

A Multilateration-based Localization Scheme for Adhoc Wireless Positioning Networks used in Information-oriented Construction

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Abstract—We have developed an adhoc wireless positioning network (AWPN) scheme for information-oriented construction that can temporarily and easily provide a positioning area in both indoor and outdoor environments. The particular requirements of AWPNS are easy deployment and easy configuration because the network should be removed on completion of construction and must frequently accompany the active construction section as it shifts from area to area. In this paper, we propose a localization scheme based on the multilateration method to fulfill the requirements of such AWPNS. The proposed scheme locally and dynamically calibrates the attenuation coefficient defined in the path loss model for radio wave propagation in order to reflect local, fresh propagation characteristics. The results of evaluations conducted on the efficacy of our proposed scheme indicate that it reduces the average error by 30% relative to the conventional approach.

Keywords—Information-oriented construction, adhoc wireless positioning network, IT color cone, multilateration, and path loss model.

I. INTRODUCTION

Information-oriented construction aims at creating a vast improvement in productivity, quality, and safety in construction by informatization of the construction process; e.g., building and tunnel construction. In information-oriented construction, one of the most important roles is effective management of construction resources such as workers, heavy construction machines, and materials. Figure 1 exhibits two management applications for effective scheduling of construction workers and avoidance of collisions between workers and machines on an actual construction site. A critical issue in realizing such management in a wide variety of construction sites is the localization technology available in both indoor and outdoor environments. Although global positioning system (GPS) technology is widely used as a localization technology in vehicles and mobile phones, it is not available in indoor environments such as tunnels and underground construction sites.

We have developed an adhoc wireless positioning network (AWPN) scheme that can temporarily and easily provide a positioning area, even in indoor environments. The particular requirements of AWPNS are easy deploy-

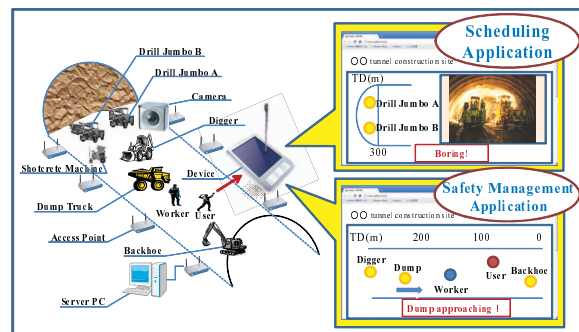


Figure 1. Example applications for information-oriented construction.

ment and easy configuration because the network should be removed on completion of construction and must frequently accompany the active construction section as it shifts from area to area. Thus, an AWPNS provides positioning capability on a wireless mesh network; i.e., the network constructed by multiple access points (APs) that are distributed over the positioning area, and that capture (or sniff) probe requests and/or data frames sent from a mobile device or a small tag with wireless-LAN communication. Each AP periodically transmits information concerning the captured frames, such as their receive signal strength indicator (RSSI) and source address, to a localization server connected to the network. The data transmissions from each AP to the server are routed through several intermediate APs using multi-hop communication. The localization server estimates the current position (or the current coordinates) of the mobile device using a localization algorithm based on the collected RSSI information.

In AWPNS, easy deployment is inherent in the nature of wireless mesh networks. It can be constructed only by deploying APs in the positioning area. In addition, in order to make the deployment more familiar to construction workers, we integrated the AP ability into a color cone, resulting in an IT color cone. This color cone is depicted in Figure 2.

For easy AWPNS configuration, we carefully selected

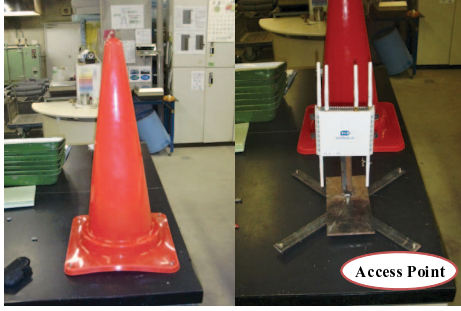


Figure 2. The IT color cone.

an RSSI-based localization algorithm, as the localization algorithm used has a direct effect on the complexity of the configuration. In this paper, we focus on a multilateration-based localization scheme that is suitable for AWPNS in terms of ease of configuration and accuracy. In the multilateration scheme, because the position of a mobile device is determined by its distances from three or more APs, the localization accuracy strongly depends on the distance measurement between a mobile device and an AP. The distance can be measured from the observed RSSI information by using the radio wave propagation path loss model. Thus, the attenuation coefficient defined in the path loss model needs to be calibrated according to the current propagation characteristics. In the conventional approach, the attenuation coefficient is determined beforehand and uniformly used in a given positioning area. However, the attenuation coefficient appropriate for positioning varies according to time and place.

In this paper, we propose a localization scheme based on the multilateration method that locally and dynamically calibrates the attenuation coefficient. In the proposed scheme, APs periodically send and receive beacons to and from each other, respectively. By analyzing the RSSI information for the received beacons, each AP determines its own attenuation coefficient to reflect its surrounding propagation characteristic. In addition, it periodically updates the attenuation coefficient to reflect the current propagation characteristic. The results of evaluations conducted on the efficacy of the proposed scheme indicate that it reduces the average error by 30% relative to the conventional approach.

The rest of this paper is organized as follows. Section II presents background technology and related work. In Section III, we report on a preliminary experiment conducted and discuss the results obtained. In Section IV, we explain our proposed scheme, and evaluate its efficacy in Section V. Finally, we conclude this paper in Section VI.

II. RELATED WORK

In this section, we first look at RSSI-based localization methods and discuss the signal path loss model that can be used to measure the distance between a transmitter and a receiver, and that is considered to be a basic technique in this paper. We then present relevant studies dealing with the multilateration method.

Many RSSI-based localization algorithms have been proposed during the last decade [1], [2], [3], [4]. These algorithms are mainly classified into three types: location fingerprinting algorithms, proximity algorithms, and multilateration algorithms. The location fingerprinting method can achieve high localization accuracy. However, with this method, a radio map of the entire positioning area has to be created beforehand, which means that the easy configuration requirement of AWPNS cannot be achieved. The proximity method can be introduced without this kind of complicated pre-configuration. However, its accuracy is relatively low. The multilateration method does not require complicated pre-configuration, i.e., it can be introduced merely by setting the positions of the deployed APs. In addition, it can achieve sufficient localization accuracy. Therefore, we focus on the multilateration method, which is suitable for AWPNS in terms of pre-configuration and accuracy.

In the multilateration method, the position of a mobile device is determined from its distances from three or more APs, i.e., it is located at the point of intersection of circles whose origins and radii are the positions of and distances from the APs, respectively. Thus, accurate distance measurement is essential in order to realize high localization accuracy. In the RSSI-based multilateration method, the distance can be measured from the observed RSSI values using the path loss model and the nature of the radio wave propagation. An RSSI value indicates the strength of a radio signal received by a receiver. Radio signals are attenuated as they propagate from transmitter to receiver. Therefore, an RSSI value is inversely proportional to the logarithm of the distance between them.

In the ITU-R recommendation [5], the total path loss L_{total} of signal propagation in indoor environments is represented as the following equation when the distance between two devices is d [m]:

$$L_{total}[dB] = 20\log_{10}f + N\log_{10}d + L_f(n) - 28, \quad (1)$$

where L_f and n denote signal attenuation loss due to the penetration of walls [dB] and the number of penetrated walls, respectively. In addition, f is the radio frequency [MHz] and N is the attenuation coefficient due to the distance (set to 20 in free space).

By using the path loss model represented in equation (1), the RSSI value is calculated from the transmission power P_t [dBm] as follows:

$$RSSI = P_t - L_{total}. \quad (2)$$

From equations (1) and (2), the following equation can be introduced:

$$\log_{10}d = \frac{RSSI - P_t + 20\log_{10}f - L_f(n) + 28}{N} \quad (3)$$

By using equation (3), the distance can be computed from the RSSI value.

A critical issue with the RSSI-based multilateration method is the determination of an appropriate attenuation coefficient (i.e., N) for the current propagation environment. In the conventional method, the attenuation

coefficient is calibrated beforehand by measuring RSSI values at known positions. After the calibration, the attenuation coefficient determined is statically and globally used in the entire positioning area. However, the attenuation coefficient needs to be dynamically calibrated and locally used because it strongly depends on unpredictable environmental factors.

Several determination schemes for attenuation coefficient have been proposed in the literature [7], [8]. In [7], the position of a mobile device is estimated using an attenuation coefficient parameter such that the evaluation value of the log likelihood function for equation (1) is maximized. In the approach taken in [8], anchors are deployed at known positions in the positioning area. The attenuation coefficient parameter and/or wall penetration loss are then calculated using the relationship between their distance from each other and the received RSSI. The localization accuracy can be improved by using these calculated parameters.

Other approaches taken to obtain accurate RSSI-based multilateration include [9], [10], [11]. In [9], the position is calculated as the mean of several points belonging to a cluster. Some methods to obtain the cluster of intersection points of circles that are formed, along with the estimated distance from the APs, are proposed. The approach in [10] seeks to mitigate the distance estimation errors caused by flip ambiguity. Flip ambiguity is a phenomenon that occurs when the selected APs used for localization is not appropriate. To mitigate flip ambiguity, a detection method is proposed. In [11], the proposed approach calculates node positions using three or more APs whose positions are known. The localization algorithm used, LELA, calculates node positions iteratively. To get the node positions in a certain iteration, it uses not only the positions of the APs, but also those node positions that were calculated in previous iterations.

III. PRELIMINARY EXPERIMENT

In the path loss model, the attenuation coefficient needs to be appropriately determined according to propagation characteristics. In this section, we look at how we confirmed the effect of locally- and dynamically-determined attenuation coefficients by means of preliminary experiments.

A. Effect of Locally-determined Attenuation Coefficient

First, we confirmed the effect of a locally determined attenuation coefficient. In this experiment, eight APs were deployed at known positions in a $13m \times 11m$ area on the second floor, Building II, Kyushu University, as shown in Figure 3. There were no obstacles between the APs. We used PicoCELA Inc., PCWL-0100 for the APs. The APs periodically sent and received beacons to and from each other, respectively. The beacon transmission interval was 1 s. To reduce the effects of random factors, each AP measured beacons for a period of 10 s and averaged the results. In this experiment, for each AP, we calculated an attenuation coefficient parameter using the RSSI values measured at the AP.

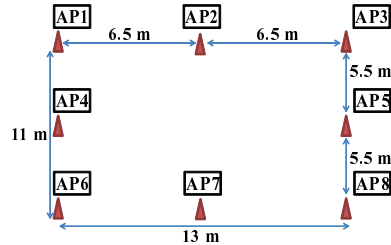


Figure 3. The preliminary experimental environment.

Table I
GRADIENT VALUE OF THE SLOPE OF THE APPROXIMATE LINES.

Slope	AP1	AP2	AP3	AP4	AP5	AP6	AP7	AP8
Gradient Value	-6.3	-13.2	1.2	0.6	0.5	-6.5	0.7	-8.4

Figure 4 graphically depicts our results in the form of plots of the RSSI values of the received beacons for each AP. In the figure, the x-axis represents the logarithm of the distance between the beacons' transmitter and receiver, while the y-axis represents the measured RSSI values for the beacons. As equation (1), the relationship between the logarithm of the distance and RSSI is linear. The straight lines represent linear approximations for the resulting measured RSSI values. Note that the slope of the regression line is the attenuation coefficient, as was described in equation (1). From the results, we observe that the relationship between distance and RSSI value is different for each AP. The slopes for AP1, AP2, AP6, and AP8 are steep, while those for AP3, AP4, AP5, AP6, and AP7 are gentle. To facilitate more detailed analysis, the gradient values for the slope are listed in Table I. In the table, it can be seen that the gradient of the slopes widely varies from -13.2 to 1.2. Hence, we can categorically state that the appropriate attenuation coefficient differs for each locality, i.e., each AP.

In the conventional method, a single attenuation coefficient is used globally over the entire positioning area. However, the results of this experiment indicate that in order to realize accurate distance measurements, locally-determined attenuation coefficients specific to each AP's surrounding propagation characteristic should be used.

B. Effect of Dynamically-determined Attenuation Coefficient

Next, we confirmed the effect of dynamically determined attenuation coefficient. In this experiment, we measured the RSSI values between two fixed APs during a period. In this experiment, we used the same experimental environment as that in Section III-A. To get each measurement, we measured the RSSI values for ten seconds. Six measurements were taken in each case, with an interval of approximately two minutes between two consecutive measurements. For each measurement, we derived the attenuation coefficient from the measured RSSI values.

Figure 5 shows the transition in the derived attenuation coefficients for each AP. From the figure, we confirmed

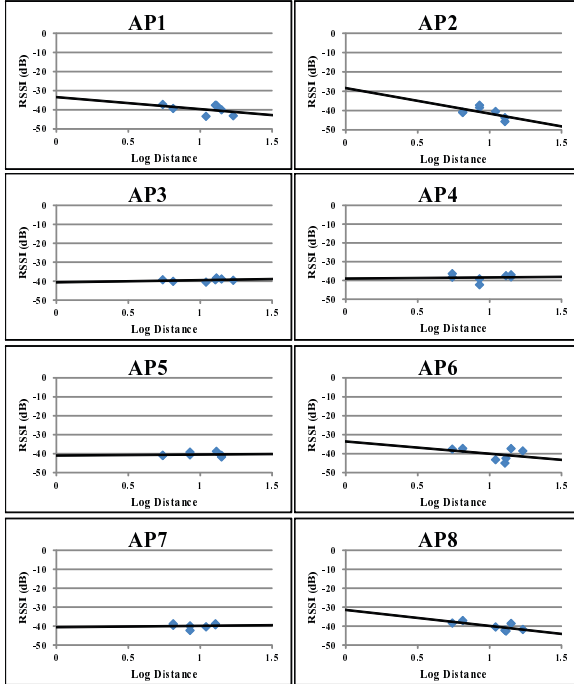


Figure 4. Differences in the slope of the approximate lines.

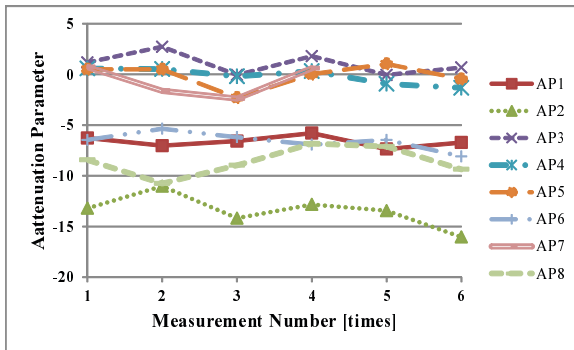


Figure 5. Transitions in estimated attenuation coefficients.

that the derived attenuation coefficients fluctuate over long time intervals, but changes only slightly over short intervals of time. In the conventional method, a single attenuation coefficient is statically used, i.e., the attenuation coefficient is calibrated beforehand during the calibration phase. However, the time lag between the calibration phase and the estimation phase causes degradation in the location estimation. Therefore, attenuation coefficients should be dynamically calibrated according to the current propagation characteristic in order to realize accurate distance measurements.

IV. PROPOSED LOCALIZATION SCHEME

In this section, we propose a localization scheme that extends the multilateration method by locally and dynamically calibrating an appropriate attenuation coefficient for

the current propagation environment, as was described in Section III. We give an overview of the proposed scheme and describe its procedure in detail.

A. Overview

In the proposed scheme, the deployed APs periodically send and receive beacons to and from each other. The APs calculate attenuation coefficients using the RSSI information associated with the beacons they receive. Hence, our proposed scheme can locally and dynamically determine appropriate attenuation coefficients.

More concretely, to realize locally-determined attenuation coefficients, each AP determines its own attenuation coefficient to reflect its surrounding propagation characteristic by analyzing the RSSI information associated with the beacons it receives from the other APs. This is in contrast to the conventional method, in which one attenuation coefficient is uniformly used. In addition, as the attenuation coefficients are dynamically determined, they can be periodically updated by using the beacons that are periodically received.

B. Procedure

The procedure used in our proposed multilateration scheme is as follows:

1) AWP construction

First, an AWP is constructed in the desired area by deploying APs and registering the positions of the deployed APs with the localization server. The localization server can then obtain the distance between any pair of APs from the registered data.

2) Data observation

APs periodically send and receive beacons to and from each other – a basic function compliant with IEEE802.11 standards. In general, the period of beacon transmission is 100 ms. Each AP can observe the RSSI information associated with the received beacons and also probe requests and data frames transferred from the mobile device to be located.

3) Parameter calculation

For each AP, an attenuation coefficient is computed from RSSI values and the distances between the APs as a slope of regression line using equation (1) and the least squares method. The RSSI values are the average of the beacons received from its surrounding APs, and the distances are obtained from the positions of APs. This calculation is periodically repeated using the latest RSSI information for a period and then the attenuation coefficient is updated.

4) Distance estimation

Using the most recently derived attenuation coefficient, the distance between each AP and the mobile device is estimated using equation (3).

5) Position estimation

The position of the mobile device is estimated by constructing simultaneous equations for the distance and the average RSSI value for each AP, and solving them.

In the next section, we explain the position estimation step used in the above procedure.

C. Position Estimation

For positioning in two-dimensional space, the position (x, y) of a mobile device is estimated by solving the following simultaneous equations based on equation (1) when the position of the i th access point, $AP_i (i = 1, 2, \dots, m)$, is (x_i, y_i) :

$$\begin{cases} rssi_1 = -20\log_{10}f + N_1\log_{10}r_1 - L_f(n) + 28 + C \\ rssi_2 = -20\log_{10}f + N_2\log_{10}r_2 - L_f(n) + 28 + C \\ \vdots \\ rssi_m = -20\log_{10}f + N_m\log_{10}r_m - L_f(n) + 28 + C \end{cases}$$

where $rssi_i$ and N_i represent the observed RSSI values and the locally determined attenuation for AP_i , respectively. We introduce an error parameter C to mitigate the impact of RSSI variation caused by the difference of transmission power between APs and a mobile device. In addition, r_i is defined as follows:

$$r_i = \sqrt{(x_i - x)^2 + (y_i - y)^2}. \quad (4)$$

Therefore, we solve a set consisting of three or more simultaneous equations, i.e., the mobile device should be observed by three or more APs. Because these equations are non-linear, the position is obtained asymptotically using Newton's method.

V. EVALUATION

In this section, we evaluate the efficacy of our proposed method.

A. Experimental Setup

In this experiment, we used the indoor space depicted in Figure 6, which shows the positions of APs and the positioning points of a mobile device. The mobile device placed at each positioning point transmits probe requests and its position is estimated. We used the same APs as those utilized in Section III and used an Android Nexus S mobile device. The APs transmitted beacons every 100 ms and the mobile device transmitted a probe request every 1 s. The APs received beacons and probe requests for a period of 10 s in a trial and used average values to estimate position. There was no wall in the evaluation environment, so we assume that wall penetration loss (i.e., L_f) is 0.

We compared the localization accuracy for three multilateration-based approaches. The first approach is a conventional approach that uses statically- and globally-determined attenuation coefficient. The second approach is our proposed scheme, which uses locally- and dynamically-determined attenuation coefficient. The third approach is an extended version of our proposed approach, in which APs with attenuation coefficients larger than -2.0 are eliminated.

We defined two performance metrics for localization accuracy:

- Average error

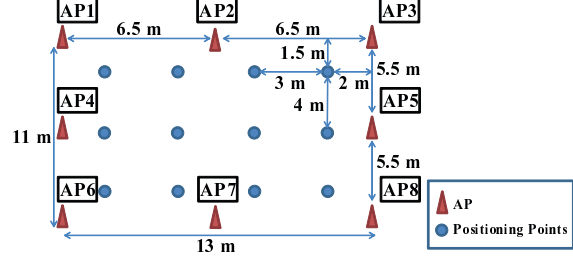


Figure 6. The evaluation environment.

Table II
COMPARISON OF AVERAGE ERROR FOR THREE APPROACHES.

	Conventional method[m]	Proposed scheme[m]	Proposed elimination method[m]
1 time	11.2	5.9	7.0
2 times	10.0	8.2	9.6
3 times	10.7	7.7	9.1
4 times	10.1	7.2	7.7
5 times	9.9	7.4	9.3
Average	10.4	7.2	8.5

Average error represents the average of the errors between the estimated position and the correct position.

- Cumulative error ratio

Cumulative error ratio indicates the probability of the estimation error is less or equal to a given value.

B. Results

The result for five trials is summarized in Table II. From the table, it can be seen that our proposed scheme reduced the error by an average of 30% relative to the conventional method; the average error for our proposed scheme was 7.2 m, while it was 10.4 m for the conventional method. This results come from the fact that our proposed scheme can deal with variations in radio attenuation by using locally- and dynamically-determined attenuation coefficients. The average error for the proposed elimination method however, increased in comparison with our proposed scheme, although it was still better than that for the conventional method.

Figure 7 shows the result of the cumulative error ratio for the three approaches. The result of the cumulative error ratio is similar to that of the average error, i.e., our proposed scheme achieved the best performance among the localization methods. It can be seen that when the average error was 5 m, the cumulative error ratio was 28% for our proposed scheme, as opposed to 7% for the conventional method.

In these experiments, the proposed elimination method did not achieve a better performance than the proposed scheme. In the proposed elimination method, we regarded an AP as unnecessary if the AP estimated a small value for its own attenuation coefficient. However, even such APs provide useful information on localization accuracy.

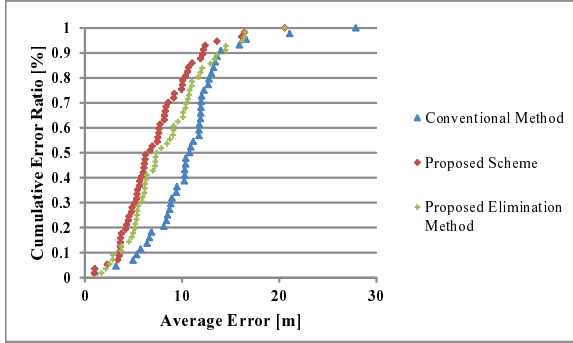


Figure 7. Result of cumulative error ratio.

VI. CONCLUSION

In this paper, we proposed a multilateration-based localization scheme for easily realizing adhoc wireless positioning networks in the field of information-oriented construction. In the conventional multilateration method, a statically- and globally-determined attenuation coefficient is used for the radio path loss model. However, the optimum attenuation coefficient is dependent on environmental dynamics; i.e., the attenuation coefficient needs to be dynamically and locally determined. We demonstrated that locally- and dynamically-determined attenuation coefficients have an effect by means of a preliminary experiment. In this paper, we proposed a localization scheme that extends the multilateration method by locally and dynamically calibrating an appropriate coefficient for the current propagation environment. In addition, we evaluated the efficacy of the proposed scheme. The results obtained indicate that the average error was reduced by 30% relative to the conventional multilateration method.

In the future, we will focus on the following: First, in this paper, we considered the locality for the attenuation coefficient. Directions between APs are also important factors in the determination of the attenuation coefficient. We plan to take directions between APs into consideration in our proposed scheme. Second, one of the requirements for an AWPN is easy configuration. However, we currently need to know the positions of the deployed APs. We would like to make this procedure easier. One way to address this issue is to obtain the positions of APs by using other positioning devices rather than wireless LAN devices. Finally, in this paper, we confirmed the efficacy of our proposed scheme. However, the average error is not yet sufficient for information-oriented construction. To realize safety management in the field of construction, high localization accuracy is required. We therefore plan to further improve the localization accuracy for AWPNS.

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