Room-Level Proximity Detection Using Beacon Frame From Multiple Access Points

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***Abstract*—Proximity detection, a technique to recognize if users exist nearby, is attracting a lot of attentions nowadays. The information for proximity of users can be an indicator of users' reliability. Some methods of proximity detection, without localization of users, utilize similarity of received signals such as FM, bluetooth, Wi-Fi, and ambient sounds. However, ambient sounds can be similar even when users are not nearby and the available range of proximity detection in the methods utilizing other signals is limited and varying from half of the wavelength to 2 m. The purpose of this study is to realize room-level proximity detection without localization: we propose a method based on similarity of received signal strength (RSS) of beacon frames received from ambient multiple access points. Through experiments, in which we recognize whether or not users exist in the same room with a size approximately equal to 5 m square, we demonstrate that our proposed method can be applied to room-level proximity detection.**

I. INTRODUCTION

Nowadays, a technique to recognize whether or not users are nearby is attracting attention: this technique is called proximity detection. Since the information that users exist in proximity can be one of the indicators of users' reliability in addition to ID and password, proximity detection is expected to be applied in authentication systems. For example, in general, we connect to an AP in a laboratory or an office by entering a password assigned for each access point (AP). Thus, if the password is leaked, someone in nearby rooms or offices can connect to the AP. In this situation, proximity of users can be used as an additional authentication information to improve security. In this paper, we assume that users who are in the same room are legitimate ones and those who are not are malicious ones trying to access the service with limited service area within the room. The purpose of this study is to recognize whether or not users are in the same room for improvement of security in authentication system, which we refer to as room-level proximity detection.

In the case of using location information of user, there can be security threats such as illegal access by faking location information. Also, in indoor or underground environments, since there is a large error of location estimation acquired by utilizing global positioning system (GPS) or cellular phone base stations, unexpected users can be recognized as legitimate ones. Furthermore, the problem of privacy protection arises by disclosing location information. Hence, it is required to avoid using location information of users in proximity detection.

Some methods of proximity detection, without localization of users, utilize various signals. In [1], received signal strength (RSS) of bluetooth sent by one user to another user are utilized. Proximity detection based on the similarity of TV and FM signal fluctuation over time is proposed in [2]. Euclidean distance [3] and time correlation [4][5] of RSS from Wi-Fi signals are adopted as an indicator of similarity. Although these methods can be applied when a user wants to detect other users existing in a relatively narrow range varying from half of the wavelength to 2 m, it is difficult to apply them to room-level proximity detection that requires wider available range of proximity detection. In [6] and [7], similarity of frequency spectrum of ambient sound is utilized. The available range of proximity detection of these methods is wider than that of the above methods. However, they have security vulnerability: ambient sound can be highly similar even if users are in different spaces.

In this paper, to realize room-level proximity detection without localization of users, we propose a method based on RSS of beacon frames received from ambient multiple APs, which are pervasive devices in many public facilities such as universities, stations, airports, and so on. This proposed method extracts RSS ratio of beacon frames sent from ambient multiple APs which both users receives as an indicator of signal similarity. This makes it difficult for users outside proximity range to disguise received information of beacon frames from these specific APs. Furthermore, By utilizing beacon frames from multiple APs, our proposed method is less likely to be affected by the relative location of APs and each user. Experiments in rooms with a size approximately equal to 5 m square are conducted to show that our proposed method improves security and expands available range in proximity detection compared to the conventional ones.

The remaining of this paper is organized as follows. Section II presents the protocol of proximity detection. Section III details the proposed method of proximity detection. Section IV shows experimental results. Section V concludes the paper.

TABLE I
EXAMPLE OF RECEIVING INFORMATION OF BEACON FRAMES FROM MULTIPLE ACCESS POINTS.

User	Access point	1	2	3	4	5	6
Alice	Number of beacon frames	N_1^A	N_2^A	N_3^A	N_4^A	0	0
	Mean RSS (mW)	m_1^A	m_2^A	m_3^A	m_4^A	-	-
Bob	Number of beacon frames	0	N_2^B	N_3^B	N_4^B	N_5^B	N_6^B
	Mean RSS (mW)	-	m_2^B	m_3^B	m_4^B	m_5^B	m_6^B

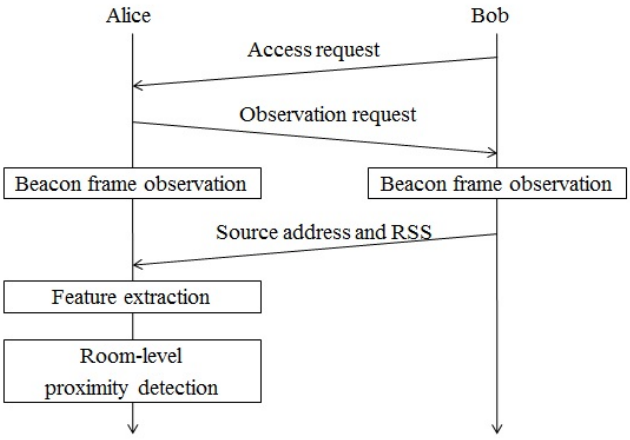

Fig. 1. Protocol of the proximity detection in our proposed method.

II. PROTOCOL OF PROXIMITY DETECTION

In this section, we consider two mobile users called Alice and Bob, who have mobile devices such as laptops or smartphones that can connect to Wi-Fi. We assume the case that Bob wants to access to a service provided by Alice with a limited service range within the room she is in. Alice allows Bob to access the service by recognizing whether or not he is in the same room as she is. There are some ambient APs around them, and each user receives beacon frames sent from these APs.

Fig. 1 shows the protocol of our proposed method that consists of following steps.

i) Bob sends an access request to Alice.
ii) After receiving access request from Bob, Alice sends observation request to Bob.
iii) Alice and Bob observe beacon frames for specified time. Then, they calculate the mean of RSS from beacon frames sent from each AP (received information).
iv) Bob sends received information to Alice.
v) Alice extracts a feature indicating similarity of RSS and recognizes whether or not Bob exists in the same room as she is by comparing with a predetermined threshold, which is discussed further in section III.

Notice that a beacon frame is sent from APs every 100 msec to let wireless devices know their existence. In this protocol, Alice and Bob never disclose their location information. Also, since source address or RSS of beacon frames are largely different in each space or room mainly due to walls, it is quite difficult for a third-party outside the proximity range to estimate them.

III. RECOGNITION METHOD

As mentioned in Section II, users calculate the mean of RSS from beacon frames sent from each AP after the observation. We define m_p^X as the mean of RSS from beacon frames that the user X receives from the AP p. It is given by

$$m_p^X = \frac{1}{N_p^X} \sum_{i=1}^{N_p^X} x_p^X(i) \tag{1}$$

where $x_p^X(i)$ and N_p^X are the RSS of the i-th beacon frame and the number of beacon frames that the user X receives from the AP, during the observation, respectively.

Here, we define an AP from which both Alice and Bob receive beacon frames as a shared AP. For example, we assume that there are six APs around Alice and Bob. TABLE I shows the number of beacon frames and the mean of their RSS that Alice and Bob receive from each AP. In this case, Alice receives beacon frames from AP 1, AP 2, AP 3, and AP 4, while Bob receives beacon frames from AP 2, AP 3, AP 4, AP 5, and AP 6. Therefore, the shared APs are AP 2, AP 3, and AP 4.

As for the shared AP s, we define a ratio of RSS r_s as

$$r_s = \begin{cases} \dfrac{m_s^A}{m_s^B}, & \text{if } m_s^A \geq m_s^B, \quad (2) \\ \dfrac{m_s^B}{m_s^A}, & \text{otherwise.} \quad (3) \end{cases}$$

In an environment where APs exist uniformly, it is assumed that there are some shared APs if Alice and Bob are within a certain range. In this case, we can evaluate the mean of r_s of all shared APs R_{ave} as

$$R_{ave} = \frac{1}{|\mathbf{S}|} \sum_{s \in \mathbf{S}} r_s \tag{4}$$

where $\mathbf{S}$ is the set of shared APs. This feature is utilized in our proposed method to judge whether users are in the same room or not.

The reason why our proposed method observes beacon frames sent from multiple APs is that if we utilize beacon frames sent from only one AP observed by both Alice and

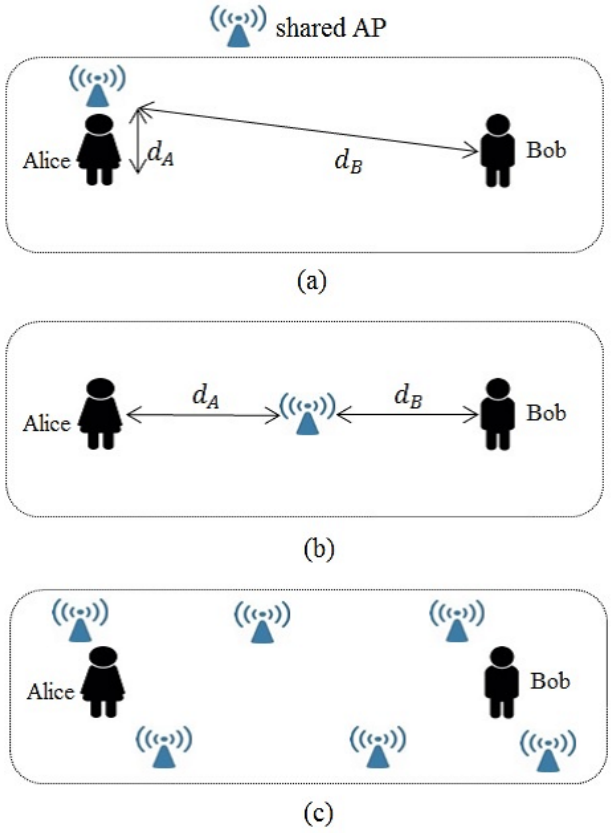

Fig. 2. Relative location of shared APs and Alice and Bob. (a) Only one AP is near Alice. (b) Only one AP is in the middle of Alice and Bob . (c) APs are placed uniformly around both users.

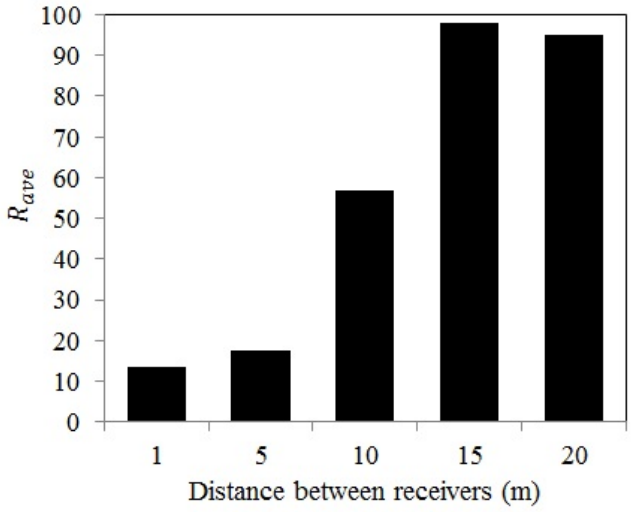

Fig. 3. The relation of R_{ave} and distance between two receivers.

TABLE II
EXPERIMENTAL SPECIFICATIONS

Number of observations	100 / case
Time of observation	5 sec / observation
Frequency	2.412 GHz

Bob, r_s can be largely influenced by the relative location of AP and users. For example, in the case of Fig. 2 (a), r_s is assumed to be much larger than that of the case in Fig. 2 (b), since the relative distance $d_{\mathrm{A}} - d_{\mathrm{B}}$ in the case of Fig. 2 (a) is larger than that of the case in Fig. 2 (b), where d_{A} and d_{B} are distances between an AP and each user, respectively. However, in the case of Fig. 2 (c), where shared APs exist uniformly, R_{ave} is less likely to be influenced by the relative location, because the RSS ratio of each AP are averaged. This case can be often seen in an office or a laboratory.

It is assumed that the larger the distance between two receivers gets, the larger R_{ave} tends to be, because the total of the relative distance between all the shared APs and each user becomes larger, and because the radio propagation environment gets more and more different. To validate the assumption, we conduct experiments in an actual environment at the corridor in Keio university. Both sides of the corridor, there are laboratories and offices and multiple APs are placed uniformly. The relation of R_{ave} and the distance between two receivers in Fig. 3. From this figure, we can find that our assumption is correct when the distance of receivers within 15 m. Therefore, we set a condition that Alice and Bob are recognized to be in the same room as follows.

$$R_{ave} \leq th \tag{5}$$

where th is a threshold of R_{ave} defined in the preliminary experiment.

IV. EXPERIMENTAL RESULTS

We performed a preliminary experiment to determine the threshold of R_{ave}. Then, using this, we recognized weather or not two receivers (users) are in the same room in two different environments to evaluate our proposed method.

A. Experimental Specifications

As receivers, we use two laptops equipped with AirPcap [8] and wireshark [9] that can receive and analyze 802.11 signal. They provide us with received information of beacon frames such as source address, destination address, arrival time, RSS, and so on. We show experimental specifications, which are common in the preliminary experiment and evaluation experiments, in TABLE II. In this table, "case" refers to the location pattern of two laptops. The distance between two receivers is from 3 m to 6 m. The maximum number of beacon frames each laptop receives from each AP is 50, since they are sent by APs every 100 msec. In these experiments, two receivers observe beacon frames sent from established APs with unknown locations.

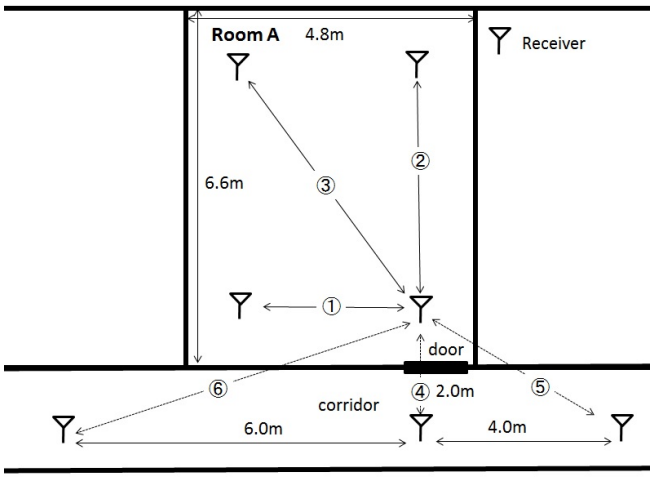

Fig. 4. Environment of preliminary experiment.

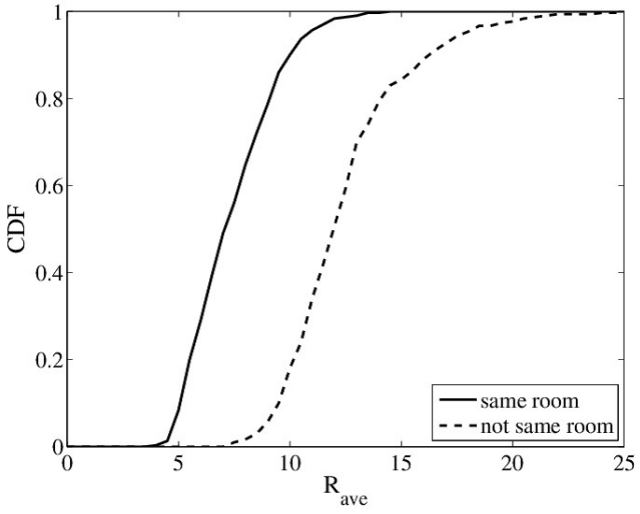

Fig. 5. CDF of R_{ave} over 300 observations in each scenario.

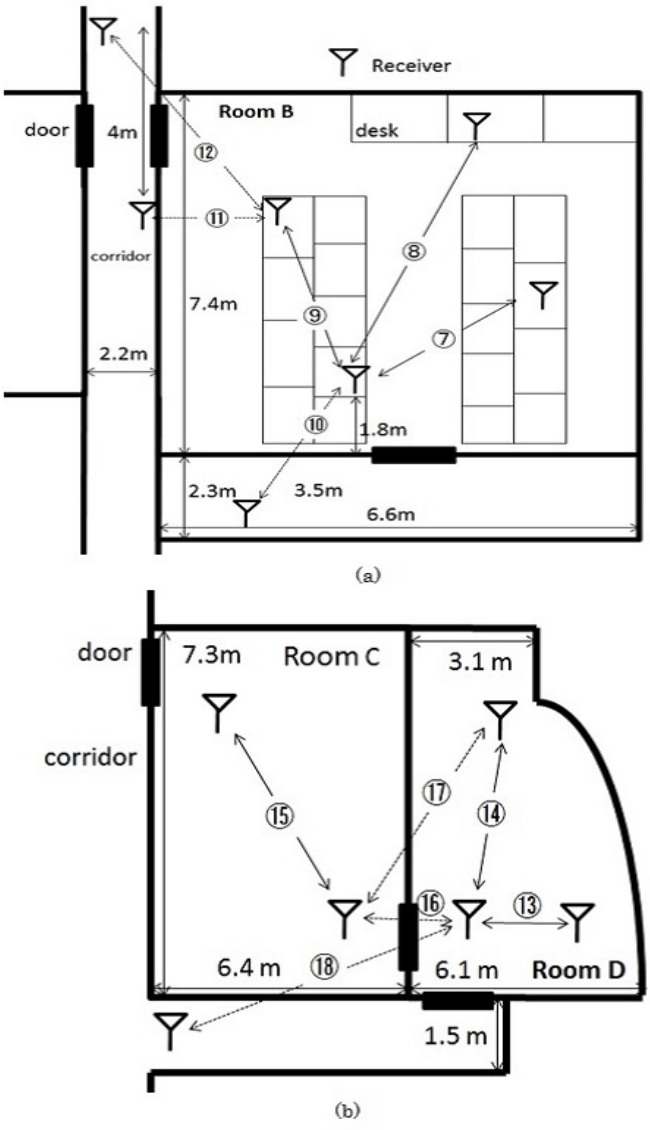

Fig. 6. Environment of evaluation experiments.

B. Preliminary Experiment

We show the environment of a preliminary experiment in Fig. 4. This experiment consists of two scenarios: one that includes three cases where two laptops exist in the same room (same room) and one that includes three cases where they do not exist in the same room (not same room), as shown in Fig. 4 as the circled numbers. Room A is surrounded with reinforced concrete walls with thickness of approximately 5 cm and there is only one observer seated.

Cumulative distribution function (CDF) of R_{ave} is shown in Fig. 5. This CDF is generated by 300 observations in each scenario. From this result, we can find that there is a difference in R_{ave} between the two scenarios.

We varied th to judge whether or not two laptops are in the same room by utilizing eq. (5) for each case. We observed that th equal to 9.6 yielded the highest accuracy of recognition. Here, recognition accuracy of each case can be written as

$$\text{Recognition accuracy} = \frac{L}{\text{Number of observations}} \times 100 \tag{6}$$

where L is the number of correct judgments, which means that when receivers are in the same room, they are correctly recognized as in the same room, and when they are not in the same room, they are correctly recognized as not.

C. Evaluation Experiments

Using the threshold determined by the preliminary experiment, we recognized whether or not two laptops are in the same room, which has a similar size that of room A in Fig. 4. These evaluation experiments were conducted in the two environments shown in Fig. 6 (a) and (b), which are different from that in the preliminary experiment.

TABLE III
RECOGNITION ACCURACY OF EACH CASE IN THE EVALUATION EXPERIMENTS

Environment	Scenario							
	same room				not same room			
	case	(i)	(ii)	Multiple APs	case	(i)	(ii)	Multiple APs
Fig. 6(a)	⑦	96%	76%	97%	⑩	0%	29%	100%
	⑧	57%	95%	98%	⑪	68%	58%	100%
	⑨	64%	100%	100%	⑫	100%	73%	100%
Fig. 6(b)	⑬	100%	98%	100%	⑯	100%	16%	96%
	⑭	100%	100%	100%	⑰	98%	29%	95%
	⑮	100%	91%	100%	⑱	63%	23%	100%

In Fig. 6 (a), room B is in a floor different from that where room A in Fig. 4 is. This room is surrounded by reinforced concrete walls with a thickness approximately equal to 5 cm. In the room B, there are some students working on their seats. In Fig. 6 (b), room C and room D are in a building different from that where room A and room B are. There is a glass walls with a thickness approximately equal to 5 cm between room C and a corridor, and there is a partition with a thickness approximately equal to 5 cm between room C and room D. In room C and the room D, there is only one observer sitting.

In the same way as in the preliminary experiment, there are two scenarios in each environment: one that includes three cases where two receivers exist in the same room and one that includes three cases where they do not exist in the same room, shown in Fig. 6 as the circled numbers. We evaluate the recognition accuracy in each case with eq. (6). To demonstrate the effectiveness of utilizing beacon frames with multiple APs, we evaluate the recognition accuracy when we select the only one shared AP for comparison. The ways of selecting it are as follows.

i) Select the shared AP from which two receivers receives the most beacon frames.
ii) Select the shared AP at random.

The recognition accuracy is shown in TABLE III. When we select the only one AP, the recognition accuracy is fluctuated between 0% and 100% depending on the cases. This indicates that utilizing the only one shared AP is largely influenced by the relative location of AP and receivers as mentioned in Section III. On the other hand, the recognition accuracy when we utilize multiple shared APs is higher than 95%. From these results, we can say that the proposed method realizes room-level proximity detection and that it is less likely to be influenced by the relative location of APs and receivers. However, when we apply this method of proximity detection to a security system such as authentication, the accuracy rate of 100% is required. In particular, it is dangerous that users not existing in the same room are recognized as if they are in the same room. For an authentication system, our proposed method would be useful to enhance the security of the system as additional authentication information along with the ID and the password.

V. CONCLUSION

In this paper, we proposed a method of proximity detection based on RSS of beacon frames from ambient multiple APs to realize room-level proximity detection that recognize whether or not users are in the same room. This method utilizes the mean of RSS ratio of beacon frames two users receives from each AP as an indicator of similarity of signal. Through experiments in a room with a size approximately equal to 5 m square, we performed a preliminary experiment and evaluation experiments. By utilizing threshold of feature value determined in the preliminary experiment performed in an environment where multiple APs are distributed uniformly, evaluation experiments performed in two environments different from the preliminary one showed that our proposed method achieved a recognition accuracy higher than 95%. Therefore, this proposed method realizes room-level proximity detection and it is less likely to be influenced by the relative location of APs and users.

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