Approaching a Target using a Protection Feature based on Received Signal Strength Indicator

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Abstract: The received signal strength indicator (RSSI) which can be obtained during wireless communication, depending on communication distance, and is used to estimate the distance between a sender and receiver. We focus on the RSSI to determine whether a mobile node is approaching or departing from a target node (TN). To determine approach or departure, we implement the protection step number (PSN) as a protection feature that determines approach or departure when RSSI varies N times of the PSN in a row. N is designed according to RSSI deviation, and the value is computed statistically. In this paper, we demonstrate a method for approaching a TN based on RSSI with and without the proposed PSN.

1 INTRODUCTION

1.1 Background and Motivation

Recently, interest in ad-hoc communication, which can enable communication between wireless devices, has been increasing. Wireless devices utilize a non directional antenna to communicate in any direction in ad-hoc communication. It can be useful during a natural disaster as an emergency request from a disaster victim can be received via ad-hoc communication(Toh, 2001)(Mase and Sakata, 2007). However, it is difficult for rescue teams to approach disaster victims if there is a lack of location information relative to the disaster victims. Thus, we focus on the received signal strength indicator (RSSI), which can be obtained during wireless communication. In theory, RSSI is an ordinal scale(Stevens, 1946) that is inversely proportional to the square of communication distance in theory(Friis, 1946). Therefore, the magnitude relationship of the RSSI value represents distance. The varying strength of the RSSI value can determine whether one is getting closer o further away from a disaster victim. Therefore, we study how wireless devices that receive an emergency request (mobile node, MN) approach a disaster victim's requesting wireless device (target node, TN).

1.2 Problem Statement

We consider the following problems.

- It is difficult to determine approach or departure, i.e., moving toward or away from the TN, respectively, by comparing between RSSI value because they can change significantly in the same environment due to seasonal and weather changes(Rappaport et al., 1996).
- It is difficult to estimate the direction of arrival (DoA) because wireless devices employ non-directional antennas(Carr, 1993).

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

1.3 Objective

When moving to a TN using varying RSSI strengths depending on measurement points, a protection feature is implemented to determine approach/departure (approach/departure determination). We propose the protection step number (PSN) as a protection feature to prevent erroneous determination and reduce the probability of moving in the wrong direction. This number is designed statistically in consideration of the current environment. To study an MN moving to a TN based on RSSI, we assume that the MN and TN

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can communicate directly. In this study, we evaluate an MN approaching a TN using the PSN 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 determination and the PSN are also discussed in the Section 3. Section 4 presents various simulation results, including a comparison between the proposed method and unused it. Section 5 discusses the results of computer simulations, and conclusions are given in Section 6.

2 RELATED WORK

In order to approach a TN, the following three elements are considered.

(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(Čapkun et al., 2002; Niculescu and Nath, 2001; Priyantha et al., 2001; Niculescu and Nath, 2003), 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 value. The trilateration method requires more than three anchor nodes ,whereas the proposed method uses only two nodes to approach the TN. (b) Estimation of DoA based on RSSI. Transmitter hunting is an activity in which participants use radio-direction-finding techniques to locate one or more radio transmitters hidden within a designated search area(Harker, 2008). Note that general wireless devices supporting ad-hoc communication use non directional antennas. The hardware used in transmitter hunting differs from that used in ad-hoc communication. (c) Movement based on RSSI. We review studies about using mobile robots for search and rescue. Such mobile robots approach a TN using sensor nodes. The mobile robot moves randomly from P_1 and stops at one of P_2, P_3, P_4 or P_5 that is closer to the TN than P_1. The movement tracking and points $P_2 \cdots P_5$ are defined by the initial distance d to the TN, and the moving distance is $(1/2)$d. The mobile robot moves to this node by heuristic movement following RSSI-based distance estimation, and which is repeated(Li et al., 2012). In the literature(Li et al., 2012), the stopping of movement and change in moving direction are determined by the difference in RSSI-based distance estimation, however, no protection feature is used.

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. Therefore, these methods differs from the proposed method, which employs the protection feature.

3 PROPOSAL METHOD

3.1 Overview

Since RSSI values vary with the environment, the calibration of RSSI propagation model(Mao et al., 2007) or filtering to remove unwanted components (noise)(Pathirana et al., 2005) and the communication distance is required. This study employ an approaching method that uses approach/departure determination based on varying RSSI values 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 PSN as a protection feature is implemented for approach/departure determination. When the protection feature is used and the departure is determined N times in a row, the moving direction changes. Approach/departure are determined by decreasing and increasing RSSI values, respectively, N times of the PSN in a row, while the MN moves in a straight line from a to c. Then, the moving direction is changed at b' when determining approach using approach/departure determination. An overview is shown in Fig. 1. With this method, incorrect approach/departure determination is prevented and the probability of determining an incorrect moving direction is reduced. We evaluate an MN approaching a TN using the PSN according to approach/departure determination through computer simulation. The notations used in this paper are described in Table 1.

3.2 Assumption

The 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 the MN. In addition, the MN has the following capabilities.

- RSSI measurement
- Moving distance measurement
- Moving direction control

Table 1: Notations.

Name	Notation	Description
Mobile Node	MN	Node approaching TN
Target Node	TN	Node approached by MN
Step width	sw	Distance of one step
Maximum number of step times	$limax$	Maximum number of step times in one trial
RSSI	P_i	RSSI at i $(i = 0, 1, 2, 3, \cdots)$
SRSSI	SP_i	Smoothed RSSI at i
Reference value	Ref_{rssi}	Value to compare with P_i
Moving direction control amount	$mangle$	Amount of change in the moving direction
Protection Step Number	PSN	Protection feature to determine
Threshold	$limen$	Distance from TN to end the approach
Decreasing counter	$Counter_D$	Increment when P_i is decreased compared to Ref_{rssi} $(Counter_D = 0, 1, 2, 3, \cdots)$
Increasing counter	$Counter_I$	Increment when P_i is increased compared to Ref_{rssi} $(Counter_I = 0, 1, 2, 3, \cdots)$
Significance level	α	Value for significance test

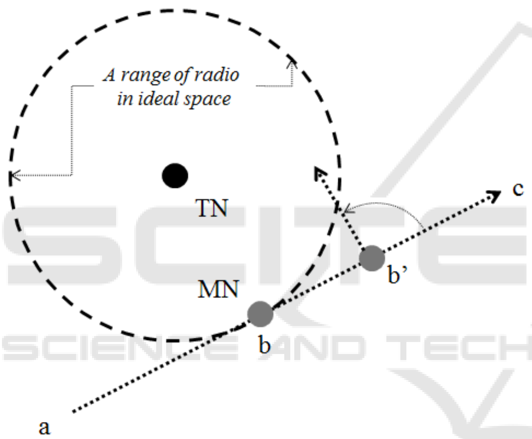


Figure 1: Overview of approach/departure determination.

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

3.3 Details

Here, we describe the TN based on RSSI using approach/departure determination. The approach procedure for the MN is described below. Fig. 2 shows a flowchart that describes the approach process.

1. $[i++]$ Update i.
2. $[Measure\,RSSI(P_i)]$ The MN measures RSSI (P_i) at i from the TN.
3. $[Set\,Reference\,RSSI]$ When starting the approach, P_i becomes the reference value (Ref_{rssi}).
4. $[Define\,Protection\,step\,number]$ PSN (N) is set.
5. $[Target\,Detection]$ Check whether the MN is within $limen$. If the MN is within $limen$, the simulation ends.
6. $[Compare\,RSSI]$ Compare P_i to Ref_{rssi}.

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

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

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

7. $[Update\,Ref_{rssi}]$ Compare each counter with N of the PSN. When $Count_D \geq N$ or $Count_I \geq N$, Ref_{rssi} is updated and both counters are reset as follows.

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

Then, Ref_{rssi} is selected as the minimum P_i between the current location $(t+N-1)$ and the location starting the counting (t) of $Count_D$ or $Count_I$. In order to prevent from occurring approach determination frequently, the minimum RSSI is selected.

$$Ref_{rssi} = min\{P_t, P_{t+1}, ..., P_{t+N+1}\} \quad (1)$$

8. $[Change\,direction]$ Execute the change in moving direction. The moving direction control amount $(mangle)$ is 0 when Count$_D < N$ or Count$_I < N$. $mangle$ is $\pi/2$ when Count$_D \geq N$. $mangle$ is 0 when Count$_I \geq N$ because the MN is approaching the TN. The MN moves in a counterclockwise direction.
9. $[Move]$ Move sw as a single step. One direction is selected when the approach process begins.
10. Repeat 1).

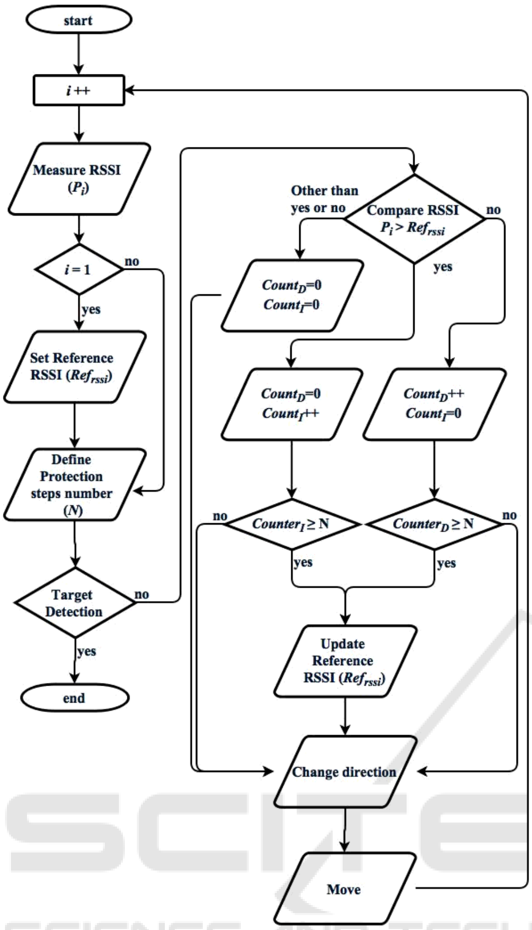


Figure 2: Flowchart of approach in processing for MN.

3.3.1 PSN in Approach/Departure Determination

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

The MN moves a single step and the probability of determining the MN is approaching or departing is 1/2 when comparing RSSI to Ref_{rssi}. We assume that the MN determines approach or departure N times sequentially and the PSN is N. The formula to calculate probability is $(1/2)^N$, and the significance level (α) is used, which is the probability of rejecting the null hypothesis. Thus, N is the minimum integer value.

$$\left(\frac{1}{2}\right)^N < \alpha$$

$$N > \frac{log_{10}(\alpha)}{log_{10}(\frac{1}{2})} \tag{2}$$

Note that α is set to 0.05 and then N becomes 5.

Due to varying RSSI values caused by environmental conditions, we assume that the deviation of RSSI is used for the PSN. This deviation is obtained as the mean deviation while the MN moves. The mean deviation (MD_i) at i is obtained from P_i and the smoothed RSSI (SP_i) at i. Then MD_i is changed to SD_i because the mean deviation is nearly equal to $1.25\times$ *standard deviation*(Jacobson, 1988), $SD_i\,[dB]$ can be obtained by MD_i in mW which is converted from dBm.

$$MD_i\,[dB] = |P_i\,[dBm] - SP_i\,[dBm]| \tag{3}$$

$$SD_i\,[dB] = 10log_{10}\,(0.8 \times MD_i\,[mW]) \tag{4}$$

SP_i is obtained by the nth RSSI from P_{i-n+1} to P_t in mW which is converted from dBm.

$$SP_i\,[mw] = \frac{1}{n}\sum_{t=i-n+1}^{i} P_t[mW] \tag{5}$$

$$SP_i\,[dBm] = 10log_{10}\,(SP_i\,[mw]) \tag{6}$$

where n is the number of samples and $i \geq n-1$ is satisfied. When i is less than $n-1$, $SP_i = P_i$. In this paper, the number of samples, n, is 3.

Here, we consider two PSNs. One is a fixed value, which is calculated statistically, and the other is based on the deviation of RSSI, which can be obtained while the MN moves. Thus, the PSN is an integer value selected as the maximum value of the two PSNs at i. Note that the PSN is defined as $N1$ as follows.

$$N1 \leftarrow \max\{SD_i, 5\} \tag{7}$$

We determine the approach to the TN when P_i increases from Ref_{rssi} $N1$ times in a row, and we determine departure from the TN when P_i decreases from Ref_{rssi} $N1$ times in a row. It is expected that $N1$ prevent incorrect determination from the varied P_i, i.e., the measured RSSI value.

3.3.2 Moving Direction Control

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

4 RESULT

Here, we evaluate the performance of the proposed method through computer simulation based on the PSN $(Eq.(7))$. First, we compare the incorrect approach determination rate using the PSN (P_i compared to Ref_{rssi}), not using the PSN (P_i compared to

P_{i-1}) and using the PSN (SP_i compared to Ref_{rssi}) to evaluate the PSN of $N1$. For approaching using the PSN with SP_i, Ref_{rssi} is selected as the minimum SP_i rather than P_i in Eq.(1). We then show the erroneous decision rate of approaching, the average MN moving distance, and the ratio between the average MN moving distance and the direct distance between the start point and the target relative to the start point.

4.1 Computer Simulation

The proposed model is evaluated by computer simulation which deals with the plane on which MN and TN are allocated and move. In addition, RSSI, which can be obtained during wireless communication, is simulated. RSSI is measured at i and is denoted by P_i.

4.1.1 Plane of Approach

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

4.1.2 MN

The 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 the MN determines P_i from the TN.

4.1.3 TN

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

4.1.4 Radio Propagation Model

The TN transmits signals such as a beacon signal, and the MN measures P_i. The radio propagation model uses a generic model, i.e., the variations in RSSI follow a log-normal distribution(Rappaport et al., 1996)(Fall and Varadhan,).

$$P_i[dBm] \sim \mathcal{N}(\bar{P_i}[dBm], \sigma_i^2) \tag{8}$$

$$\bar{P_i}[dBm] = P_0[dBm] - 10 \cdot \gamma \cdot log_{10}(\frac{d}{d_0}) \tag{9}$$

Here, P_i $[dBm]$ is RSSI measured at i and $\bar{P_i}$ $[dBm]$ is the average RSSI at i. σ_i^2 is the variance, i.e., the varied measurements of RSSI, and $\mathcal{N}(\bar{P_i}[dBm], \sigma_i^2)$ indicates a log-normal distribution of $\bar{P_i}$ and σ_i^2. P_0 $[dBm]$ is RSSI at reference distance d_0 $[m]$, and d_0 $[m]$ is 1 $[m]$. Thus, P_0 using a free space model(Friis, 1946) (frequency: 2.4 $[GHz]$, transmitting power: 10 $[mW]$(Porcino and Hirt, 2003), antenna gain: 1) as -30.05 $[dBm]$. d $[m]$ is communication distance, and γ is the path loss exponent. It is assumed that d and γ are unknown parameters in the MN and TN. The parameters used in Eq.(8) are listed in Table 2.

Table 2: RSSI parameters.

σ_i^2	Variance	3^2, 6^2, 9^2, 12^2 $[dB]$
P_0	RSSI at reference distance	-30.05 $[dBm]$
d_0	Reference distance	1 $[m]$
γ	Path loss exponent	2

Table 3: Simulation parameters.

Parameter	Using PSN	Unused PSN
sw	0.5 $[m]$	0.5 $[m]$
$limax$	5000 $[times]$	5000 $[times]$
$limen$	5 $[m]$	5 $[m]$
$N1$	$max(SD_i, 5)$	*Not used*
$mangle$	0 or $\pi/2$	0 or $\pi/2$

4.1.5 Threshold to Terminate Approaching

It is assumed that the TN can be confirmed visually when the MN approaches it within a certain threshold. When the MN approaches the TN within the threshold, the approach is terminated.

4.2 Simulation Setup

The proposed method was evaluated using Visual C++ 2013. In this simulation, an MN and a TN were positioned on the plane of approaching. The MN started from the following start points respectively: in $x-y$ plane, $\{x,y\}$=$\{100,100\}$, $\{90,90\}$, $\{80,80\}$, $\{70,70\}$, $\{60,60\}$, $\{50,50\}$, $\{40,40\}$, $\{30,30\}$, $\{20,20\}$. This is a range that the MN can receive the signal from the TN in roughly maximum -100 $[dBm]$.

The TN is allocated at the origin $(0,0)$ at $x-y$ plane and the TN is fixed.

Table 3 used in the simulation. The simulation was performed 100 times for each starting point.

4.3 Results with and without PSN

The simulation was performed with and without the PSN (Section 4). Figure 3 shows the erroneous decision rate of approach with using the PSN (P_i compared to Ref_{rssi} per σ^2 in Eq.(8)), and Fig. 4 shows

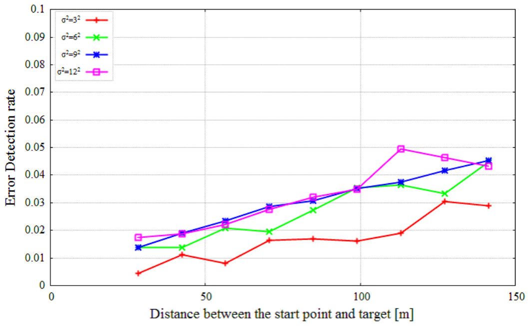


Figure 3: Erroneous decision rate of approach with the PSN with P_i compared to Ref_{rssi}.

the erroneous decision rate of approach without the PSN (P_i compared to P_{i-1} per σ^2 in Eq.(8)). Figure 5 shows the erroneous decision rate of approach using PSN (SP_i compared to Ref_{rssi} per σ^2 in Eq.(8)). In these figures, the horizontal axis is the distance between the start point and the target $[m]$ and the vertical axis is the error determination rate. As can be seen, the erroneous decision rate of approach using the PSN with P_i is less than 0.05. This result was expected because the PSN was set to the maximum value in this simulation, i.e., either SD_i of the deviation or α of significance level is 0.05. The erroneous decision rate of approach without the PSN was approximately 0.5, and the erroneous decision rate of approach with the PSN with SP_i was approximately 0.05 to 0.1. Approaching without the PSN is whether the approach or departure was determined by compared to P_{i-1} measured at a previous step. For approaching using the PSN with SP_i rather than P_i, the erroneous decision rate increases. Next, the approach failure rate with and without the PSN were compared. The results per σ^2 in Eq.(8) are shown in Table 4. If the MN could not enter $limen$ within $limax$, the attempt was considered a failure. The failure rate was computed as (failed attempts/total attempts) per σ^2. All attempts with the PSN were successful, and the failed attempts occurred without the PSN.

This result indicates that the PSN of $N1$ prevented incorrect determination for an MN when the determination is based on RSSI. Hereafter, approach with the PSN using P_i is considered and is referred to as "approach with the PSN".

In the next section, we evaluate the approach with the PSN.

4.4 Average Moving Distance

The average MN moving distance is shown per σ^2 in Eq.(8) in Fig. 6. In the figure, the horizontal axis is the distance between the start point and the target $[m]$ and the vertical axis is error average moving distance

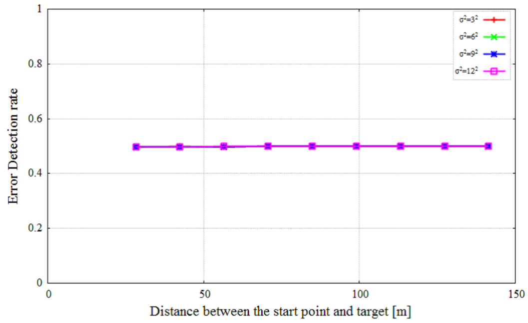


Figure 4: Erroneous decision rate of approach without the PSN with P_i compared to P_{i-1}.

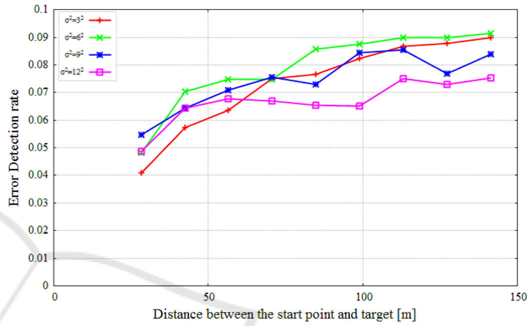


Figure 5: Erroneous decision rate of approach with the PSN with SP_i compared to Ref_{rssi}.

Table 4: Failure rate of approach with and without the PSN.

σ^2	3^2	6^2	9^2	12^2
Using PSN	0	0	0	0
Unused PSN	7	24.67	39.78	47.89

Unit: [%]

$[m]$. As the start point becomes closer to the TN, the moving distance decreases, and we can confirm that the moving distances has a proportionate relationship to the distance between the start point and the target.

In the next section, the relationship between moving distance and the distance between the start point and the target is described.

4.5 Ratio between Moving Distance and Distance between Start Point and Target

The ratio of average moving distance to the distance between the start point and the target is shown per σ^2 in Eq.(8) in Fig. 7. In the figure, the horizontal axis is the distance between the start point and the target $[m]$ and the vertical axis is the ratio between the moving distance and the distance between the start point and

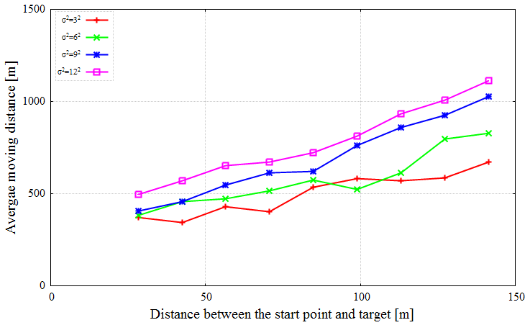


Figure 6: Average MN moving distance.

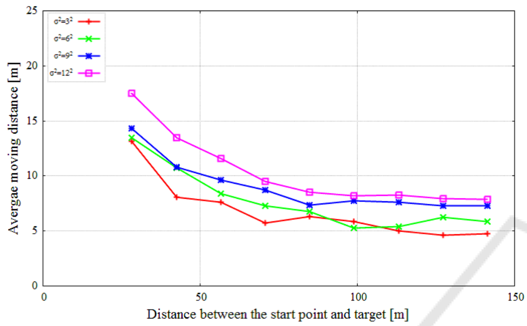


Figure 7: Ratio between moving distance and the distance between the start point and target.

the target. As the start point comes closer to the TN, this ratio increases to be greater than 10. As can be seen, the MN could approach the TN efficiently when the MN started at a point that was distant from the TN.

4.6 Movement Locus

Example of movement loci of the average moving distance when the MN approached per σ^2 in Eq.(8) are shown in Fig. 8. In these samples, the MN started from $\{x,y\} = \{100, 100\}$ on the $x-y$ plane.

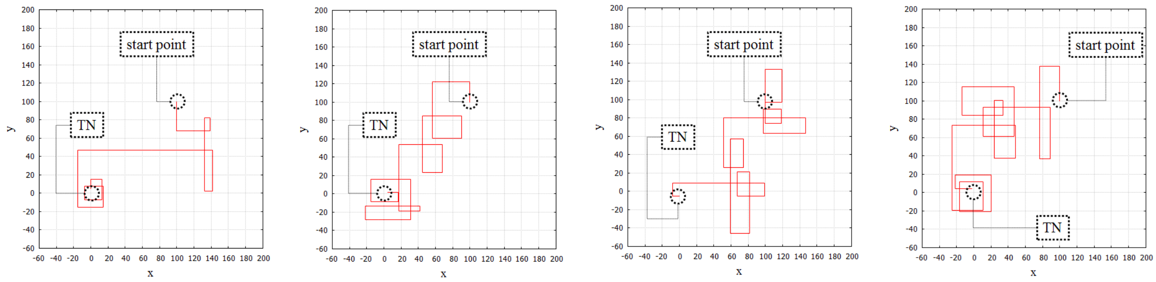
5 DISCUSSION

As shown in Table 4, the MN could enter *limen* and approach the TN when the PSN is used. We identified that using PSN reduced the probability of incorrect approach determination (Fig 3 and 4). The PSN was designed as a protection feature to determine the approach to or departure from the TN. The value of PSN varied depending on the environment. The PSN should be small if the environment is favorable, e.g., σ^2 in Eq.(8). In fact, the failure rate of σ^2 equal to 3^2 was the least, which is confirmed in Table 4. Therefore, the PSN was designed to use the value obtained by testing α at 0.05 and SD_i considering the environment, and the maximum PSN value was selected from the two. Thus, the PSN of $N1$ was a variable value, which chose the maximum value of 5 or SD_i. The MN could successfully approach the TN within *limen* when using $N1$; thus, we can confirm that the moving distances demonstrate a proportionate relationship to the distance between the start point and the target, as shown in Fig. 6. On the other hand, when the MN approached the TN, the MN demonstrated a moving distance of approximately $6 \sim 7$ times he distance between the start point and the target when the start point was more distant from the TN. However, the MN demonstrated a moving distance approximately 10 times greater when the start point was close to the TN than when the start point was distant from the TN, as shown in Fig. 7. This is a limitation of using a PSN of $N1$; however, this result shows that approach/departure determination works well with the PSN values based on varying RSSI value.

6 CONCLUSION

In this paper, we have proposed an approach/departure determination method based on varying RSSI values. The proposed method was evaluated using computer simulation. A key concept of this method is the use of a PSN as a protection feature. The PSN was implemented to determine approach/departure and was set to a maximum value of either SD_i of the deviation or α of the significance level as 0.05. In our evaluation, an MN and a TN were positioned on an $x-y$ plane with two-dimensional lattice. The moving direction changed when departure was determined, and remained unchanged when approach was determined. As a result, we can confirm that the MN could successfully enter into *limen* (i.e., a distance threshold), which means that the MN approached the TN when the PSN was used.

In the future, we plan to device a method for approach/departure determination that considers geographical and environment conditions during a natural disaster. The primary study target is wireless devices, which communicates directly; however, it can be expected approach in the wide-area by using ad-hoc communication because numerous wireless devices can collaborate to increase the range of communication. In addition, a quicker approach can be expected because of collaboration among a greater number of wireless devices.



(a) $\sigma^2 = 3^2$ (b) $\sigma^2 = 6^2$ (c) $\sigma^2 = 9^2$ (d) $\sigma^2 = 12^2$

Figure 8: Examples of MN's movement loci.

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