

A Method for Controlling Scan Rate Based on Estimated Retransmission Rate of Background Traffic

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Abstract—For efficient network scan to narrow-band wireless networks, this paper proposes a method for controlling a scan rate based on the estimated retransmission rate of background traffic from a scan response delay obtained at a scan rate. This proposed method is aiming to select the highest scan rate that can keep the estimated retransmission rate of the background traffic below a predetermined retransmission threshold. First, through computer simulations considering a Wi-SUN sensor network with two different network situations and multiple scan rates, we derive a regression function between the mean of scan response delay and COR (Channel Occupation Rate) of the background traffic, and that between the COR and the retransmission rate of the background traffic, for each the network situation and the scan rate using the least-squares method. Then, we propose a method for estimating the retransmission rate of the background traffic at a different scan rate using three kinds of estimators; network situation estimator, COR estimator, and retransmission rate estimator. After that, we propose a control scheme of scan rate based on the estimated retransmission rate of the background traffic. We evaluate the estimation accuracy of the retransmission rate of the background traffic using the proposed estimation method. We confirm that the proposed estimation method can estimate the retransmission rate of the target network with the average error lower than 0.058 regardless of the situation of the target network and the scan rate. Moreover, we evaluate the performance of scan rate control using proposed method. We confirm that proposed method can scan faster by 0.18 pps and decrease the retransmission rate of the background traffic by 0.015 compared with a fixed scan rate.

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

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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 a wide area of the Internet [1], a scanner makes the network scan at a high rate to finish the scan quickly. However, when making a 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 QoS degradation of the background traffic at an allowable level, it is necessary to select the highest scan rate that can keep a balance between the processing time of the network scan and the QoS degradation of the background traffic. Examples of QoS are throughput and delay of background traffic observed in application layer. In this paper, we focus on the retransmission rate of the background traffic in MAC (Medium Access Control) layer which causes these QoS degradations. For realizing this control, the scanner needs to know the retransmission rate of the background traffic 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]. This is because that collision is occurred by congestion of the target network and retransmission is triggered by the collision. Therefore, the scanner needs to estimate the retransmission rate of the background traffic which is different for each target

network by using information which can be observed at the scanner such as scan response delay.

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]. These methods aim to grasp the network situation using the collision information which is obtained from the target network directly.

As other related work, estimating the available bandwidth in IEEE 802.11-based multi-hop wireless networks using the number of retransmission is proposed by [8]. By this method, the number of retransmissions is directly obtained from the target networks. Although there are various related works as mentioned above, it is difficult to apply these methods to estimate the retransmission rate of background traffic at the scanner. Therefore, a method for estimating the retransmission rate of background traffic at the scanner existing out of the target network is required.

In order to estimate the retransmission rate of the background traffic via Internet, we have proposed a method for estimating the retransmission rate of the background traffic from the scan response delay [9]. The proposed method consists of two kinds of estimators. The first one estimates the situation of the target network from the distribution of the scan response delay. The second one 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 (Personal Area Network).

For realizing the control of the scan rate, we need to determine the proper scan rate from the current scan rate and obtained scan response delay. Therefore, we also proposed a method for estimating the retransmission rate of the background traffic at a different scan rate using three kinds of estimators; network situation estimator, COR (Channel Occupation Rate) estimator, and retransmission rate estimator [10].

This paper shows a method for controlling the scan rate based on the retransmission rate of the background traffic estimated from the scan response delay using the estimators proposed in [10]. First, the followings are confirmed through 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.

- 2) The relationship between the transmission interval of the background traffic and the retransmission rate of the background traffic can also be expressed by a regression function.
- 3) The shape of the regression function is different depending on the situation of the target network and the scan rate.

Next, based on the above empirical analysis, we propose a method for estimating the retransmission rate of the background traffic for various scan rates different from the current scan rate and the scan response delay. The proposed estimation method consists of three kinds of estimators. The first one estimates the situation of the target network from the distribution of the scan response delay. The second one estimates the COR 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. Here, the COR of the background traffic is used instead of the transmission interval of the background traffic. The third one 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.

Finally, we propose a control scheme of the scan rate based on the estimated retransmission rate of the background traffic. The proposed method selects the highest scan rate that can keep the estimated retransmission rate of the background traffic below a predetermined retransmission threshold. 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.

In the empirical analysis, we consider a sensor network that consists of Wi-SUN devices. Examples of the factor of determining the network situation are the number of terminals, the transmission interval, frame length, and communication direction. In this paper, we focus on the number of terminals and the transmission interval because these factors affect the congestion situation of the background traffic significantly.

As shown in Fig. 1, we vary 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 transmission interval of the background traffic.

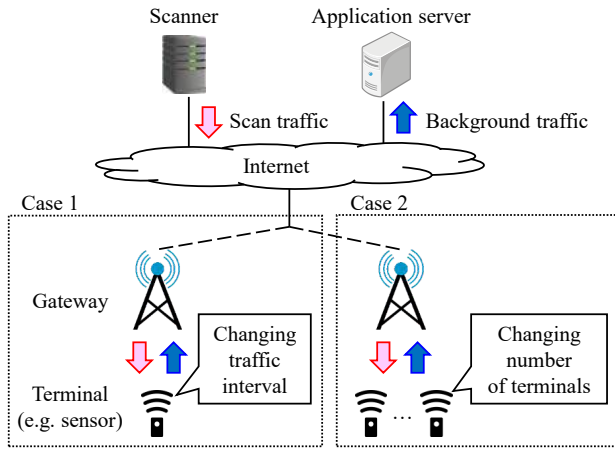


Fig. 1: Example of situations of target network (without scan traffic).

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

We conduct 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 by a polynomial regression function given by Eq. (1).

$$p(x) = \sum_{k=0}^n a_k \cdot x^k \quad (1)$$

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

In order to determine 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 the COR of the background traffic instead of its transmission interval. We simulate two different network situations by ns-3 [11]. Table I shows the baseline parameters for the entire simulation in this paper. As a network topology, there are at least two terminals (for the background traffic source(s) and for the scan traffic) that are connected to the same Wi-SUN gateway. The Wi-SUN gateway is connected to the scanner by wired LAN. 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 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

TABLE I
Baseline parameters for entire simulation.

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
	Background traffic	Scan rate	1–10 pps
		Frame length	12.8 ms
Case 1	Background traffic (Situation index 1)	Communication direction	UL
		Frame length	27.84 ms
		Number of terminals	1
		Transmission 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
	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
		Transmission interval	180 ms

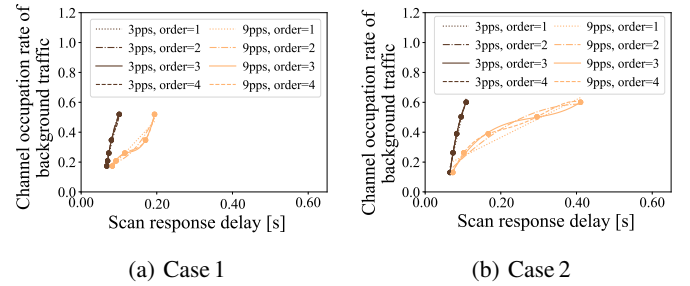


Fig. 2: Regression function of scan response delay vs. COR of background traffic [10].

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 the average COR of the background traffic with different networks situations, i.e. the values of the transmission interval in Case 1 or the number of terminals in Case 2.

Figure 2 shows the regression functions derived for different regression order n . When both the network situation and traffic configuration are same, the COR of the background traffic is also same regardless of the scan rate. The mean of the scan response delay of the higher scan rate (9 pps) is higher than

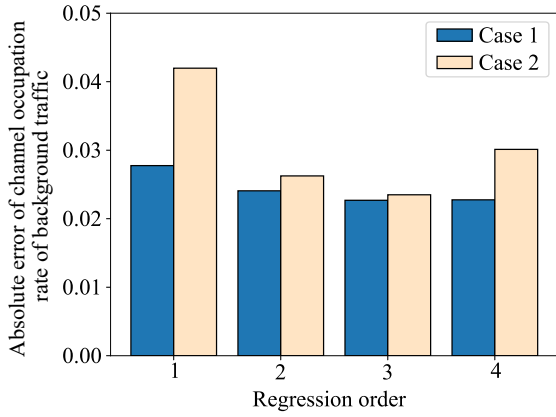


Fig. 3: Fitting accuracy of each regression order [10].

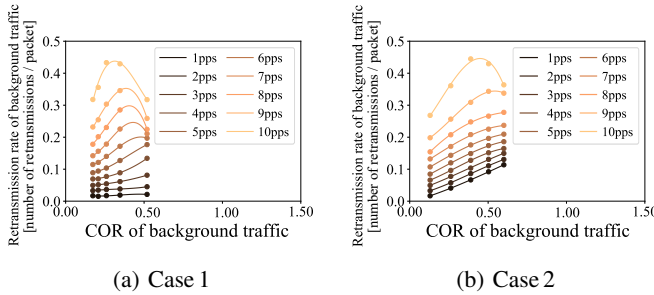


Fig. 4: Regression function of COR of background traffic vs. retransmission rate of background traffic [10].

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 in background traffic between COR and retransmission rate

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 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 confirmed the relationship between the scan response delay and its variance through empirical analysis of the distribution of the scan response delay.

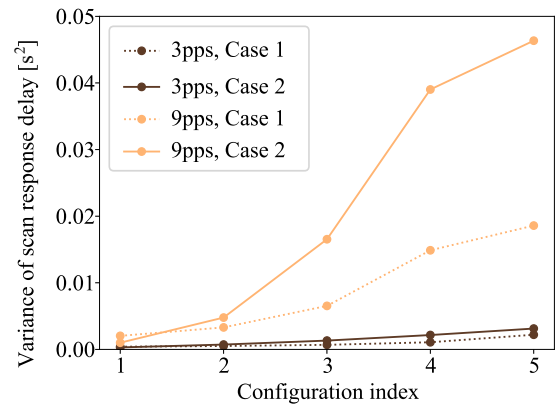


Fig. 5: Variance of scan response delay [9].

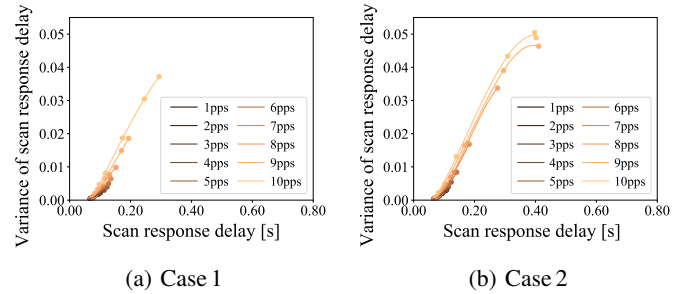


Fig. 6: Regression function of scan response delay vs. its variance [9].

Figure 5 shows the variance of the scan response delay versus the situation of the target network at scan rates of 3 pps and 9 pps. The variance of the scan response delay becomes larger as the amount of the background traffic or 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 for each network situation in the same way as in Section III-A. Since the shapes of curves are different between two network situations, 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. ESTIMATION OF RETRANSMISSION RATE OF BACKGROUND TRAFFIC

Based on the empirical analysis described in Section III, we propose a method for estimating the retransmission rate of the background traffic at the target scan rate from a scan response delay obtained at a different scan rate. Figure 7 shows the block diagram of the proposed method that employs three kinds of estimators $\mathbb{E}$. The first estimator E^S estimates

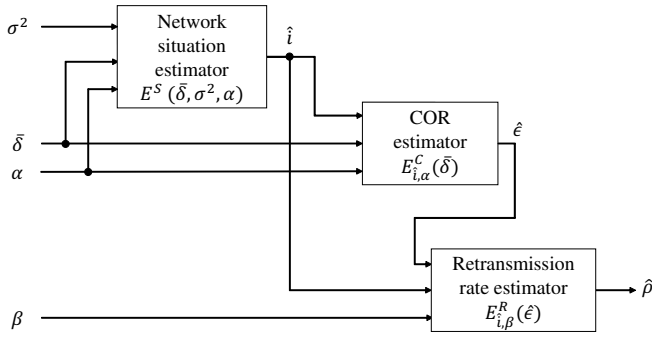


Fig. 7: Block diagram of proposed method.

the situation $\hat{i}$ 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 network; hereafter, we call this estimator as COR estimator. The third estimator E^R estimates the retransmission rate of the background traffic in the target network; hereafter, we call this estimator as retransmission rate estimator. Each estimator of $\mathbb{E}$ is trained for each cases $\mathbb{I}$ i.e. Case 1 or Case 2 mentioned in previous section. Therefore, the function E of the proposed estimation and its output $\hat{\rho}$ are described as following equation.

$$\hat{\rho} = E(\bar{\delta}, \sigma^2, \alpha, \beta) = E_{i,\beta}^R(E_{i,\alpha}^C(\bar{\delta})) \quad (2)$$

$$\hat{i} = E^S(\bar{\delta}, \sigma^2, \alpha) \quad (3)$$

where $\bar{\delta}$ is the mean of the scan response delay observed at the scanner, σ^2 is the variance of the scan response delay, α is the scan rate when the scan response delay is observed, β is the target scan rate for estimating retransmission rate of the background traffic, and $\hat{\rho}$ is the estimated retransmission rate of the background traffic at β .

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

The index $\hat{i}$ of the situation of the target network is estimated from the following equation.

$$\hat{i} = E^S(\bar{\delta}, \sigma^2, \alpha) = \arg \min_i |\sigma^2 - V_{i,\alpha}(\bar{\delta})| \quad (4)$$

where $V_{i,\alpha}$ is the regression function for the mean of the scan response delay and its variance shown in Fig. 6.

COR estimator E^C estimates the COR $\hat{\epsilon}$ of the background traffic from the mean $\bar{\delta}$ of the scan response delay by 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 $\hat{\epsilon}$ of the background traffic is estimated from the following equation.

$$\hat{\epsilon} = E_{i,\alpha}^C(\bar{\delta}) = \sum_{l=0}^3 a_{l,i,\alpha}^C \cdot \bar{\delta}^l \quad (5)$$

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

Retransmission rate estimator E^R estimates the retransmission rate $\hat{\rho}$ from the COR $\hat{\epsilon}$ of the background traffic by using the regression function for the COR and the retransmission rate of the background traffic, for the situation index i and the scan rate β .

The retransmission rate $\hat{\rho}$ is estimated from the following equation.

$$\hat{\rho} = E_{i,\beta}^R(\hat{\epsilon}) = \sum_{l=0}^3 a_{l,i,\beta}^R \cdot \hat{\epsilon}^l \quad (6)$$

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

V. CONTROL OF SCAN RATE BASED ON ESTIMATED RETRANSMISSION RATE OF BACKGROUND TRAFFIC

We propose a method for controlling the scan rate based on the estimated retransmission rate of the background traffic by using the proposed estimation method described in Section IV. Figure 8 and Table II show a processing image and notations of the proposed method, respectively. First, the proposed method requires following information; the observed scan response delay ($\mathbb{D}$), the scan rate ($\alpha \in \mathbb{B}$) for observing the scan response delay, the candidate scan rates for estimation target ($\mathbb{B}$), and the retransmission rate threshold (θ). Second, the estimated retransmission rate ($\hat{\rho}_k$) of the background traffic for each candidate scan rate ($B_k \in \mathbb{B}$) is estimated by using the proposed estimators ($\mathbb{E}$) which are trained with cases (the set of the indexes is defined by $\mathbb{I}$). Finally, the highest scan rate ($\alpha' \in \mathbb{B}$) that satisfied the condition $\hat{\rho}_k \leq \theta$ is calculated.

 TABLE II
Notations.

i	Case index of network situation.
j	Configuration index of network situation.
θ	Retransmission rate threshold.
$\mathbb{I}$	Trained cases for proposed estimators.
$\mathbb{E}$	Proposed estimators trained with $\mathbb{I}$.
$\mathbb{B}$	Candidate scan rates for estimation target.
k	Scan rate index of $\mathbb{B}$.
$\alpha (\in \mathbb{B})$	Scan rate when observed scan response delay.
$\alpha' (\in \mathbb{B})$	Scan rate controlled by proposed method.
$\mathbb{D}$	Samples of scan response delay when using α .
ρ_k	Retransmission rate at B_k .
$\hat{\cdot}$	A value estimated by using proposed method.

Figure 9 shows the scanning flow of the proposed method. First, the scanner is initialized by setting θ , α , $\mathbb{E}$, and $\mathbb{B}$. After that, the scanner makes a scan using α in phase $2n$ of the n -th trial. Here, n is a natural number. During phase $2n$, the scan

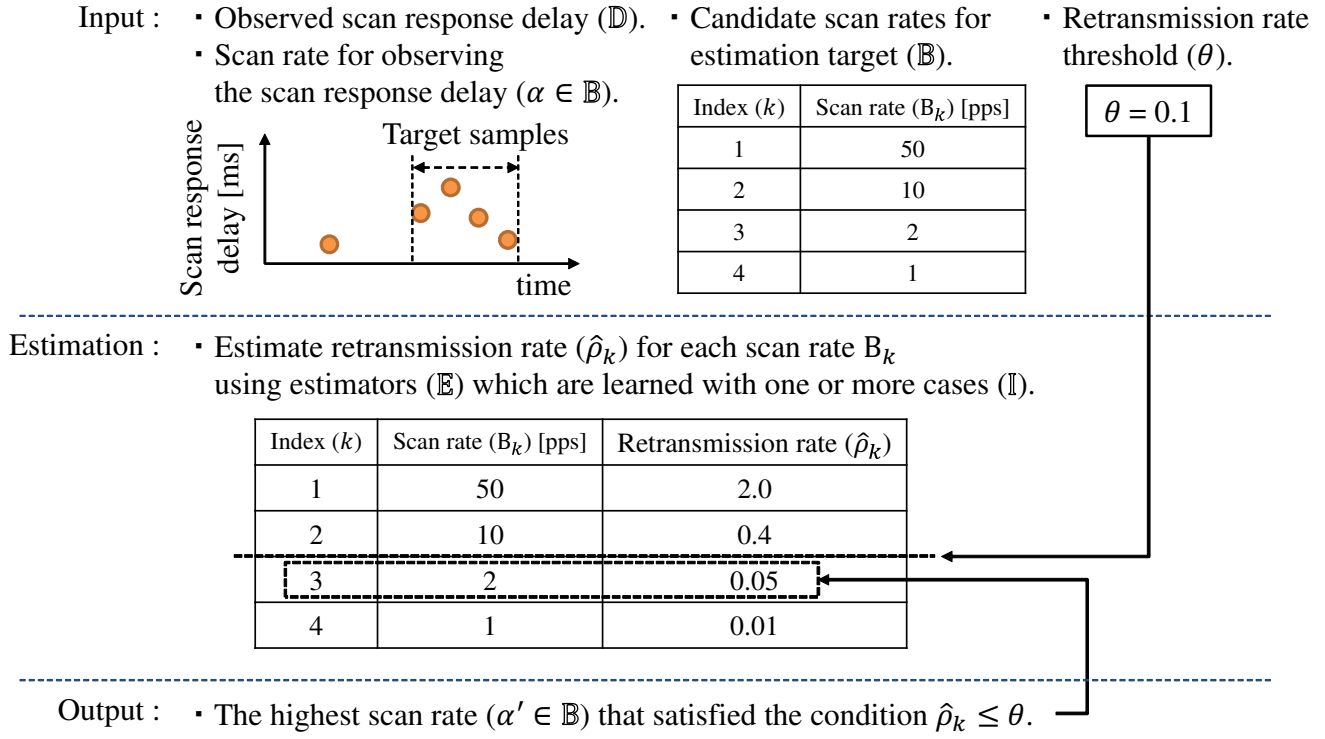


Fig. 8: Processing image of proposed method.

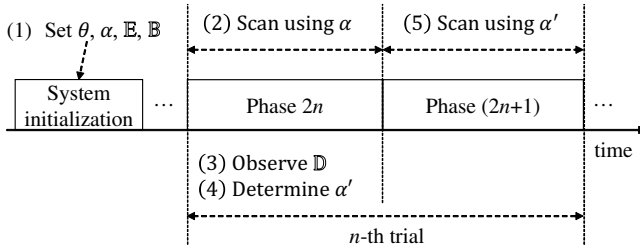


Fig. 9: Scanning flow of proposed method.

response delay $\mathbb{D}$ are observed at the scanner. At the end of phase $2n$, the scanner determines α' by using the proposed algorithm shown in Fig. 10. Finally, the scanner makes a scan using α' during phase $(2n+1)$. In this paper, we assume that the situation of the target network is stable from phase $2n$ to phase $(2n+1)$. Moreover, we assume that the scanner can get one or more samples of the scan response delay in each phase.

Figure 10 shows the proposed algorithm for controlling the scan rate based on the estimated retransmission rate of the background traffic. First, the average $\bar{\delta}$ and the variance σ^2 of the scan response delay are calculated from the observed scan response delay $\mathbb{D}$. After that, the retransmission rate $\hat{\rho}_k$ of the background traffic for each candidate scan rates is estimated by using the proposed estimators in Fig. 7. While estimating the retransmission rate of the background traffic, β is added into the set of the candidate scan rates $\mathbb{B}'$ when satisfied the condition $\hat{\rho}_k \leq \theta$. Finally, the controlled scan rate α' is

calculated by getting the maximum scan rate in $\mathbb{B}'$ if $\mathbb{B}'$ is not empty. Otherwise, the minimum scan rate in $\mathbb{B}$ is set to α' .

VI. PERFORMANCE EVALUATION OF PROPOSED METHOD

In this section, we evaluate the proposed method by the following steps. First, we evaluate the estimation accuracy of the retransmission rate of the proposed estimators. Next, we evaluate the performance of the scan rate control of the proposed algorithm. Finally, through analysis of these evaluation results, we confirm that proposed method can scan faster and improve the retransmission rate of the background traffic compared with a fixed scan rate.

A. Estimation accuracy of the retransmission rate

We evaluate the estimation accuracy of the retransmission rate of the proposed method. We calculate the estimation error γ between an actual value γ_A and the estimated one γ_E by the following equation.

$$\gamma = |\gamma_E - \gamma_A|. \quad (7)$$

Figure 11 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 12 shows the average estimation error of the COR of the background traffic for different training cases. When

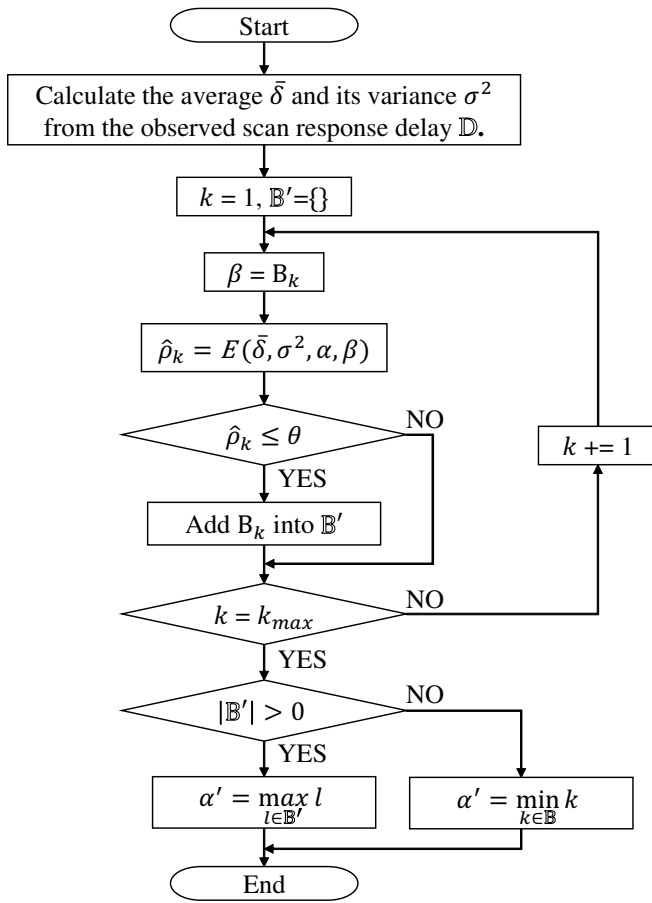
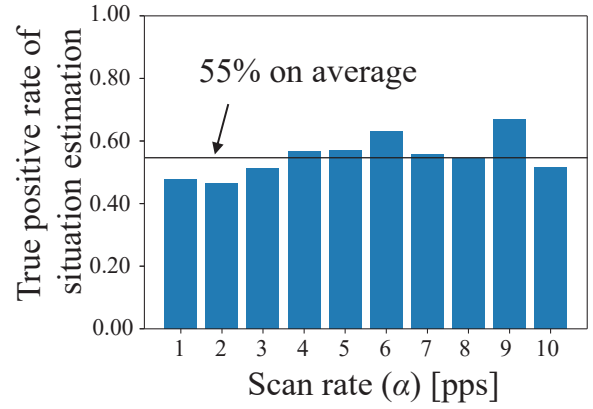


Fig. 10: Proposed algorithm.

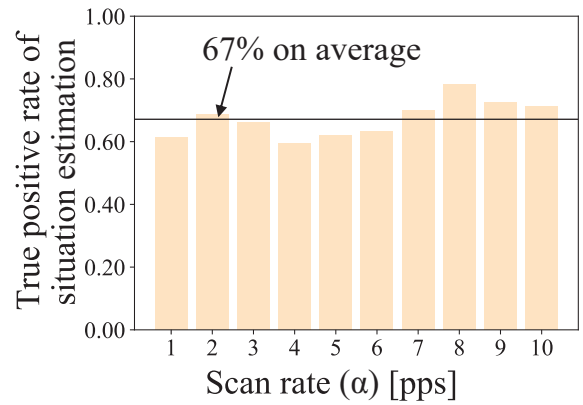
estimating the retransmission rate in Case 1, the estimator trained both for Cases 1 and 2 can decrease the estimation error by 0.003 from that of the estimator trained only for Case 2 (i.e., the mismatched training case). On the other hand, when estimating the retransmission rate in Case 2, the estimator trained for both Cases 1 and 2 can decrease the estimation error by 0.015 from that of the estimator trained only for Case 1 (i.e., the mismatched training case).

Figure 13 shows the average estimation error of the retransmission rate of the background traffic for different training cases. When estimating the retransmission rate in Case 1, the estimator trained both for Cases 1 and 2 can decrease the estimation error by 0.004 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 decrease the estimation error by 0.009 from that of the estimator trained only for Case 1 (i.e., the mismatched training case).

From Figs. 12 and 13, 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



(a) Case 1



(b) Case 2

Fig. 11: True positive rate of situation estimation of target network [9].

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 compared with the matched training case. Therefore, training for both cases can be a fail-safe approach.

Figure 14 shows the average estimation error of the retransmission rate of the background traffic for each the current scan rate α and the candidate scan rate β when the estimators are trained for both Cases 1 and 2. This result shows that the average error is lower than 0.058 regardless of the scan rates α and β .

B. Performance of controlling scan rate

We evaluate the performance of the scan rate control. Table III shows the parameter set for the performance evaluation. In this simulation, the proposed method scans according to the scanning flow explained in the previous section V. Here, the candidate scan rates $\mathbb{B}$ are set 1–10 pps. We also evaluate the performance when a fixed scan rate is used as in existing scan applications for comparison. In the case, a fixed scan rate α

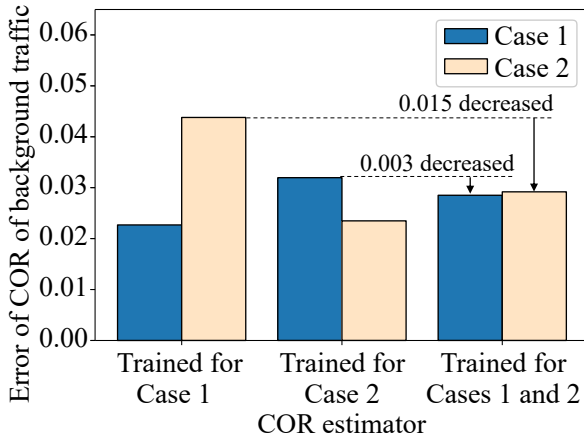


Fig. 12: Average estimation error of COR of background traffic for different estimators [10].

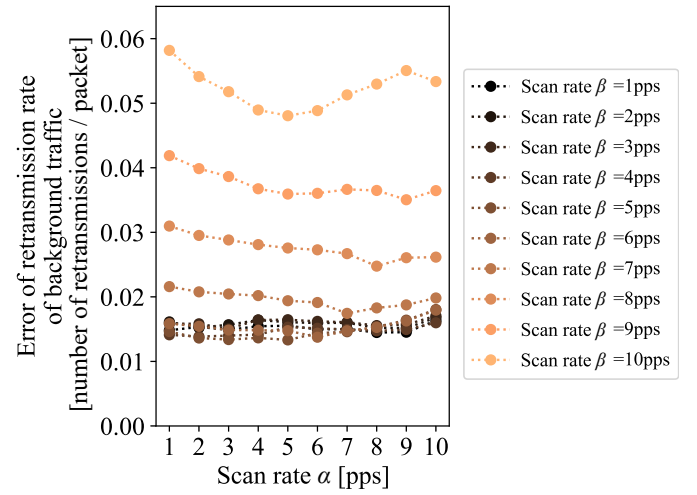


Fig. 14: Average estimation error of retransmission rate of background traffic for different scan rates (α, β) [10].

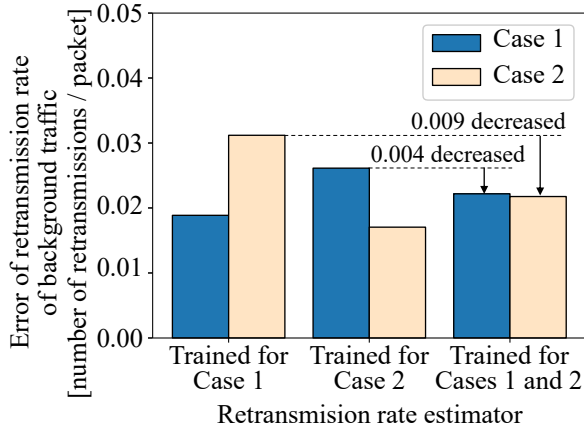


Fig. 13: Average estimation error of retransmission rate of background traffic for different estimators [10].

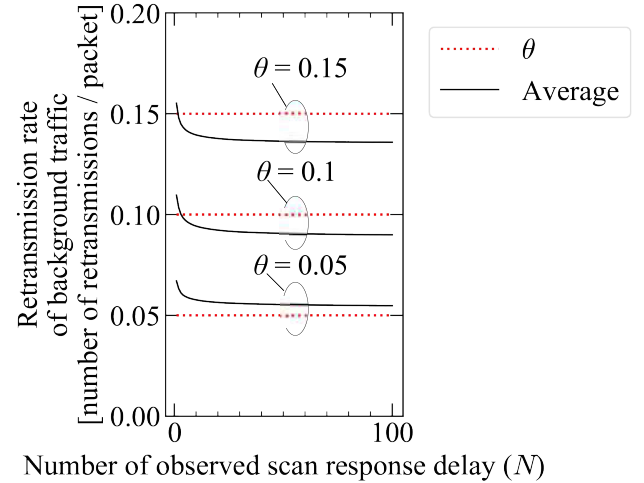


Fig. 15: Average retransmission rate of background traffic for all situations when $\mathbb{I} = \{1, 2\}$.

is used from phase $2n$ to phase $(2n + 1)$ of the scanning flow. During scanning, we assume that the situation of the target network is stable in each phase. In addition, the samples of the scan response delay observed at the scanner is not empty. We ran simulation with 10,000 different seeds.

Figure 15 shows the average retransmission rate of the background traffic for all situations when $\mathbb{I} = \{1, 2\}$. This

result shows that proposed method can converge the average retransmission rate of the background traffic with the increase of the number of the observed scan response delay (N). When $\theta = 0.1$ and 0.15 , the average retransmission rate of the background traffic can achieve less than θ if at most 10 samples of the observed scan response delay are obtained. However, when $\theta = 0.05$, the average retransmission rate of the background traffic dose not achieve θ regardless of N . This result implies that there is the lower bound of the achievable retransmission rate because the accidental retransmission of the background traffic can occur as long as scanning.

Figure 16 shows the average retransmission rate of the background traffic for defferent situation (i, j) of the target network when $\theta = 0.1$ and $\mathbb{I} = \{1, 2\}$. When $i = 1$ (case 1), θ is satisfied regardless of j with the increase of N . On the

TABLE III
Parameter set for performance evaluation.

Parameter	Value
Case index of network situation (i)	[1-2]
Configuration index of network situation (j)	[1-5]
Trained case for proposed estimators ($\mathbb{I}$)	[1, 2, {1, 2}]
Retransmission rate threshold (θ)	[0.05, 0.1, 0.15]
Scan rate when observed scan response delay (α)	[1-10]
Number of observed scan response delay (N)	[1-100]

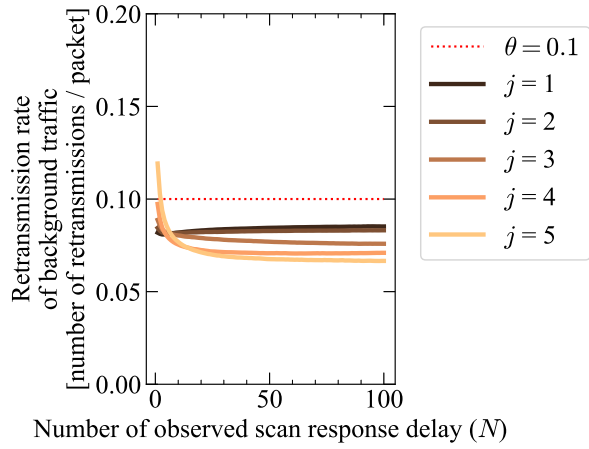
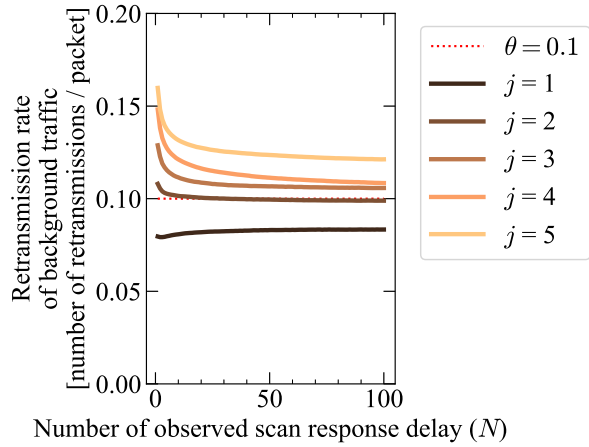
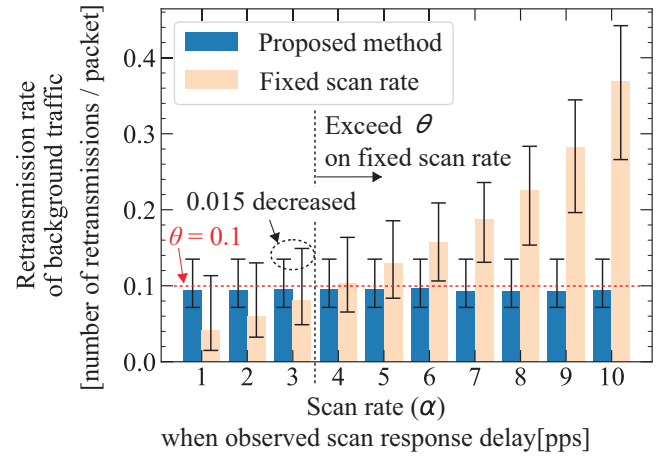
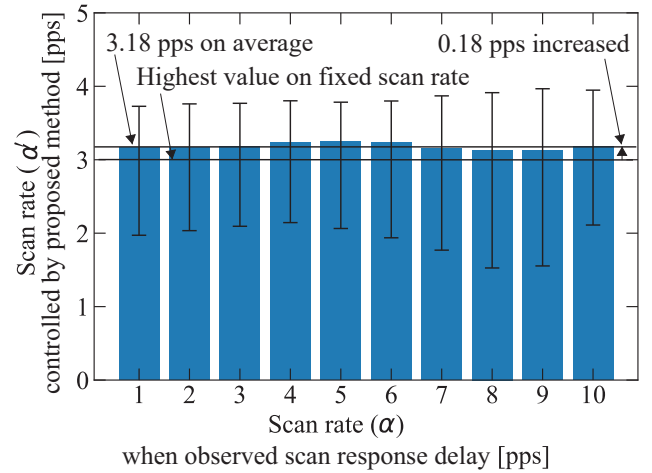

 (a) Case 1 ($i = 1$)

 (b) Case 2 ($i = 2$)

 Fig. 16: Average retransmission rate of background traffic for different situation of target network when $\theta = 0.1$ and $\mathbb{I} = \{1, 2\}$.

other hand, when $i = 2$ (case 2), θ is not satisfied in most case of j even if the N increases. Here, the higher value of j represents the higher congesting level. And also, each j of case 2 is congested compared with the same j of case 1. Therefore, these results imply that the lower bound of the achievable retransmission rate of case 2 is higher than that of case 1 because the collision of the background traffic is easily occurred in case 2 in which there are more terminals than case 1.

Figures 17 and 18 show the average retransmission rate of the background traffic and controlled scan rate α' for different current scan rates α when $\theta = 0.1$, $N = 10$, and $\mathbb{I} = \{1, 2\}$. Here, each error bar in each graph shows the range of the average value for all situations of the target network. This result shows that the proposed method can keep the retransmission rate of the background traffic below


 Fig. 17: Average retransmission rate of background traffic for different current scan rates (α) when $\theta = 0.1$, $N = 10$, and $\mathbb{I} = \{1, 2\}$.

 Fig. 18: Average scan rate (β) for different current scan rates (α) when $\theta = 0.1$, $N = 10$, and $\mathbb{I} = \{1, 2\}$.

θ regardless of the current scan rate α . As seen in the result of a fixed scan rate, $\alpha = 3$ pps is the highest scan rate which satisfies θ on average. Compared with this result, the proposed method can decrease the upper range of the retransmission rate of the background traffic by 0.015. Moreover, the proposed method increases the scan rate by 0.18 pps compared with the highest scan rate of the fixed scan rate. Therefore, the proposed method can scan faster and improve the retransmission rate of the background traffic compared with the fixed scan rate.

Figures 19 and 20 show the average of the retransmission rate of the background traffic and the average of the controlled scan rate α' for all situations of the target network. The proposed estimators are trained for different cases $\mathbb{I}$, respectively. Figure 19 shows that the estimator trained for case 2 only and cases 1 and 2 can keep the average retransmission

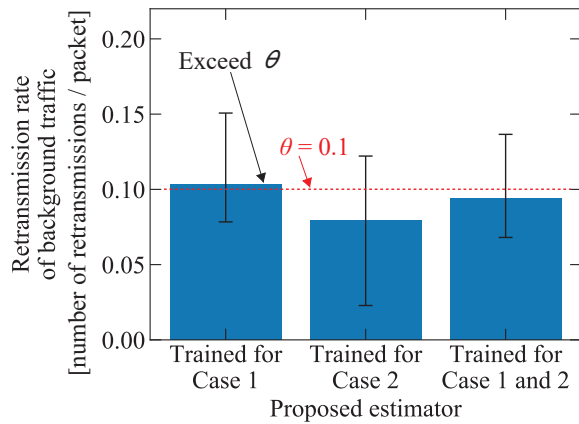


Fig. 19: Average retransmission rate of background traffic for different training cases (II) when $\theta = 0.1$ and $N = 10$.

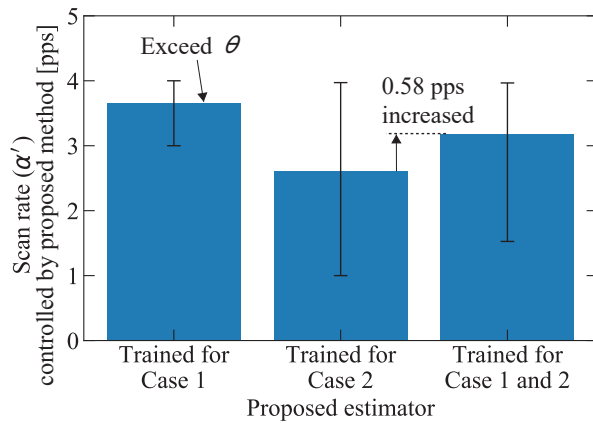


Fig. 20: Average scan rate (α') for different training cases (II) when $\theta = 0.1$ and $N = 10$.

rate of the background traffic below θ . Moreover, Fig. 20 shows the estimator trained for cases 1 and 2 can scan faster by 0.58 pps compared with the estimator trained for case 2 only on average. Therefore, the proposed estimator trained for multiple cases can more effectively control the scan rate than the estimator trained for a single case.

VII. CONCLUSION

This paper proposed a method for controlling the scan rate based on the retransmission rate of the background traffic from a scan response delay obtained at a scan rate.

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

Then, we proposed the method for estimating the retransmission rate of the background traffic for various scan rates different from the current scan rate and the scan response delay. 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 the 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 at the estimated situation of the target network, and a scan rate of estimation target.

After that, we proposed the method for controlling the scan rate based on the estimated retransmission rate of the background traffic. First, the scanner is initialized by setting retransmission rate threshold, scan rate for observing the scan response delay, the proposed estimators trained for one or more cases of the situation of the target network, and candidate scan rates. Second, the scanner scans by using the current scan rate and observes the scan response delays during scanning. Finally, the scanner selects the highest scan rate that can keep the estimated retransmission rate of the background traffic below the retransmission threshold.

We evaluated the estimation accuracy of the retransmission rate of the background traffic by using the proposed estimation method. We confirmed that the proposed estimation method can estimate the retransmission rate of the background traffic with the average error lower than 0.058 regardless of the situation of the target network and the scan rate. Moreover, we evaluated the performance of scan rate control by using the proposed method. We confirmed that the proposed method can scan faster by 0.18 pps and decrease the retransmission rate of the background traffic by 0.015 compared with the case using a fixed scan rate.

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