

A Study on Estimation of Retransmission Rate of Background Traffic for Various Scan Rates with Scan Response Delay

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Abstract—For efficient network scan to narrow-band wireless networks, this paper proposes a method to estimate the retransmission rate of the background traffic at the target scan rate from a scan response delay obtained at a different scan rate. First, through computer simulations considering a Wi-SUN sensor network with two different network situations and multiple scan rates, we derive a regression function using the least-squares method for the mean of the scan response delay and the COR of the background traffic, and the COR of background traffic and the retransmission rate of background traffic. Then, we propose the new estimation scheme of the retransmission rate of the background traffic. First, Network situation estimator estimates the situation of the target network from observed value and estimated value regarding the variance of scan response delay. Second, COR estimator estimates the COR of the background traffic from the mean of scan response delay, the estimated situation of target network, and the scan rate which is used for observing the scan response delay. Third, Retransmission rate estimator estimates the retransmission rate of the background traffic from the COR of the background traffic the estimated situation of the target network, and a scan rate of estimation target. Through computer simulations, it is confirmed that the proposed method can estimate the retransmission rate of the target network with the average error lower than 5.8% regardless of the situation of the target network and the scan rate.

Index Terms—Network scan, Wi-SUN, QoS estimation, Network simulation

I. INTRODUCTION

Recently, the number of IoT (Internet of Things) wireless devices has been increasing dramatically, and vulnerable IoT devices for cyber-attacks are also increasing rapidly. Attacked IoT devices can be used as a stepping stone by attackers and are used as perpetrators of DDoS attacks. Such devices transmit a large number of packets of unauthorized traffic to disturb traffic which is originally transmitted in their network; hereafter, we call this original traffic as background traffic. In order to find such vulnerable IoT devices, network scan toward a wide area of the Internet is useful.

In existing applications of network scan for the wide area of the Internet [1], a scanner performs the network scan at a high rate to finish the scan quickly. However, when this scanner performs the network scan toward wireless networks with a small network capacity like LPWA (Low Power, Wide Area) networks such as Wi-SUN [2] and LoRa [3], these networks are easily congested. Consequently, QoS (Quality-of-Service)

such as transmission delay will be degraded due to collide and retransmit packets [4].

In order to keep the retransmission rate of the background traffic at an allowable level, it is necessary to control the scan rate as higher as possible with keeping a balance between the processing time of the network scan and the retransmission rate of the background traffic. In order to realize this control, the scanner needs to know the retransmission rate in the target network.

However, the scanner cannot directly know the QoS in the target network if it scans from the outside of the target network. The retransmission rate of the background traffic depends on the situation of the target network. For example, the retransmission rate of the background traffic increases as the mean of the scan response delay or scan rate increases [5].

As related works for estimating the situation of network, a method for estimating the number of users in IEEE 802.11 network based on collision probability obtained through an analysis of state transition of CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) is proposed by [6]. Moreover, a method for estimating the number of users using a PDF (Probability Density Function) of transmission deferring time in the backoff algorithm of IEEE 802.11 and collision probability obtained through simulations is proposed by [7]. Although these methods aim to grasp the network situation, the retransmission rate of background traffic cannot be estimated. Estimating the available bandwidth in IEEE 802.11-based multihop wireless networks using the number of retransmission is proposed by [8]. According to this method, the number of retransmission is directly collected from the target networks. Therefore, a method to estimate the retransmission rate of background traffic is required.

For the control of the scan rate considering both the processing time of the network scan and the retransmission rate of the background traffic, We have proposed a method to estimate the retransmission rate of the background traffic from the scan response delay [9]. The proposed method consists of two kinds of estimators. The first estimates the situation of the target network from the distribution of the scan response delay. The second estimates the retransmission rate of the background traffic in the target network from the mean of scan response delay and the regression function between the mean of scan response delay and the retransmission rate of the background

traffic corresponding to the estimated network situation. The regression function is empirically obtained for several network situations through simulations assuming a Wi-SUN PAN.

However, we need to determine the proper scan rate from the current scan rate and obtained scan response delay. In order to realize this, we need to estimate the retransmission rate of the background traffic at a different scan rate. Therefore, we consider estimating the retransmission rate of the background traffic for various scan rates. We have shown that the retransmission rate of the background traffic is proportional to the transmission interval of the background traffic and the scan rate [5]. If the scanner can know the transmission interval of the background traffic, the retransmission rate of the background traffic for various scan rates can be estimated based on the relationship between the transmission interval of background traffic and the retransmission rate of the background traffic for each scan rate.

This paper first shows the following through an empirical analysis using network simulation assuming various situations with different number of terminals or the transmission interval of the background traffic.

- 1) The relationship between the scan response delay and the transmission interval of the background traffic can be expressed by a regression function using the least-squares method.
- 2) The relationship between the transmission interval of the background traffic and the retransmission rate of the background traffic can be expressed by a regression function using the least-squares method.
- 3) The coefficients of the regression function are different depending on the situation of the target network and the scan rate.

Next, based on the above empirical analysis, we propose a method to estimate the retransmission rate of the background traffic for various scan rates different from the current scan rate and the scan response delay. The proposed method consists of three kinds of estimators. The first estimates the situation of the target network from the distribution of the scan response delay. The second estimates the COR (Channel Occupation Rate) of the background traffic, that is used instead of the transmission interval of the background traffic, from the mean of the scan response delay, the scan rate at which the scan response delay is obtained, and the estimated situation of the target network. The third estimates the retransmission rate of the background traffic at the target scan rate from the estimated COR of the background traffic and the estimated situation of the target network. The performance of the proposed method is also evaluated through computer simulations.

II. SITUATION OF TARGET NETWORK

In general, a situation of a network varies by time of day such as morning, work time, or midnight. In addition, how the network situation varies depends on the application run in the network or network topology. Therefore, it is necessary to analyze the statistical characteristics of the retransmission of the background traffic in various situations of target networks.

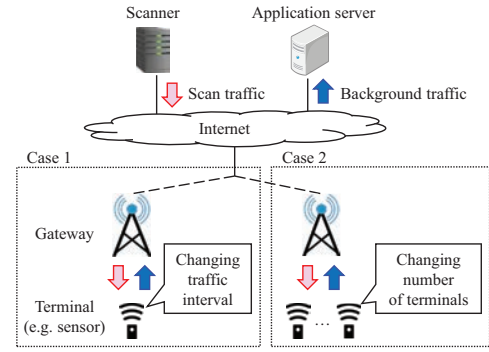


Fig. 1: Example of situations of target network.

In the empirical analysis, we consider a sensor network that consists of Wi-SUN devices. As shown in Fig. 1, we change the situation of the target network by changing the transmission interval of the background traffic (Case 1), or the number of terminals which transmit the background traffic (Case 2). The background traffic is transmitted from terminals to their application server. We assume that the interval of situation change is much longer than the occurring interval of the background traffic.

III. EMPIRICAL ANALYSIS OF RELATIONSHIP BETWEEN THE SCAN RESPONSE DELAY AND RETRANSMISSION RATE OF BACKGROUND TRAFFIC

We conduct an empirical analysis of the relationship between the scan response delay and the retransmission rate of the background traffic through computer simulations, assuming the system model described in the previous section. We try to express the relationship between the retransmission rate of the background traffic and the scan response delay by the polynomial regression function given by Eq. (1).

$$p(x) = a_n \cdot x^n + a_{n-1} \cdot x^{n-1} + \dots + a_1 \cdot x + a_0 \quad (1)$$

where n is the regression order of the least-squares method, a_k is the coefficient for the k -th regression order that minimizes the squared error.

In order to obtain the coefficients in Eq. (1), we first evaluate the scan response delay, the transmission interval of the background traffic, and the retransmission rate of the background traffic for various scan rates and network situations. Here, we assume that the packet length of the background traffic is fixed, and thus we use COR of the background traffic instead of its transmission interval. We simulate two different network situations by ns-3 [10]. Table I shows the simulation parameters. As a network topology, there are at least two terminals that are connected to the same Wi-SUN gateway. The Wi-SUN gateway is connected to the scanner by wired LAN. One terminal is the scan target, and the others transmit the background traffic. The scan rate changes in a range of 1–10 pps (packet per second).

In the network situation corresponding to Case 1 in Fig. 1, we assume that there is one terminal that transmits the

TABLE I: Simulation parameters.

Common	Overall	Simulation time	100 sec
		Number of trials	100
	Wi-SUN system	Bandwidth	200 kHz
		Phy communication rate	50 kbps
		Symbol duration	50 kbps
		CCA duration	0.16 us
		Turnaround time	1 ms
		Unit of backoff period	1.16 ms
		Minimum backoff exponent	3
		Maximum backoff exponent	5
	Scan traffic	Number of terminals	1
		Scan rate	1–10 pps
		Frame length	12.8 ms
	Background traffic	Communication direction	UL
		Frame length	27.84 ms
Case 1	Background traffic (Situation index 1)	Number of terminals	1
		Occurring interval	60–180 ms
		Configuration index 1	180 ms
		Configuration index 2	150 ms
		Configuration index 3	120 ms
		Configuration index 4	90 ms
		Configuration index 5	60 ms
		Configuration index 6	30 ms
		Configuration index 7	15 ms
		Configuration index 8	7.5 ms
Case 2	Background traffic (Situation index 2)	Number of terminals	1–5
		Configuration index 1	1
		Configuration index 2	2
		Configuration index 3	3
		Configuration index 4	4
		Configuration index 5	5
		Configuration index 6	6
		Configuration index 7	7
		Configuration index 8	8
		Configuration index 9	9

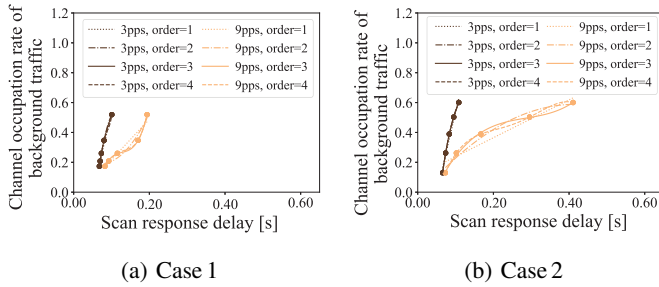


Fig. 2: Regression function of scan response delay vs. COR of background traffic

background traffic, and its transmission interval is changed from 60 to 180 ms with a 30 ms step. In the network situation corresponding to Case 2 in Fig. 1, we assume that there are several terminals for transmitting the background traffic with a fixed transmission interval of 180 ms, and the number of terminals is changed from one to five.

A. Relationship between scan response delay and COR of background traffic

In order to determine the regression order of the regression function, we draw regression curves for different regression orders from 5 points of the average scan response delay and average COR of the background traffic with different networks situations, i.e. the situations of the transmission interval in Case 1 or the situations of the number of terminals in Case 2.

Figure 2 shows the regression functions derived for the different regression order n . When both the network situation and traffic configuration are same, the COR of the background traffic is also same regardless the scan rate. The mean of the

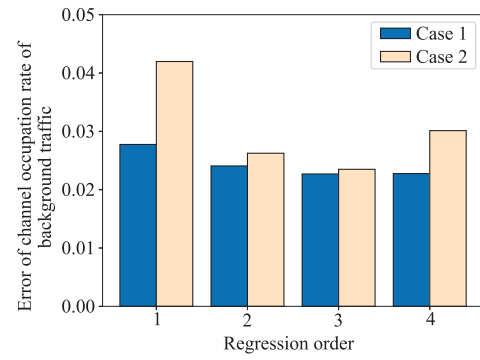


Fig. 3: Fitting accuracy of each regression order.

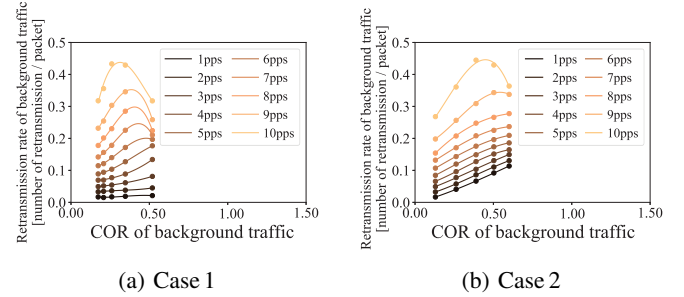


Fig. 4: Regression function of COR of background traffic vs retransmission rate of background traffic.

scan response delay of the higher scan rate (9 pps) is higher than that of the lower scan rate (3 pps). We can also find that the shapes of curves are different between two network situations.

Figure 3 shows the fitting accuracy of the regression function for different regression orders and network situations. The fitting accuracy is calculated as the absolute error between the fitting data and the actual simulation result. Since regression order 3 shows the best performance, we use it for the subsequent evaluation.

B. Relationship between COR of background traffic and retransmission rate of background traffic

Figure 4 shows the regression functions for the COR of the background traffic and the retransmission rate of the background traffic. We draw a regression curve from 5 (average COR of background traffic, average retransmission rate of background traffic) points in the same way as in Section III-A for each network situation. Since we can also find that the shapes of curves are different between two network situations, we use these regression functions for the estimation of the situation of the target network.

C. Distribution of scan response delay

This section summarizes the previous research [9] for estimating the network situation in the target network through empirical analysis of the scan response delay.

We confirmed the relationship between the scan response delay and its variance through an empirical analysis of the

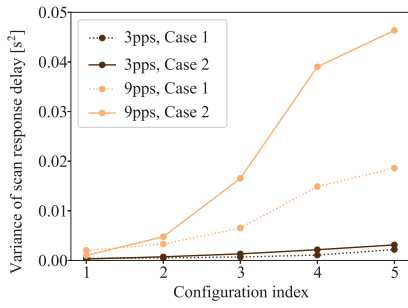


Fig. 5: Variance of scan response delay [9].

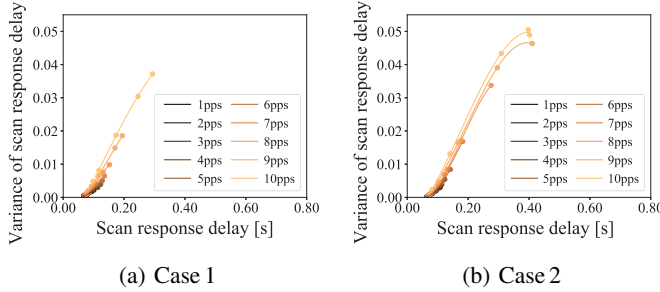


Fig. 6: Regression function of scan response delay vs. its variance [9].

distribution of the scan response delay depending on the situation of the target network and the scan rate. Figure 5 shows the variance of the scan response delay in each situation of the target network and the scan rate. The variance of the scan response delay becomes larger as its mean increases, and the scan rate increases. Therefore, the relationship between the scan response delay and its variance can also be derived with a regression function.

Figure 6 shows the regression functions for the mean of scan response and its variance. We draw a regression curve from 5 (*average scan response delay, variance of scan response delay*) points in the same way as in Section III-A for each network situation. In these analyzes, we confirmed that the shapes of curves are different between two network situations. This result implies that the network situation can be distinguished by the relationship between the mean of scan response and its variance. Therefore, in order to estimate the situation of the target network, we use the regression functions for the mean of scan response and its variance.

IV. PROPOSED ESTIMATION METHOD

We propose a method to estimate the retransmission rate of the background traffic at the target scan rate from a scan response delay obtained at a different scan rate, based on the empirical analysis described in Section III. Figure 7 shows the block diagram of the proposed method that employs three kinds of estimators. The first estimator E^S estimates the situation of the target network; hereafter, we call this estimator as Network situation estimator. The second estimator E^C estimates the COR of the background traffic in the target

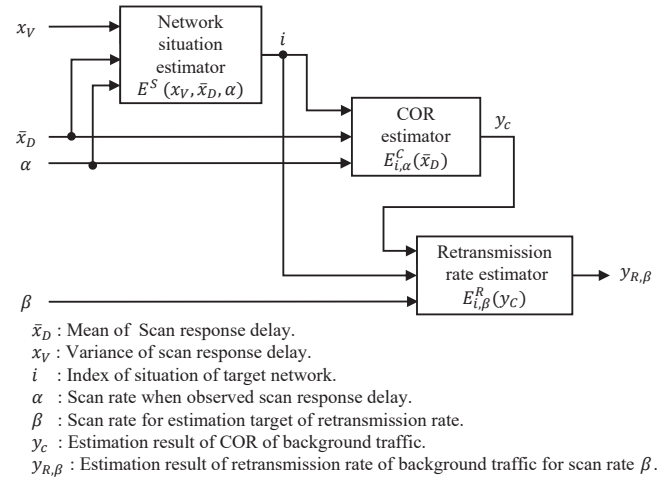


Fig. 7: Block diagram of proposed method.

network; hereafter, we call this estimator as COR estimator. The third estimator E^R estimates the retransmission rate of the background traffic of the target network; hereafter, we call this estimator as Retransmission rate estimator.

In Network situation estimator E^S , the network situation index i is estimated by finding the situation that gives the minimum distance between the observed value and estimated value at the scanner regarding the variance of the scan response delay. The observed variance of the scan response delay is calculated from the scan response delay observed at the scanner. The estimated variance of the scan response delay is calculated from the mean of the scan response delay using the regression functions for the mean of the scan response delay and its variance, for each situation of the target network.

The index i of the situation of the target network is estimated from the following equation.

$$i = E^S(x_V, \bar{x}_D, \alpha) = \arg \min_k |x_V - V_{k,\alpha}(\bar{x}_D)| \quad (2)$$

where $V_{i,\alpha}$ is the regression function for the mean of the scan response delay and its variance shown in Fig. 6, $\bar{x}_D$ is the mean of the scan response delay, and α is the scan rate when observed scan response delay.

COR estimator E^C estimates the COR y_C of the background traffic from the mean $\bar{x}_D$ of the scan response delay using the regression function for the mean of the scan response delay and the COR of the background traffic, for the situation index i and the scan rate α .

The COR y_C of the background traffic is estimated from the following equation.

$$y_C = E_{i,\alpha}^C(\bar{x}_D) = a_{3,i,\alpha}^C \cdot \bar{x}_D^3 + a_{2,i,\alpha}^C \cdot \bar{x}_D^2 + a_{1,i,\alpha}^C \cdot \bar{x}_D + a_{0,i,\alpha}^C \quad (3)$$

where $a_{k,i,\alpha}^C$ is the coefficient for the k -th regression order that minimizes the squared error for the situation index i

Retransmission rate estimator E^R estimates the retransmission rate $y_{R,\beta}$ from the COR y_C of the background traffic using the regression function for the COR of the background

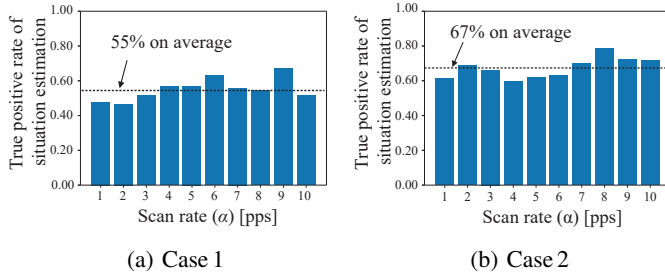


Fig. 8: True positive rate of situation estimation of target network [9].

traffic and the retransmission rate of the background traffic, for the situation index i and the scan rate β .

The retransmission rate $y_{R,\beta}$ is estimated from the following equation.

$$y_{R,\beta} = E_{i,\beta}^R(y_C) = a_{3,i,\beta}^R \cdot y_C^3 + a_{2,i,\beta}^R \cdot y_C^2 + a_{1,i,\beta}^R \cdot y_C + a_{0,i,\beta}^R \quad (4)$$

where $a_{k,i,\beta}^R$ is the coefficient for the k -th regression order that minimizes the squared error for the situation index i .

V. PERFORMANCE EVALUATION OF PROPOSED METHOD

We evaluate the estimation accuracy of the retransmission rate of the proposed method. We calculate the estimation error δ between an actual value ϵ_A and the estimated one ϵ_E by the following equation.

$$\delta = \epsilon_E - \epsilon_A. \quad (5)$$

Figure 8 shows the true positive rate (TPR) of the situation estimation as the performance of Network situation estimator, which had evaluated in previous research [9]. The TPR of Case 1 is 55% on average, and the TPR of Case 2 is 67% on average. Therefore, Network situation estimator sometimes selects the wrong situation.

Figure 9 shows the average estimation error of the COR of the background traffic for the different training cases. When estimating the retransmission rate in Case 1, the estimator trained both for Cases 1 and 2 can improve the estimation accuracy by 0.3% from that of the estimator trained only for Case 2 (i.e., the mismatched training case). On the other hand, when estimating the retransmission rate in Case 2, the estimator trained for both Cases 1 and 2 can improve the estimation accuracy by 1.5% from that of the estimator trained only for Case 1 (i.e., the mismatched training case).

Figure 10 shows the average estimation error of the retransmission rate for the background traffic of the different training cases. When estimating the retransmission rate in Case 1, the estimator trained both for Cases 1 and 2 can improve the estimation accuracy by 0.4% from that of the estimator trained only for Case 2 (i.e., the mismatched training case). On the other hand, when estimating the retransmission rate in Case 2, the estimator trained for both Cases 1 and 2 can improve the estimation accuracy by 0.9% from that of the estimator trained only for Case 1 (i.e., the mismatched training case).

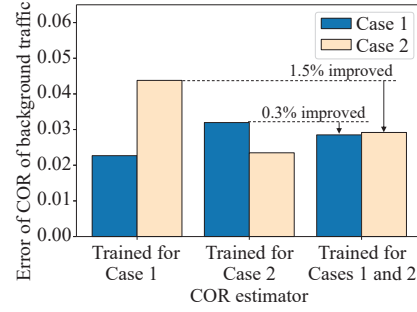


Fig. 9: Average estimation error of COR of background traffic for different estimators.

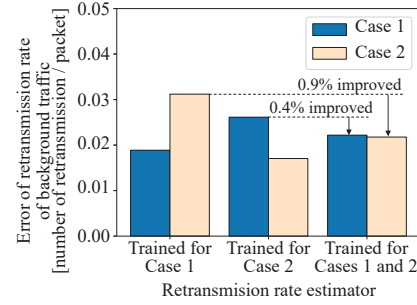


Fig. 10: Average estimation error of retransmission rate of background traffic for different estimators.

According to Figs. 9 and 10, we can find that COR estimator and Retransmission rate estimator trained both for Cases 1 and 2 can improve the estimation accuracy compared with the mismatched training case. On the other hand, compared with the estimator trained for the actual situation of the target network (i.e., the matched training case), the estimator trained for both Cases 1 and 2 degrades the estimation accuracy because of the imperfect estimation of the situation at Network situation estimator. However, the estimation error of the COR and that of the retransmission rate are not significant.

Figure 11 shows the average estimation error of the retransmission rate of background traffic for each scan rate α and β when the estimators are trained for both Cases 1 and 2. This result shows that the average error is lower than 5.8% regardless of the scan rates α and β .

VI. CONCLUSION

This paper proposed a method to estimate the retransmission rate of the background traffic at the target scan rate from a scan response delay obtained at a different scan rate.

First, through computer simulations considering a Wi-SUN sensor network with two different network situations and multiple scan rates, we derive a regression function using the least-squares method for the mean of the scan response delay and the COR of the background traffic, and the COR of background traffic and the retransmission rate of background traffic.

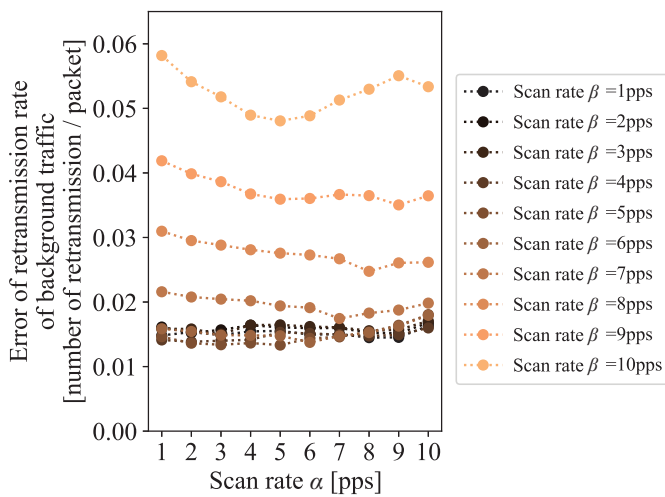


Fig. 11: Average estimation error of retransmission rate of background traffic for different scan rates (α, β).

Then, we proposed the new estimation scheme of the retransmission rate of the background traffic. First, Network situation estimator estimates the situation of the target network from observed value and estimated value regarding the variance of scan response delay. Second, COR estimator estimates the COR of the background traffic from the mean of scan response delay, the estimated situation of target network, and the scan rate which is used for observing the scan response delay. Third, Retransmission rate estimator estimates the retransmission rate of the background traffic from the COR of the background traffic the estimated situation of the target network, and a scan rate of estimation target.

We evaluated the estimation accuracy of the retransmission rate using the proposed method. We confirmed that the proposed method can estimate the retransmission rate of the target network with the average error lower than 5.8% regardless of the situation of the target network and the scan rate.

In order to confirm the effectiveness and the necessity of Network situation estimator, the validation assuming various network configurations is left as future work. In order to improving the estimation accuracy of the retransmission rate of the background traffic, the consideration for estimating the retransmission rate directly without using COR estimator is also left as future work.

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