Phantom Positioning Technology for Indoor WLAN

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Abstract

We propose a new positioning technology, *Phantom Positioning*, to enhance the accuracy of RF propagation models by replacing each transmitter with a phantom (virtual) transmitter at a different location. By taking the position of a phantom transmitter, instead of the original transmitter, as the input to the signal propagation model, the Phantom Positioning technology may obtain a more accurate distance estimation than that of taking the position of the original transmitter as the input. A more accurate distance estimation will lead to a more accurate position determination. Our initial experimental results indicate an up to 20% and 12% improvement on the accuracy in estimating distance and position, respectively. Our technique can be applied to various positioning models to enhance their accuracy or to reduce their training samples.

Keywords: Wireless Positioning

1. Introduction

Many positioning systems designed to determine or track a user's location have been proposed over the years [1]. One of such systems is *RF signal based indoor WLAN positioning systems*. For indoor positioning, it is an economical solution when there exists a well-infrastructed WLAN network. The WLAN-based positioning system may work in a large building or even across many buildings [2,3,4,5,6]. This paper proposes a new technique, *phantom positioning*, to improve the accuracy of such systems.

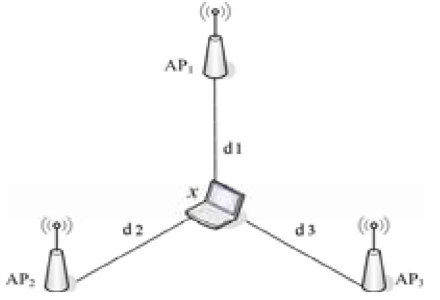


Fig. 1. Triangular Positioning Method

Most positioning systems estimate the position of an object by estimating its distances to at least three objects whose positions are known.

As shown in Fig. 1, x is the object whose position is to be determined; AP_1, AP_2, AP_3 are access points (APs) whose positions are known; d_1, d_2, d_3 are the distances from x to AP_1, AP_2, and AP_3, respectively; the position of x can be determined if d_1, d_2, and d_3 are also known.

From the example shown above, the accuracy of a positioning system depends on the accuracy of the determination of the distance between a transmitter and a receiver. Among many wireless technologies that are used in positioning systems, the most popular one is the RF signal. Theoretically, the distance between a transmitter and a receiver can be determined by the signal strength measured at the transmitter and the receiver, referred as *propagation model*. However, due to the distortions caused by environmental factors such as reflection, deflection, and multi-path effects, a propagation model may not be very accurate, especially in an indoor environment [3,4].

In many WLAN-based indoor positioning technologies, the signal distribution of access points is collected to train a position-determination model. The *training phase* is followed by the *working phase*, during which the mobile device observes the WLAN signals and applies the position-determination model using a propagation model to calculate the positions of mobile devices. The complexity of the training phase, which implies high labor cost, depends on the accuracy of the propagation model and the position-determination model. The higher their accuracies, the lower the training complexity. In other words, the number of training samples will be reduced if there is an accurate propagation model or a position-determination model available.

In practice, the WLAN receiver in each notebook PC has its own distinct characteristic so that the *RF Signal Strength Index* (RSSI) received in different WLAN receivers may be different. As a consequence, it may need to provide a distinct training database for each WLAN receiver since sharing a common training database may impair the accuracy of position estimation. Therefore, reducing the size of training database while maintaining a certain level of accuracy becomes an important task.

In this paper, we propose a new technology, *Phantom Positioning*, to enhance the accuracy of a propagation model by replacing each transmitter with a phantom (virtual) transmitter at a different location. By taking the position of a phantom transmitter, instead of the original transmitter, as the input to the signal propagation model, *Phantom Positioning* technology may obtain a more accurate distance estimation than that of conventional methods. A more accurate distance estimation will lead to a more accurate position determination.

2. Basic Ideas

As mentioned in Section 1, the RSSI received in a receiver may be influenced by many environmental factors such that it is not easy to develop an accurate propagation model, especially in an indoor environment. We take the example shown in Fig. 2 to illustrate our basic idea. In this example, we assume RF signals travels along curve lines instead of straight lines to reach receivers.

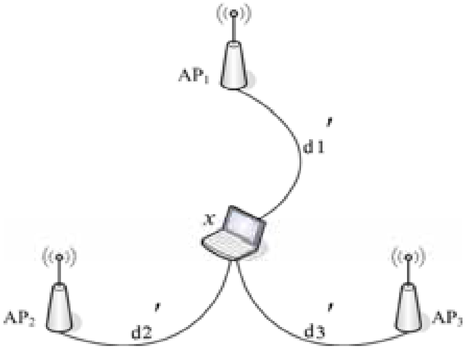


Fig. 2. Inaccurate Positioning

d_1', d_2', d_3' are the path distances the RF signals traveled from AP_1, AP_2, and AP_3, respectively to x. An "accurate" positioning system will take d_1', d_2', and d_3', instead of d_1, d_2, and d_3, as the distances from x to APs in calculating the position of x. This won't be able to obtain accurate results.

As shown in Fig. 3, if we create three phantom APs, AP_1', AP_2', and AP_3' whose positions are also known, to replace AP_1, AP_2, and AP_3, the position of x could be estimated more accurately using the same position-determination model.

3. Applying Phantom Positioning Technology

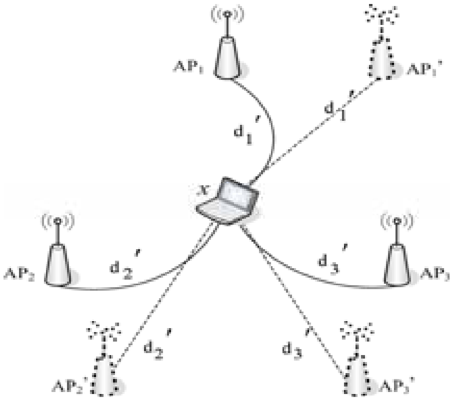


Fig. 3. Phantom Positioning

3.1 Challenges

There are few challenges yet to overcome in order to apply this phantom positioning technique to a real world positioning system. First, it is not easy, if not impossible, to figure out the path a RF signal actually travels. Secondly, RSSI is usually a complicate combination of several replicated signals traveling along several different paths, referred to as *multi-path effect*[3,4]. Thirdly, with respect to a transmitter and a propagation model, the best position of phantom transmitter, referred to as the *optimal phantom position* for a receiver not only depends on the propagation model, but also depends on the location of the receiver. In other words, there might exist a distinct optimal phantom position for each receiver location and for each propagation model. As a consequence, the labor cost to determine the optimal phantom transmitters for all points will be extremely high. A model to apply phantom positioning technology is yet to be developed.

Our basic ideas are as follows. First of all, with respect to set of parameters (a transmitter, a propagation model, a receiver and the RSSI at the receiver), as long as there is an estimation error, we can always place a phantom transmitter at a position where its Euclidean distance (say, *d*) to the receiver is equal to the estimated distance. (Actually, the set of optimal phantom position is the circle of radius *d* with center *r*). Thus, there is no need to know how the signal actually travels. Secondly, although the optimal phantom positions are location dependent, the practical experiences show that within a limited space, such as a room, most locations may share the same propagation model and the same phantom transmitter without impairing estimation accuracy significantly. Therefore, we can reduce the number of required phantom transmitters significantly by partitioning the space into regions and letting all sample points in each region share the same set of parameters. A phantom transmitter that is shared by the set of sample points in a region is called a *regional phantom transmitter*. The model is illustrated in the rest of this section.

3.2 Phantom Positioning Model

Basic notations are defined as follows:

t	transmitter that transmits a RF signal with strength s_0
t'	a phantom transmitter that pretends to be the transmitter t
$p(x)$	position of object x
$s(x)$	signal strength (RSSI) received by object x
$f(s)$	estimation functions (propagation model) that estimates the distance between the transmitter t and a receiver whose RSSI is s
$d(x,y)$	Euclidean distance between objects x and y
$d'(r,s,f)$	estimated distance from any point to r using estimation function f when RSSI at r is s (assume the transmitted power is s_0)

A transmitter t at position $p(t)$ transmits a RF signal of strength s_0 and a receiver r at position $p(r)$ that receives the signal of strength s. A phantom transmitter t' at position $p(t')$ pretends to transmit a RF signal of strength s_0 and a receiver r at position $p(r)$ that receives the signal of strength s.

With respect to a distance estimation method and distance measures between two points, the *error distance* is the discrepancy between the estimated distance and the Euclidean distance. The *estimation error* is the error distance divided by the Euclidean distance.

With respect to a transmitter t, a phantom transmitter t', a receiver r, and an estimation function f, the error distances by estimating the distances between t and r as well as between t' and r are then $e(t) = |d'(\mathrm{r}, s(r), f) - d(t, r)|$ and $e(t') = |d'(\mathrm{r}, s(r), f) - d(t', r)|$ respectively. Estimation errors are $E(t) = (e(t) / d(t, r))$ and $E(t') = (e(t') / d(t', r))$ respectively. (Note that the error distance between a phantom transmitter t' and receiver r is the discrepancy between the estimated distance and the Euclidean distance between t' and r. It is defined in such a way because it is for positioning, but not for distance measure.) With respect to a transmitter t, a set of receivers $R=\{r_i \mid i=1,\dots,n\}$, and an estimation function f, an *optimal phantom position* is a phantom position where the average estimation error is the smallest. By this definition, the estimation function is assumed fixed. However, the estimation function can be optional so that the optimal phantom position must be the smallest among all possible estimation functions.

Some questions are: how to choose an appropriate propagation model; how to partition sample spaces; and how to find the optimal phantom positions with respect to a transmitter and a propagation model. Finding an optimal solution for these problems may not be practically tractable. Thus, suboptimal solutions will be more practical.

4. Experiments

To prove the concept of phantom positioning technology and to investigate its property, we set up an experimental positioning system at the Mobile Computing and Communication Laboratory, National Chengchi University.

4.1 Experimental Setup

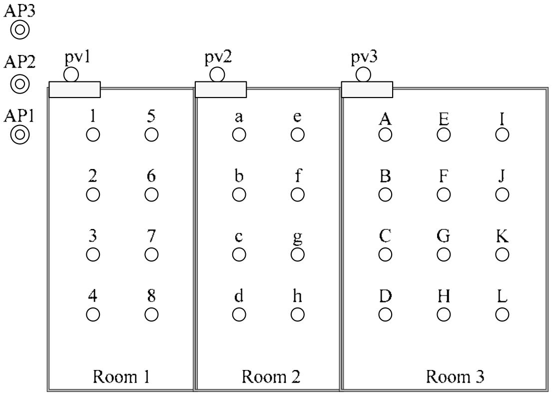


Fig. 4. Site Map and Placement of APs

As shown in Fig. 4, the experiment site consists of three rooms with dimensions of 4mx8.7m, 4mx8.7m, and 8mx8.7m, respectively. In these rooms, we choose 2x4, 2x4, and 3x4 sample points. The distance between a sample point and an AP is estimated using the following *power rule*:

$$s_x / s_v = (d_v / d_x)^n$$

where s_x and s_v are the RSSIs at the point x and v respectively; d_x and d_v are the distances between the AP and x and v respectively; n varies from 2 to 10 and is determined experimentally. Assuming the position of v is known, d_x can be estimated using d_v, s_x, s_v, and power rule n. With respect to a sample point x and an AP, there must be associated with a reference point (point v in the power rule) whose position is known in advance, referred to as *pivot point of x* , as well as a power rule n, referred to as *power rule of x* .

In the first experiment, we evaluate the accuracy of phantom positioning technique in estimating the distance between sample points and APs. In the second experiment, we evaluate the accuracy of phantom positioning technique in estimating the positions of sample points.

4.2. Distance Estimation

As shown in Fig. 4, on the left side of Room 1, there are three outdoor transmitters, AP_1, AP_2, and AP_3. To observe the effect of phantom positioning, we choose some phantom positions around each AP as shown in Fig. 5. Note that position 0 (red cell) is the original position of the AP.

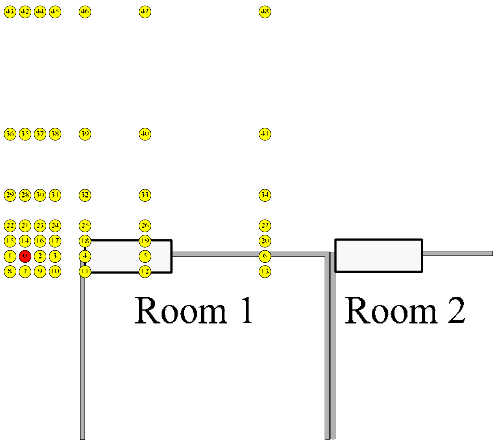


Fig. 5. Testing Phantom Positions for AP_2

In Experiment 1, we choose three pivot points, pv_1, pv_2, and pv_3, one for each classroom. All sample points in the same room is associated with the same pivot point. In experiment 1.1, we search the optimal phantom position for each sample point over all possible power rules. Only 1 out of 84 cases (28 sample points multiplied by 3 APs) phantom positioning performs worse. Out of 84 cases, only 3 cases have 1% error and the reminding 81 cases have 0% error. Parts of results are shown in Fig. 6.

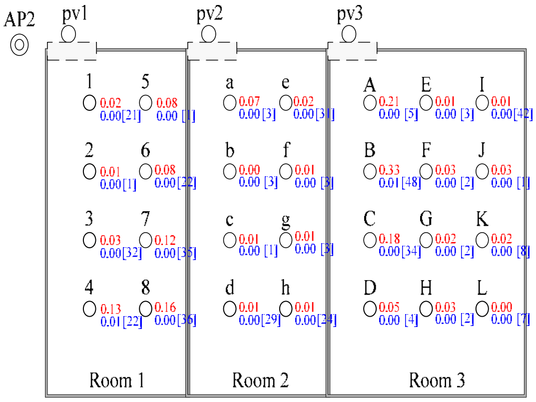
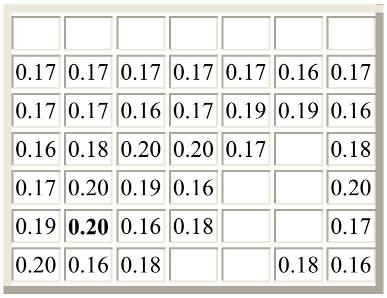


Fig. 6. Estimation Errors w.r.t. AP 2

Although Experiment 1.1 shows that phantom positioning is able to offer a very precise distance estimation, it will not be practical to associate with each sample point a distinct power rule, a distinct pivot point, and a distinct phantom transmitter. Therefore, in Experiment 1.2 and 1.3, the site is partitioned into regions of rooms and half-rooms respectively. All sample points in the same region share the same power rule, the same pivot point, and the same phantom transmitter. It is obvious that the accuracy of distance estimation is highly dependent on the size of a region (of cause, and other factors). The smaller the region, the higher the accuracy. The challenge in phantom positioning technique is to find the best site partitioning with adequate pivot points, power rules, and phantom positions.

For each sample point, we calculate the estimation error for every combination of power rule and phantom position. For each region, we calculate the average error over all sample points in the region for each combination of power rule and phantom position. For each region and each phantom position, we select the smallest error over all power rules.

Parts of the results of experiments 1.2 and 1.3 are shown in Fig. 7, Table 1 and Table 2. For simplicity, we define *method x* as the estimation method that uses phantom position *x* and use whatever power rule that can minimize the estimation error. Because position 0 (marked in bold) is the original position of an AP, method 0 is actually a non-phantom positioning method. The number in cell *x* in Fig. 7 is the lowest average estimation error when method *x* is used. Note that those errors that are higher than that of method 0 (non-phantom positioning method) are ignored. In Table 1 and 2, *x* is the estimation error of method 0, *y* is the smallest estimation error among all but method 0, and *z* is the number of phantom methods that can obtain equal or smaller error than method 0.



0.17	0.17	0.17	0.17	0.17	0.16	0.17
0.17	0.17	0.16	0.17	0.19	0.19	0.16
0.16	0.18	0.20	0.20	0.17		0.18
0.17	0.20	0.19	0.16			0.20
0.19	**0.20**	0.16	0.18			0.17
0.20	0.16	0.18			0.18	0.16

Fig. 7. Average Estimation Errors of Phantom Positioning
(Region=Room 1, AP=3)

Table. 1. Average Estimation Errors
(Region Size = Room)

AP	**Room**	*x*	y	*z*
1	1	0.13	0.13	5
1	2	0.20	0.18	20
1	3	0.20	0.16	34
2	1	0.10	0.10	16
2	2	0.10	0.09	34
2	3	0.12	0.12	20
3	1	0.14	0.13	27
3	2	0.15	0.15	28
3	3	0.11	0.11	53

Table. 2. Average Estimation Errors
(Region Size = Half Room)

AP	**Room**	**Region**	*x*	*y*	*z*
1	1	Upper	0.07	0.07	8
1	1	Lower	0.08	0.07	11
1	2	Upper	0.11	0.10	25
1	2	Lower	0.05	0.03	28
1	3	Upper	0.12	0.11	22
1	3	Lower	0.03	0.01	22
2	1	Upper	0.08	0.08	25
2	1	Lower	0.03	0.04	0
2	2	Upper	0.08	0.08	33
2	2	Lower	0.03	0.03	21
2	3	Upper	0.07	0.07	25
2	3	Lower	0.05	0.04	18
3	1	Upper	0.07	0.06	45
3	1	Lower	0.09	0.08	32
3	2	Upper	0.09	0.09	16
3	2	Lower	0.07	0.06	35
3	3	Upper	0.07	0.07	31
3	3	Lower	0.05	0.05	39

As we can see, in most of the regions, there is some number of phantom positions that can offer better distance estimation than non-phantom positioning. The improvement by using our proposed technology is up to 20%.

In Experiment 2, APs and pivot points are placed at appropriate locations for positioning. The optimal phantom position for each AP for each region is determined first using the method developed in Experiment 1. The result shows that phantom positioning can improve the precision by 12%. Although further investigations and experiments need to be done yet to reach a more concrete conclusion, our experiments show a great potential to improve the precision of current positioning methods. However, radio signals are probabilistic, time variant, and highly dependent on many environment factors. Many existing techniques that can overcome these factors must be integrated into our method in order to make it practically useful.

5. Concluding Remarks

The Phantom Positioning is able to enhance the accuracy of RF propagation models by replacing each transmitter with a phantom (virtual) transmitter at a different location. Our initial experimental results indicate an up to 20% and 12% improvement on the accuracy in estimating distance and position, respectively in an indoor WLAN environment. This technique can be applied to various positioning models to enhance their accuracies or to reduce their training samples. Because accuracy of a position system is highly dependent on the environmental factors and the accuracy of WLAN devices, further researches are yet to be conducted to obtain countable results.

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