

Optimal Decision Number of Times for Search by Approach and Departure with RSSI

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Abstract To study to take the right information from fluctuated data, we take a scenario of searching the signal source by the received signal strength indicator (RSSI). We proposed the moratorium steps for the decision (MSD) to protect the decision until the defined number of times. The evaluation was simulated with fluctuated RSSI and two wireless nodes were simulated. One node broadcasted the signaling and another node received this signaling and measured RSSI. During the moving, RSSI was measured per regular distance. Due to observing the RSSI's increasing multiple times in a row or de-creasing multiple times in a row, the decision can make whether to approach to the signal source or not. In the simulation, the proposed method and the existing proposal were implemented, and the delay performance was compared. As a result, the proposed method was obviously a higher performance of about a maximum of 30 times. Therefore, it was evaluated that it could be good to protect the decision until the defined number of times taking the right information from fluctuated data.

Keywords Search, Approach and Departure Decision, RSSI, GPS-free, Efficiency, Optimal decision number of times

1. Introduction

1.1. Background and Motivation

It is important to take the right information from fluctuated data. By defining the rule, the right information has been taken from mass data. This rule wants to be defined objectively. We have studied the decision rule from the fluctuated data and the rule is based on the same observation multiple times [1]. Therefore, in this study we study the scenario of searching the signal source by the received signal strength indicator (RSSI) because RSSI is fluctuated based on the environments and RSSI can be used the decision of approach or departure so that RSSI is an ordinal scale that is inversely proportional to the square of communication distance in theory and the magnitude relationship of the RSSI represents distance [2]. In this paper, we focus on the RSSI which can be obtained during wireless communication [11]. And the scenario is based on ad-hoc communication, which can enable communication between wireless devices. In this paper, the signal source node is called the target node (TN), which broadcast periodically a beacon per certain times. The node to search TN by RSSI of the beacon from TN is the mobile node (MN).

1.2. Problem Statement

We consider the following problems:

1. It is difficult to determine approach or departure, i.e., moving toward or away from TN, respectively, by comparing between RSSI because they can change significantly in the same environment due to seasonal and weather changes [2].
2. It is difficult to estimate the direction of arrival (DoA [13]) because wireless devices employ non-directional antenna.

For these reasons, it is difficult for MN to search TN when the distance between MN and TN and the direction of TN's signal are unknown.

1.3. Objective

When moving to a TN under fluctuated RSSI depending on measurement points, a protection feature is implemented to determine approach/departure (approach/departure decision). We propose the moratorium steps for the decision (MSD) as a protection feature to reduce movement distance. To study an MN moving to a TN based on RSSI, we assume that MN and TN can communicate directly. In this study, we evaluate that MN search TN using the MSD through computer simulation.

The reminder of this paper is organized as follows. Section 2 discusses related work. Section 3 describes the proposed method, including an overview, details, and a description of our computer simulation model. Approach/departure decision and the MSD are also discussed in the Section 3. Section 4 presents various simulation results, including a

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comparison between the proposed method and unused it. The conclusions are given in Section 5.

2. Related Work

(a) Estimation of distance based on RSSI.

Many studies of positioning techniques using wireless devices have been conducted. In these studies, distance is estimated by trilateration [6] [7] [8] [12], which estimates the distance of an objective node while measuring the distance from more than three anchor nodes. Trilateration is prone to error in distance estimation due to error in the measured RSSI. The trilateration method requires more than three anchor nodes, whereas the proposed method uses only two nodes to search TN.

(b) Estimation of AOA with RSSI [15].

This method is the combination of two method. The angle measurement and the distance measurement are equally important in determining the position of the target node. It converts polar coordinates into Cartesian coordinates to locate the target node T with respect to the anchor node A as below

$$\begin{aligned} x_T &= x_A + d_A \cdot \sin(\theta), \\ y_T &= y_A + d_A \cdot \cos(\theta) \end{aligned}$$

where θ is the AOA of signal which is transmitted from the target node T and arrives at node A. The advantage of this method is that we can locate nodes with a minimum of one anchor node. However, AOA rely on special hardware that is expensive and energy consuming. Figure 1 shows the graphical representation of AOA with RSSI.

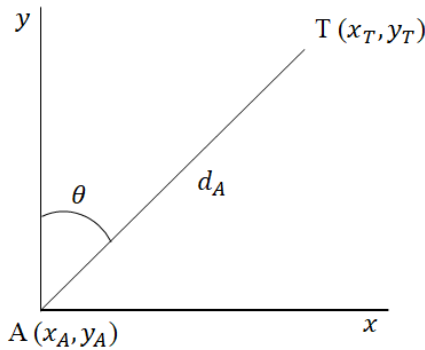


Figure 1. Graphical Representation of AOA with RSSI

(c) Movement based on RSSI.

We review studies about using mobile robots for search and rescue. Such mobile robots search TN using sensor nodes [9]. The mobile robot moves randomly from q_0 and stops at one of q_1, q_2, q_3 and q_4 that is far away to TN than q_1 . The movement tracking are defined by the initial distance $|q_0S|$ to TN, and the moving distance is $(1/2) \cdot |q_0S|$. The mobile robot moves to this node by heuristic movement following RSSI-based distance estimation, and which is

repeated. Until q_4 it cannot search S, it implies no progress and it stays at the initial position (q_0). Then new iteration is run to search S. Figure 2 shows the sample of heuristics movement with distance noise.

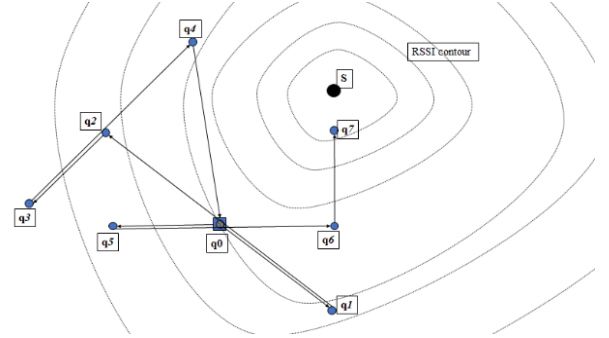


Figure 2. Heuristics movement with distance noise in DREAMS

As described above, the related work is described from three perspectives. These studies use trilateration for distance estimation, directional antennas to determine radio direction, and heuristic movement according to RSSI-based distance estimation.

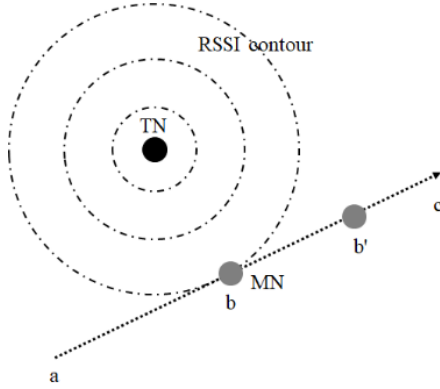
3. Proposal Method

3.1. Overview

Since RSSI is fluctuated based on the environment, the calibration of RSSI propagation model [3] or filtering to remove unwanted components (noise) [4] and the communication distance is required. This study employs search method that uses approach/departure decision based on fluctuated RSSI from wireless devices with non-directional antennas. The proposed method does not use calibration or filtering to measure RSSI or estimate communication distance. It is difficult to determine approach/departure depending using RSSI strength. The MSD as a protection feature is implemented for approach/departure decision. An overview is shown in Figure 3 assumed on the free-space propagation model without noise to explain easily. When the protection feature is used and the decreasing is determined multiple times in a row, the moving direction changes, that is, approach/departure are determined by decreasing and increasing RSSI, respectively, multiple times in a row, while MN moves in a straight line from a to c. Then, the moving direction is changed at b' when determining departure using approach/departure decision. With this method, incorrect moving direction is reduced because incorrect approach/departure decision can be prevented. It is that “multiple times in a row” is MSD of a protection feature and MSD is an integer value. We evaluate that MN search TN using the MSD according to approach/departure decision through computer simulation. The notations used in this paper are described in Table 1.

Table 1. Notations

Name	Notation	Description
Mobile Node	MN	Node to search TN
Target Node	TN	Node of signal source
Step width	sw	Distance of one step
Maximum number of step times	s_max	Maximum number of step times in one trial
Position	i	Position index ($i = 0, 1, 2, 3, \dots$)
RSSI	R_i	RSSI at i
SRSSI	SR_i	Smoothed RSSI at i
Reference value	Ref_{rssi}	Value to compare with R_i
Amount of moving direction control	m_angle	Amount of change in the moving direction
Moratorium steps for the decision	MSD	Protect the decision until the defined number of times
Threshold	r_src	Distance from TN to end the search
Decreasing counter	$Counter_D$	Increment when R_i is decreased compared to Ref_{rssi} .
Increasing counter	$Counter_I$	Increment when R_i is increased compared to Ref_{rssi} .
Significance level	α	Value for significance test

**Figure 3.** Overview of approach/departure decision

3.2. Assumption

MN assumes a general wireless node that implements IEEE 802.11b and supports ad-hoc communication. It is assumed that a non-directional antenna is employed by MN. In addition, MN has the following capabilities:

- RSSI measurement
- Moving distance measurement
- Moving direction control

TN has the same functions and sends a beacon signal to MN periodically.

3.3. Details

Here, we describe TN based on RSSI using approach/departure decision. The search procedure for MN is described below.

- (1) MN measures RSSI (R_i) at i from TN.

- (2) When starting the search, R_i becomes the reference value (Ref_{rssi}).
- (3) MSD is set an integer value (k).
- (4) Check whether MN is within r_src . If MN is within r_src , the simulation ends.
- (5) Compare R_i to Ref_{rssi} .

$$R_i > Ref_{rssi} (Increase) \rightarrow \begin{cases} Counter_D = 0 \\ Counter_I ++ \end{cases}$$

$$R_i < Ref_{rssi} (Decrease) \rightarrow \begin{cases} Counter_D ++ \\ Counter_I = 0 \end{cases}$$

$$R_i = Ref_{rssi} (Unknown) \rightarrow \begin{cases} Counter_D = 0 \\ Counter_I = 0 \end{cases}$$

- (6) Compare each counter with MSD times. When $Counter_D = k$ or $Counter_I = k$,

$$Counter_D = k \rightarrow m_angle = \frac{\pi}{2}$$

or

$$Counter_I = k \rightarrow m_angle = 0$$

then

Go to (7)

else if

$$\begin{cases} Counter_D < k \\ Counter_I < k \end{cases} m_angle = 0$$

then

Go to (8)

- (7) Ref_{rssi} is updated and both counters are reset as follows.

$$\begin{cases} Counter_D = 0 \\ Counter_I = 0 \end{cases}$$

Ref_{rssi} is selected as the minimum R_i between the current location ($t + N$) and the location (t) which is starting the count of $Counter_D$ or $Counter_I$. In order to prevent from occurring approach determination frequently, the minimum RSSI is selected.

$$Ref_{rssi} = \min\{R_t, R_{t+1}, \dots, R_{t+N}\}$$

- (8) Move sw as a single step. One direction is selected when the search process begins.
- (9) Repeat (1)

3.3.1. MSD in Approach/Departure Decision

The purpose of approach/departure decision is to determine whether MN moves toward or away from TN according to the measured RSSI at each step. MN compares R_i and Ref_{rssi} to determine the magnitude relation.

MN moves a single step and the probability of decision is 1/2 because the comparison of RSSI is the increased or decreased when comparing R_i to Ref_{rssi} . We assume that MN determines that the comparison result is increasing or decreasing multiple times in a row. The formula to calculate the multiple times in a row is $(0.5)^N$ because increasing or decreasing can occur the propagability of 0.5. Where N is the number of times and the significance level (α) is used, which is the probability of rejecting the null hypothesis. Thus, k is the minimum integer value.

$$(0.5)^N < \alpha$$

$$N > \frac{\log_{10}(\alpha)}{\log_{10}(0.5)} \quad (1)$$

Note that N becomes 5 because α is set to 0.05.

Due to fluctuated RSSI caused by environmental conditions, we assume that the variance of RSSI is used for the MSD. The variance at i is obtained from R_i and the smoothed RSSI (SR_i) at i [2]. This is expressed as D_i ,

$$D_i = \sqrt{(R_i - SR_i)^2} \quad (2)$$

SR_i is smoothed RSSI,

$$SR_i = (1 - a) \cdot SR_i + a \cdot R_i \quad (3)$$

where a is the smoothing constant and a is set to 0.125.

Here, we consider N which is calculated statistically and the variance D_i . One is a fixed value, and the other is a variable value because it is based on the variance of RSSI which is obtained while MN moves. Thus, the MSD is an integer value selected as the maximum value of N or D_i . Note that the MSD at i is defined as below.

$$MSD_i = \max\{D_i, 5\} \quad (4)$$

We determine the approach to TN when the comparison R_i with Ref_{RSSI} is increasing MSD_i times in a row, and we determine departure from TN when the comparison R_i with Ref_{RSSI} is decreasing MSD_i times in a row. It is expected that N prevent incorrect determination from the varied R_i , i.e., the measured RSSI.

3.3.2. Moving Direction Control

The moving direction control controls the moving direction according to the approach/departure decision. To increase the possibility of encountering TN, the movement trajectory of MN is a spiral box search, i.e., m_angle is 0 or $\pi/2$ in a counterclockwise direction.

4. Evaluation

In this section, we evaluate the performance of the proposed method through computer simulation. The proposed method is a generic algorithm that is designed for realistic settings without prior knowledge of sensory filed and with RSSI measurement noise. Only a few mobility scheduling algorithms were presented in the literature. However, none of them is comparable to the proposed method (see Section 2 for a related work). In this case, we decide to use the RSSI-based mobility algorithm for comparison which is DREAMS [9]. The reason is that this algorithm is a heuristic movement as having four attempts of one iteration to compare the RSSI-based distances and it is similar to the proposed method that compares the RSSI within several times of one iteration. Our study focuses on:

Delay performance: It is measured by moving distance divided by distance between the starting point and TN. The former is the total distance that MN moves during the search, the latter is the direct distance until TN from the starting

point of search. It is a metric in order to measure how much MN takes a detour toward TN. The metric is detour rate (τ) described as below. τ has a numeric value that is greater than 1.

$$\tau = \frac{\text{moving distance}}{\text{distance between the starting point and TN}} \quad (5)$$

4.1. Plane of Search

The plane of search is a two-dimensional lattice in the x - y plane. The distance between the lattices is 0.5 [m]. MN and TN are positioned on this x - y plane, and it is assumed that there are no obstacles between these nodes.

4.1.1. MN

MN moves at a constant speed to adjacent lattice points on the left, right, top or bottom of the x - y plane. At each lattice point MN determines R_i from TN.

4.1.2. TN

TN is located on at the origin (0,0) at x - y plane and does not move.

4.1.3. Radio Propagation Model

TN transmits signals such as a beacon signal, and MN measures R_i . The radio propagation model uses a generic model, i.e., the variations in RSSI follow a log-normal distribution [2] [10].

$$R_i \sim N(\bar{R}_i, X_\sigma^2) \quad (6)$$

$$\bar{R}_i = R_0 - 10 \cdot \gamma \cdot \log_{10} \left(\frac{d}{d_0} \right) \quad (7)$$

Here, R_i [dBm] is RSSI measured at i and (\bar{R}_i) [dBm] is the average RSSI at i . X_σ^2 [dB] is the variance, i.e., the varied measurements of RSSI. $N(\bar{R}_i, X_\sigma^2)$ indicates a log-normal distribution of (\bar{R}_i) and X_σ^2 . R_0 [dBm] is RSSI at reference distance d_0 [m], and d_0 [m] is 1 [m]. Thus, R_0 using a free space model [5] (frequency: 2.4 [GHz], transmitting power: 10 [mW] [14], antenna gain: 1) as -30.05 [dBm]. d [m] is communication distance. γ is the path loss exponent and it is covered as a fixed value. It is assumed that d and γ are used as unknown parameters. The simulations cover X_σ^2 of 3^2 to 12^2 [dB] because these values are reported in the literature [10]. The parameters are listed in Table 2 in the both simulations.

Table 2. RSSI parameters

Name	Notation	Value	Unit
Reference distance	d_0	1	[m]
RSSI at reference distance	R_0	-30.05	[dBm]
Variance	X_σ^2	$3^2, 6^2, 9^2, 12^2$	[dB]
Path loss exponent	γ	2	-

4.2. Simulation Setup

We implemented the proposed method and DREAMS [9] in a custom simulator by Visual C++ 2017. In the both simulations, an MN and TN were positioned on the search

space. MN started from the following start points given as an x, y coordinate respectively: $\{x,y\}=\{100,100\}, \{90,90\}, \{80,80\}, \{70,70\}, \{60,60\}, \{50,50\}, \{40,40\}, \{30,30\}, \{20,20\}$ (Unit: [m]). This is a range that MN can receive the signal from TN in roughly maximum -100 [dBm]. TN is allocated at the origin (0,0) at x - y plane and TN is fixed. Table 3 shows the simulation parameters which is used in the both simulations. However, the amount of moving direction control (m_angle) and significance level (α) were used in only the proposed method. We conducted 100 simulation runs at each starting point. Note that the simulation of DREAMS calculated the distance by Equation (7) with γ in Table 2 and it limited the Maximum moving distance in one time was set to 100 [m] because of avoiding the unrealistic distance calculating by RSSI.

Table 3. Simulation parameters

Name	Notation	Value	Unit
Step width ^{*1}	sw	0.5	[m]
Maximum number of step times	s_max	5000	[times]
Threshold	r_src	5	[m]
Amount of moving direction control ^{*1}	m_angle	0 or $\pi/2$	[rad]
Significance level ^{*1}	α	0.05	-

*1 This is only for the proposed method.

4.3. Simulation Result

We evaluate the proposed method and DREAMS [9] in single-hop scenario. Table 4 shows τ in the both simulation results. From the results, the proposed method shows the better result of τ than DREAMS. In the proposed method,

the results show a shorter distance of about 3 to 40 times depending on x^2_{σ} . This can be explained by the fact that the RSSI-based distance causes the wrong distance in DREAMS.

In the next, RSSI is a sampling (10 times) at the same position and averaged in DREAMS. This result shows in Table 5. Though DREAMS in Table 5 is the better than one in Table 4, the proposed method presents the better result than DREAMS with the averaged RSSI. However, in $X^2_{\sigma}=3^2$ [dB] and $\{20, 20\}$, DREAMS is better than the proposed method about 1.4 times. This is only one case in which DREAMS is better. Other cases are the shorter distance of about 1.7 to 30 times. Figure 4 shows one example of movement locus (Position i on x -axis, MSD_i on y -axis) in $X^2_{\sigma}=12^2$ [dB]. Though MN had several wrong decisions, the direction was recovered. In Figure 4, MN started the search at Start Point of MN of $\{x,y\}=\{100,100\}$ and had a wrong decision at (B) and changed the direction and moved until (C). At (C), (D) and (E) MN detected departure from TN due to that the comparison was decreasing MSD_i time in a row. Then, the direction was recovered. Later, there were the same procedures which contains a wrong decision at (G). Finally, MN searched TN because of arriving within r_src from TN. Since MSD_i became the bigger value because of the high variance environment, MN consumed the movement until the decision of approach or departure.

This is worth nothing that delay performance greatly depends on RSSI-based distance accuracy. And this is a key point that the proposed method is using the moratorium steps for the decision and it is independent of RSSI-based distance accuracy.

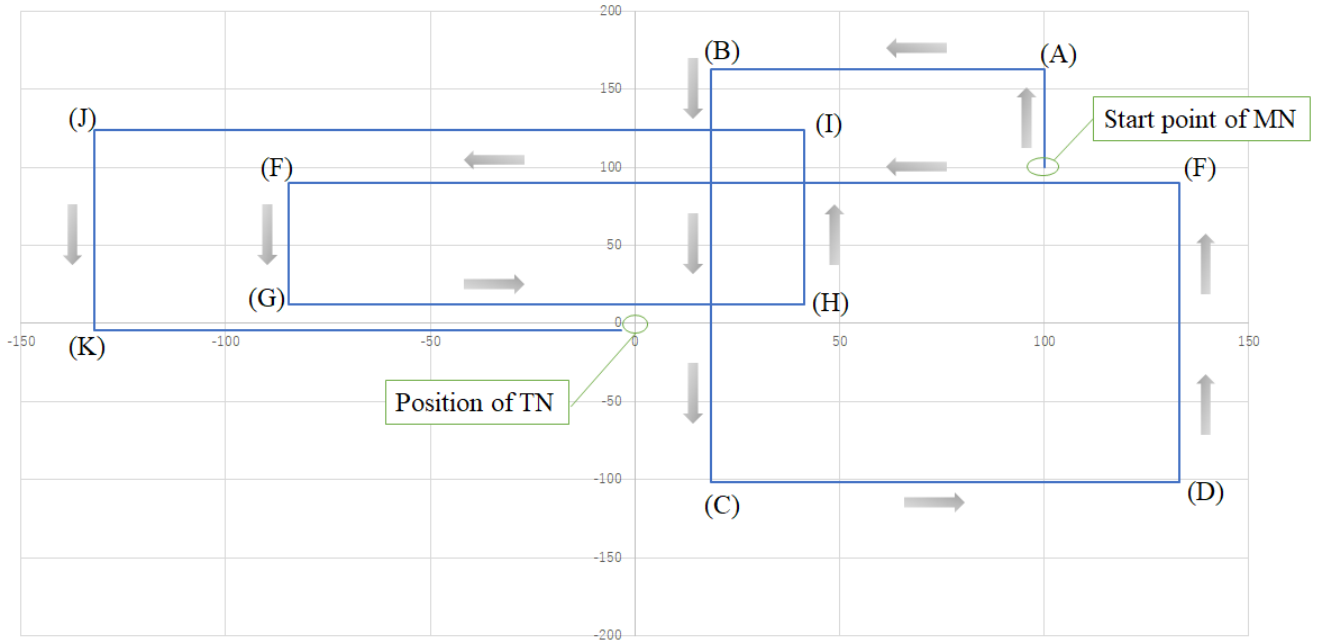


Figure 4. Example of movement locus

Table 4. τ of Proposed method and DREAMS

Distance between the starting point and TN		Proposed method				DREAMS			
		X_{σ}^2 [dB]				X_{σ}^2 [dB]			
Coordinate	Distance [m]	3 ²	6 ²	9 ²	12 ²	3 ²	6 ²	9 ²	12 ²
{20, 20}	28.28	14.34	20.89	34.36	35.31	18.06	55.39	167.76	355.53
{30, 30}	42.43	9.33	16.75	25.93	26.53	20.75	85.87	201.37	404.43
{40, 40}	56.57	9.56	14.72	19.48	19.22	21.70	80.27	217.14	432.37
{50, 50}	70.71	7.38	12.28	15.80	16.74	23.41	85.76	245.26	423.52
{60, 60}	84.85	7.26	10.89	13.47	15.55	29.14	80.54	246.29	542.80
{70, 70}	98.99	7.15	11.60	10.09	13.30	30.78	76.14	188.20	356.28
{80, 80}	113.14	6.71	10.13	11.17	10.41	25.51	92.58	227.06	515.65
{90, 90}	127.28	5.93	9.06	9.27	10.68	26.17	107.55	252.48	474.56
{100, 100}	141.42	5.92	8.75	8.10	9.20	25.95	117.69	351.60	565.13

Table 5. τ of Proposed method and DREAMS with averaged RSSI

Distance between the starting point and TN		Proposed method				DREAMS (with averaged RSSI)			
		X_{σ}^2 [dB]				X_{σ}^2 [dB]			
Coordinate	Distance [m]	3 ²	6 ²	9 ²	12 ²	3 ²	6 ²	9 ²	12 ²
{20, 20}	28.28	14.34	20.89	34.36	35.31	9.69	17.45	57.79	124.31
{30, 30}	42.43	9.33	16.75	25.93	26.53	9.53	21.50	85.80	230.16
{40, 40}	56.57	9.56	14.72	19.48	19.22	10.48	22.75	129.75	315.37
{50, 50}	70.71	7.38	12.28	15.80	16.74	11.05	37.92	165.50	373.57
{60, 60}	84.85	7.26	10.89	13.47	15.55	13.00	36.69	173.19	392.41
{70, 70}	98.99	7.15	11.60	10.09	13.30	11.56	40.29	223.18	431.49
{80, 80}	113.14	6.71	10.13	11.17	10.41	13.70	46.36	257.60	426.58
{90, 90}	127.28	5.93	9.06	9.27	10.68	13.62	44.10	248.04	419.13
{100, 100}	141.42	5.92	8.75	8.10	9.20	13.15	60.22	323.46	406.71

5. Conclusions

The search based on the moratorium steps for the decision (MSD) is a cost-effective search in delay tolerant scenario. In this paper, we used the search of signal source by fluctuated RSSI scenario to evaluate the effective search using the effective steps for a decision. We studied how to avoid the mis decision under fluctuated RSSI. We proposed the moratorium steps for the decision, protecting the decision until the multiple times. The evaluation was performed under fluctuated RSSI to search the signal source in the simulation. Our simulation results imply that the proposed method using the moratorium steps for the decision has better the delay performance than the existing proposal DREAMS [9] at reasonable delay cost. The different results from the both were whether to consider the variance of RSSI. It indicated that the proposed method could make the better decision under fluctuated RSSI.

In this paper, it was handled a simple way such as a single-hop scenario, no movement of target or no obstacle environments. When MN cannot receive instructions from TN, it starts a random walk to discover the area which can be got instructions from TN. Once it is found, MN runs the proposed method from there. By this means, it is a limitation of a single-hop scenario and it implies that a multi-hop

scenario can be solved. It is a challenging task to enable moving TN which means that variance of RSSI is so high and it is required to take the right information from fluctuated data. And a multi-hop scenario means considering the organized search including the task of moving TN for further investigation. Finally, it is expected that this study helps to take the right information from fluctuated data.

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