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Improving the Positioning Accuracy using Virtual Access Points in the Border Area

MyungIn Ji, Youngsu Cho, Jooyoung Kim, Yangkoo Lee, Sangjoon Park
Electronics and Telecommunications Research Institute
Positioning Information Technology Research Team
Daejeon, Republic of Korea
{myungin, choys, kimjy, yk_lee, sangjoon}@etri.re.kr

***Abstract*—In this paper, we introduce a Border Effect Problem and mitigation algorithm that can be applicable for Weighted Centroid Localization (WCL) based indoor positioning system. First, we generate virtual APs based on a terminal's initial estimated position by symmetrically flipping real APs position and their RSSI. Then we re-estimate terminal's position using both real APs and the selected virtual APs until it converges. We verified our proposed method mitigates the problem effectively through various simulation scenarios and their results.**

Keywords-Indoor Positioning; WPS, Weighted Centroid Localization, Border Effect Problem

I. Introduction

Weighted Centroid Localization (WCL) is a one of the simple approach for indoor positioning, which calculates the weighted sum between access points' position and corresponding received signal strength. In general, WCL is more suitable for terminal-based (e.g., smartphone) positioning system rather than server-based (e.g., fingerprint) system, since its small amount of access points location DB and computational process.

However, by its own calculation characteristics, WCL has disadvantage of increasing localization error in the border area (such as boundary of the building). Generally, it called the Border Effect Problem.

In this paper, we present reasons for this problem, and to mitigate this effect, we use virtual access points. First, we create virtual access points (vAP) around the terminal's initial estimated position. This position is calculated by existing (real) access points (rAP) with basic WCL algorithm. vAPs are generated geometrically symmetrical placement manner based on this initial position. If vAPs placed within the rAPs area, positioning error can be increased. Therefore, we construct a convex hull that rAPs formed with their edges and eliminate any vAP that placed in the convex hull. Finally, we can calculate the terminal's position based on the combination of rAPs and selected vAPs. Because the result can affect to the initially estimated position, above procedures repeat until the result converges.

II. Related Works

Centroid Localization (CL) algorithm is designed to simply identify the location of sensor nodes. CL computes the sensor position by average-sum of all scanned beacon's position. On the other hand, in WCL estimates the position using weighted sum. That is, the closer AP gets the larger weights [1, 2].

R. Behnke proposed Adaptive WCL (AWCL) algorithm [3]. This method uses received LQI information as a weight value, but it varies depending on its distribution. Also they analysis the border area effect problem in WCL, and proposed a solution which can be used in regularly distributed beacon scenario [4]. They showed remarkable result, but these methods have environmental limitations.

In this paper, we aimed expansion of AWCL-*like* method to adopt in real situation; randomly placed APs, indented border line.

III. Research Motivations

A. Indoor Localization using WCL

The positioning algorithm using WCL in terminal provides relatively high precision despite its simple calculation process. Generally the weight values are calculated from its distance information on the assumption that the terminal knows access points' location information.

Equation 1 converts RSSI (dBm) which received from each AP to their weight value.

$$w_i = \frac{1}{\left(d_i\right)^g} \tag{1}$$

w_i represents weight for i-th AP. It is inversely proportional to the square of g of the distance between the AP and the terminal. In general, the received signal strength from the terminal can be converted through the log-distance path loss model as follows.

$$\begin{aligned} P_d &= P_t - P_{PL(d_0)} - 10 \times n \times log_{10}\left(\frac{d}{d_0}\right) \\ \Leftrightarrow d &= d_0 \times 10^{\frac{P_0 - P_d}{10n}} \quad \left(\because P_0 = P_t - P_{PL(d_0)}\right) \end{aligned} \tag{2}$$

where P_t is the tx power (dBm) of AP and P_d is the rx power (dBm) of received terminal at distance d . Typically, in the indoor environment, the signal attenuation exponent n is 2 to 4.

The basic WCL algorithm for estimating the terminal position $P_{user}(x,y)$ is as follows where $P_{AP_i}(x,y)$ i-th AP position [3].

$$P_{user}(x,y) = \frac{\sum_{i=1}^{n}\left(w_i \times P_{AP_i}(x,y)\right)}{\sum_{i=1}^{n} w_i} \qquad (3)$$

B. Weakness in the Border Area

R. Behnke analyzed the causes of increasing errors in border area when positioning using WCL, as two kinds of reasons [4]. First, in consideration of more APs can be achieved the precise positioning in WCL, less APs are provided in the border area, and also available APs are too far to effectively use. So, large errors occurred when converting RSSI to distance. Second, when WCL uses all of available APs, a terminal in the border area is biased toward to the center through its calculation characteristics. Figure 1 shows an example of this problem.

In the Figure 1, U1 located in the center of area. Since it receives almost identical signal strength from four APs, the position estimated near the center because each weight can be calculated as same. U2, slightly off-center located, receives different signal strength received from each AP, but estimated close to the actual location because the lower weights for away-located APs (smaller RSSI) and higher weights for close-located APs (bigger RSSI).

However, relatively large error occurred in U3 case. In the figure, U3 located in the middle of AP #3 and #4, but the weights from AP #1 and #2 are also affected. Then, estimated position is biased toward to the center.

Indoor positioning algorithm, especially for WCL, because of this border effect problem brings overall performance degradation, and it should be solved.

C. Directions

In order to solve this problem, R. Behnke proposed virtual beacon creation and drop beacon strategy [4]. They create virtual beacon outside of border area, with an assumption that beacons are installed uniformly in the service area. However, considering in real indoor Wi-Fi AP installed situation, it has limitations for applying in our real environment. We also create virtual access points around the border area, but we overcame the uniformity constraints. To do this, we generated virtual APs based on initial estimated position which firstly estimated of the terminal. When a virtual AP is created in the real AP's enclosing area, we delete them to prevent for double biased. Detailed algorithms are described in next chapter.

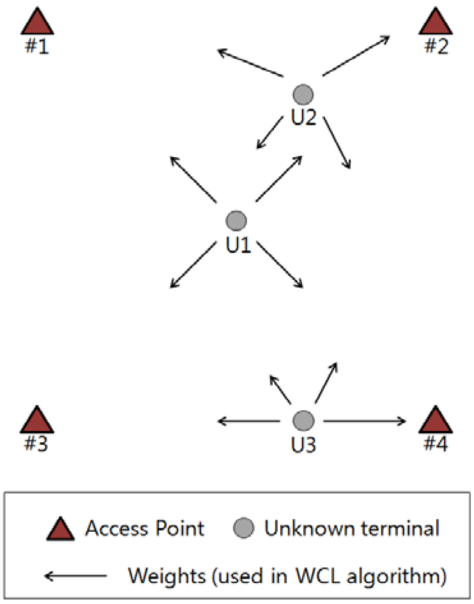

Figure 1. An example of Border Area Effect

IV. vWCL: Virtual Access Point assisted Weighted Centroid Localization Algorithm

Figure 2 shows an example of the accuracy improving method for indoor localization using virtual APs. In Figure 2-(a), the terminal estimated toward to the center in basic WCL; even it located in the border area of real APs (rAP). In vWCL, we called it as initial estimated position (P_{IE}). The candidate virtual APs (vAP) are generated based on the P_{IE} by symmetrically flipping the scanned APs in the terminal. The reason of generating candidate vAPs by flipping manner is that we can assume the signal strength of rAP and vAP is identical to the actual position of terminal. In Figure 2-(b) shows both real and virtually generated APs.

If virtual APs are existed in the rAPs enclosing area, it rather increases the error with pulling effect toward to the center. To prevent this reverse effect, vWCL constructs the convex hull that connects outside area of rAPs, and removes the vAP within this region as Figure 2-(c).

Figure 2-(d) shows the final configured APs to estimate the terminal location by combining real and selected virtual APs. The estimated terminal position has been corrected toward to the border area.

The following summarizes the sequence of vWCL algorithm.

A. Algorithm Procedures

1) *Select APs that above signal strength threshold among retrieved from terminal*: **rAP'**

2) *Localization using* **rAP'**: $\mathbf{P_{IE}}$ (*Initially Estimated Position*)

3) *Construct the convex hull that connects* **rAP'**: $\mathbf{Conv_i}$

4) *Generate virtual APs based on* $\mathbf{P_{IE}}$ *by symmetrically flipping* **rAP'**: **vAP** (*Virtual AP Group*)

5) *Determine each coordinate of* **vAP** (**vAP_j**) *is within the convex hull* **$Conv_i$** *or not*

a) *If it is on the outside, add* **vAP_j** *to* **vAP'**

b) *If not, remove* **vAP_j**

6) *Re-estimate the position using* {**rAP'**+ **vAP'**}: **P_i**

7) *Repeat the process 4)~6) based on the* **P_i** *as a reference position until* **P_i** *is in stable*

B. *Making Convex Hull*

The convex hull is a kind of polygon that minimal convex set containing given points [5]. vWCL uses this convex hull to configure the vAP to avoid it is located within the polygon. Then, it reduces border effect effectively by creating virtual APs on the border area, and also prevents bias toward to the center. To make convex hull, there are several algorithms exists, such as Graham's scan method [6].

C. *Re-estimating the Position*

The main reason for vWCL repeatedly re-estimates terminal position is that, the reference position and estimated terminal position (P_i) are constantly re-calculated by newly generated virtual AP group. However, about 5-10 times repeated after re-estimation process, the terminal position will converge within a certain point.

V. Simulation and Results

We verified our proposed method vWCL, with various scenarios. Firstly, we placed APs with 20m regular. In second, we distributed 10 APs randomly, and third, 30 APs are randomly placed. In order to obtain generalized results, 100 times simulation was performed in each scenario.

Figure 3 shows the simulation results. The left-side figure in each case represents a relative positioning error using basic WCL. Especially higher error occurred in the border area in every case. The middle figure shows the result of vWCL. Not only in the border area, but also in most test points, it improves the positioning performance. The right-side is a CDF graph for positioning error. According to the scenario, the performance improved up to 50%.

VI. Conclusion

In this paper, we presented vWCL as a solution for the border effect problem especially using WCL algorithm for indoor positioning. vWCL uses initially estimated position to generate virtual APs by symmetrically flipping the real APs. It selects useful virtual APs using convex hull which constructed by real APs' edge points.

In various simulation scenarios, most of region and especially in the border area, we verified vWCL improves the positioning accuracy.

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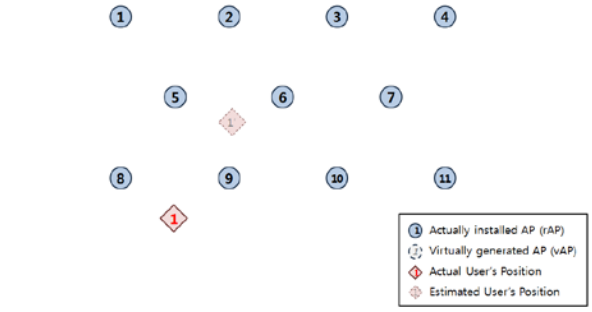
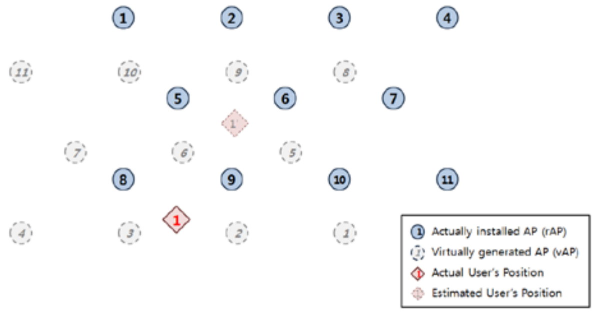
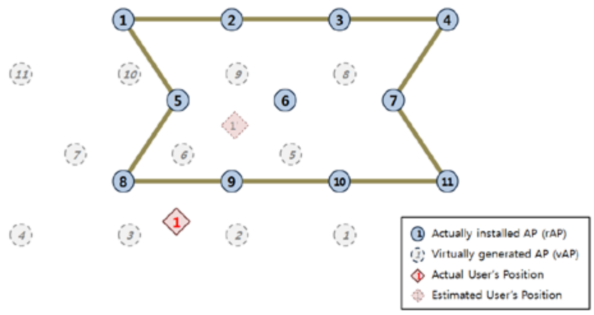


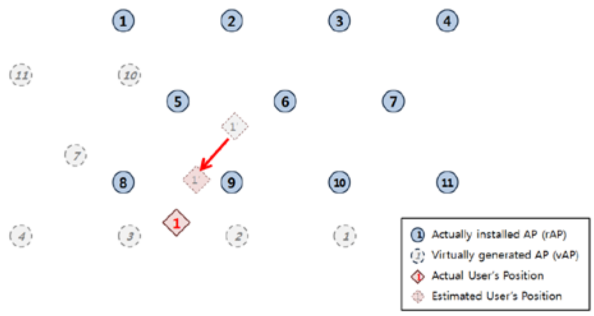
(a) Initially Estimated only using **rAPs** : **P_{IE}**



(b) Generate virtual APs based on **P_{IE}**

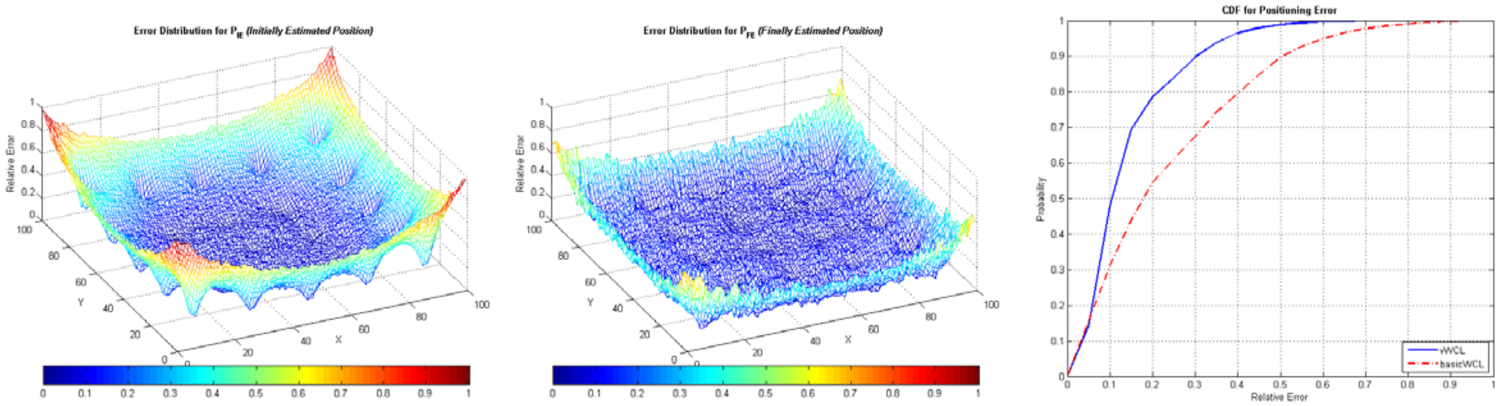


(c) Select virtual APs using Convex hull

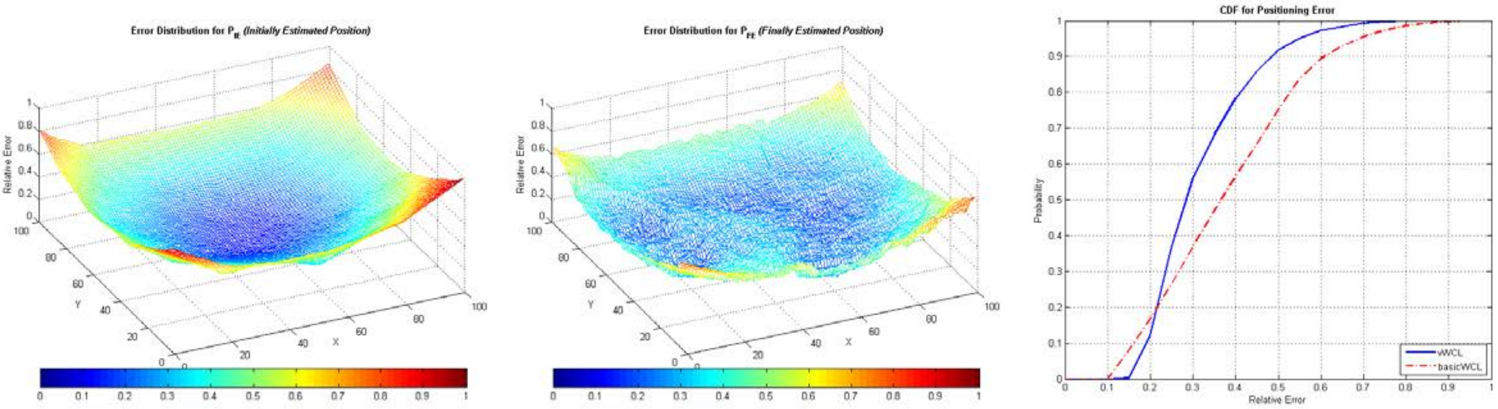


(d) Re-estimate the position using **rAPs** + selected **vAPs**

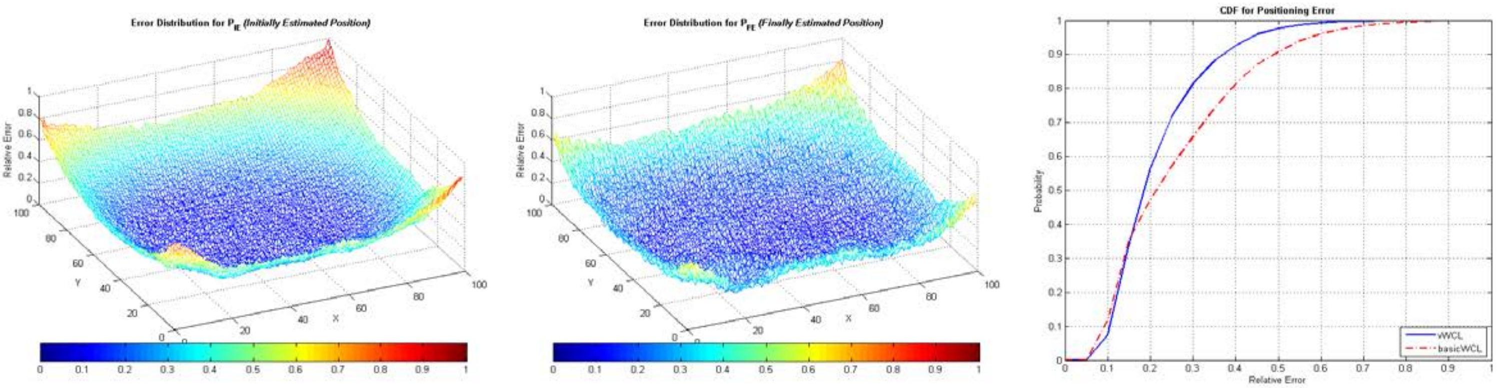
Figure 2. vWCL Example



(a) Simulation #1 : Regularly Distributed APs (Distance between APs: 20m)



(b) Simulation #2 : 10 Randomly Distributed APs



(c) Simulation #3 : 30 Randomly Distributed APs

Figure 3. Simulation Scenarios and Results

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