
WLAN	200	0	0
LPWA (Wi-SUN)	6	194	0
LPWA (LoRa)	0	0	200

shown in Table II. The proposed method is able to successfully identify WLAN, 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 III.

We can find the proposed approach have a higher success rate than that the method based average delay property, which fails 6 times in 200 estimation tests in the evaluation. 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.

Figures 9, 10, and 11 further 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 ($D_{Min}[x]$). Figure 9 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. Figure 10 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. Figure 11 illustrates that the response delay in LoRa network is closest to the minimum response delay of LoRa network, with the distance

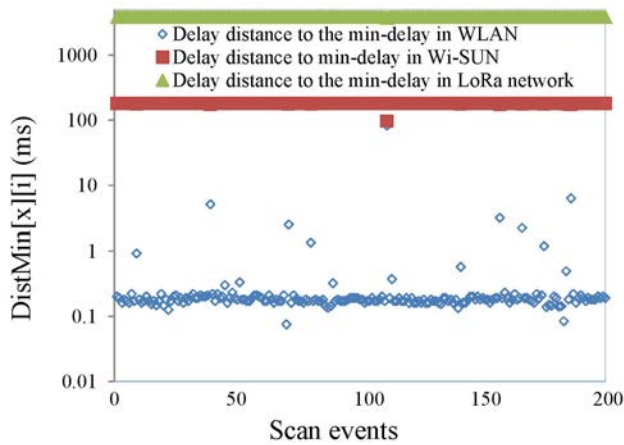


Fig. 9: WLAN case: distances between the response delay ($D[i]$) of each scan event and the minimum response delay of each network type ($D_{Min}[x]$).

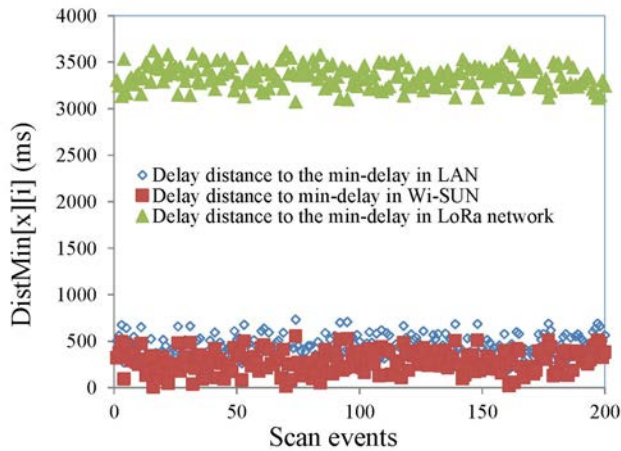


Fig. 10: Wi-SUN case: distances between the response delay ($D[i]$) of each scan event and the minimum response delay of each network type ($D_{Min}[x]$).

ranging from 34 ms to 5239 ms.

V. CONCLUSION

In this paper, we investigated the basic properties of the minimum response delay in the network scan in WLAN, Wi-SUN and LoRa network. By indoor 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 event. 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 network of WLAN, Wi-SUN and LoRa network in scan events.

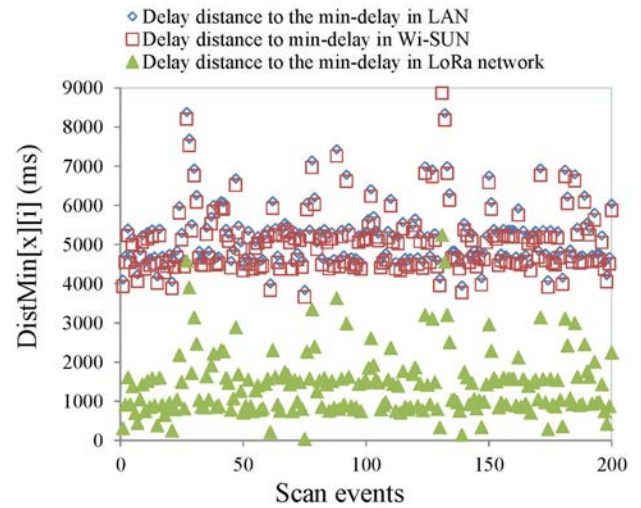


Fig. 11: LoRa network case: distances between the response delay ($D[i]$) of each scan event and the minimum response delay of each network type ($D_{Min}[x]$).

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