A Novel technique for Reference Node Placement in Wireless Indoor Positioning Systems based on Fingerprint Technique

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ABSTRACT

Accuracy of location determination is one of the keys to success for any indoor positioning system. This performance metric is influenced by how reference nodes (RNs) are installed. However, most of existing research studies ignored the problem of optimal reference node placement and efficient system design for indoor positioning systems. In this paper, we propose a novel technique using heuristic approach that can design suitable location to install the reference nodes and improve the location determination performance for a single-floor area and the multi-floor building. A mathematical formulation of reference node placement is developed as a Binary Integer Linear Programming (BILP) problem. The proposed formulation aims to minimize the number of reference nodes and derive their suitable locations for the indoor positioning systems. We developed an efficient solution technique based on Simulated Annealing algorithm (SA), called Maximizing Summation of the Maximum RSS for Multi-floor building (MSMR-M). The results from performance study show that by using the proposed RN placement technique, the indoor positioning systems can gain up to five meters of accuracy at 90% precision for single-floor building. Moreover, in the case of the multi-floor building, the proposed technique can improve the error distances up to 20% which is better than those of the other techniques. The proposed technique can provide an average error distance within 1.42 meters where the grid spacing of fingerprint is 2m×2m.

Keywords: Indoor Positioning Systems, Reference Node Placements, Optimization System Design, Multi-floor Building, Wireless Sensor Networks

Manuscript received on July 15, 2014 ; revised on August 4, 2014.

Final manuscript received on October 7, 2015.

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This work was supported in part by Suranaree University of Technology, the Office of the Higher Education Commission under NRU project of Thailand and the National Research Council of Thailand (NRCT).

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1. INTRODUCTION

Indoor positioning systems increasingly gain attention to become important add-ons to today's pervasive wireless technologies. The indoor positioning systems using radio frequency signals of indoor wireless networks have been suggested as alternatives where signals of Global Positioning System (GPS) cannot reach receivers inside buildings [1]. Compared to outdoor environment, indoor environment often does not have line-of-sight communication between reference node and receiver. The radio signal propagation is greatly influenced by multi-path effect and attenuation of various obstacles, which can degrade the accuracy of indoor positioning system. These issues created challenges in the design of the indoor positioning systems [2].

Among different radio frequency techniques used to determine indoor position such as Angle-of-Arrival (AOA) and Time-of-Arrival (TOA) measurement, the location fingerprinting technique is the simplest technique which assumes unique relationship between received signal strength (RSS) patterns called location fingerprints and locations [3]. It is an attractive approach because almost all wireless transceivers have built-in received signal strength measurement capability and no other specialized hardware is required at the mobile station (MS). This kind of technique has been applied to both Wireless Local Area Network (WLAN) and Wireless Sensor Network (WSN) in the literature.

Generally, the wireless indoor positioning system based on location fingerprinting technique can be deployed in two phases [4]. First, in the offline phase the location fingerprints are collected by performing a site-survey of the received signal strength (RSS) from multiple reference nodes. The measurement of RSS is usually performed on points or positions inside rectangular grid which covers the localization area. The RSS patterns or location fingerprints from all positions are recorded in a database called radio map. Second, in the online phase a sample of RSS pattern at a current mobile station's location is fed into a location estimation algorithm that utilizes radio map created in previous phase. An estimated location is reported by the indoor positioning system where the location accuracy is usually reported as the error distance deviated from the actual position [4].

The simplest location estimation algorithm is based on the computation of Euclidean distance between the current measured RSS patterns and all location fingerprints in the radio map. The position that associated with the fingerprint that has the shortest distance to the current sample or RSS pattern is reported as the estimated position [5]. In this research study, we will assume this type of positioning system and algorithm as baselines for our performance comparison. We will show that optimal placement of reference node can improve the accuracy performance of the system.

Thus far, there are a number of studies investigating on techniques that can locate objects inside building using either IEEE 802.15.4 wireless sensor networks or IEEE 802.11 wireless local area networks. For instance, Stoyanova et al studied factors that influence the RSS of wireless sensor network using Tmote Sky nodes [6]. They concluded that there are a number of parameters that affect the accuracy of mobile localization which are the transmitter-receiver distance, the variation among the same type of transceivers, the orientation of antenna, and the location of reference nodes. The study of Sugano et al [7] utilized RSS of ZigBee based wireless sensor network to create an indoor localization system. Yao et al [8] also studied the use of location fingerprinting technique for localization in ZigBee based wireless sensor network. The measurement of RSS distribution in form of Probability Density Function (PDF) at the location of cluster-head of wireless sensor network was studied and used in standard hypothesis testing for the proposed localization system of [9].

The research work in [10] studied the impacts of access points (APs) placement on localization in WLAN based indoor positioning system. A related work in [11] proposed an algorithm that required strategic placement of nodes in each room and suggested a new range-free solution based on simple RSSI measurement. From the system design perspective, Kaemarungsi [4] suggested a framework for efficiently design an indoor positioning system based on location fingerprint. A number of system parameters that influence positioning performance were identified such as grid spacing, number of reference nodes, path loss exponent, and standard deviation of RSS. Recently, the impact of reference node placement in wireless indoor positioning system was presented in [3].

Some works considering optimal reference node placement problems for the indoor positioning systems include [21] and [22]. In [21], the authors proposed the access point placement problem for the WLAN based indoor positioning systems with an objective to find the minimum number of access points that guarantee the radio coverage. Ref. [22] proposed the access point placement problem for the WLAN based indoor positioning systems with objectives to maximize the signal to noise ratio in the service area.

Based on our literature review above, existing studies are interested in the impacts of reference node placement such as [3], while other studies [6], [10], and [4] are only focused on the problem of efficiently design the networks of positioning system. There are few works considering the optimal reference node placement. However, the existing works [21], [22] only consider the quality of radio signal coverage in the service area. They lack of the conditions to guarantee the accuracy performances of the indoor positioning systems.

In order to enhance the localization performance of the indoor positioning systems. An example of wireless sensor network design problem that used Binary Integer Linear Programming (BILP) in determining the placement of relay nodes was reported in [12]. In Research [19], the authors presented a localization technique for multi-story buildings by considering the RSS along with the temperature and humidity to create the fingerprinting database in service area. Although this technique could yield high accuracy but this technique has not considered the problems of placement design of reference nodes for indoor positioning systems in multi-story buildings. Existing work has not considered the optimum placement of reference nodes for multi-story buildings. Therefore, in this work, we will apply the BILP and Simulated Annealing algorithm (SA) to the design of indoor positioning systems where the reference nodes of wireless network (both WLAN and WSN) are optimally placed in order to provide better localization performance. Our main goal is to find a design with minimum number of required reference nodes while maintaining maximum level of RSS possible over the positioning area. Our contributions are summarized as follows:

- We proposed a novel reference node placement technique using BILP approach to design efficient wireless indoor positioning systems based on fingerprint technique.
- We developed an efficient solution technique using a simple and effective heuristic approach based on Simulated Annealing technique.
- The proposed techniques can be applied to various service area structures ranging from single floor to multi-floor areas.

The organization of this paper is as follows. Section 2 described the problem definition and problem formulation. Section 3 presents experimental study and analysis demonstrating the optimal RN placement. Section 4 presents an analysis of the accuracy of the positioning systems. Finally, Section 5 provides conclusion and guidelines for future research work.

2. PROBLEM DEFINITION AND FORMULATION

In this section, we will describe our mathematical models for optimal placement of reference nodes (RNs) in wireless indoor positioning systems. In particular, we consider the positioning systems based on the location fingerprinting. In such system, RNs are wireless transceivers that are installed within the target service area of the positioning systems and signal test points (STPs) are locations where the received signal strength from RNs is recorded to create a fingerprinting database. Some RNs should be able to respond to a signal inquiry from a target node of which a location needed to be determined. Therefore, RNs should have sufficient coverage over the service area. That is the number of reference nodes should be sufficient to cover the design area and research results presented in [3] recommended that each STP should be able to receive signal from at least four RNs in order to achieve good positioning performance.

Incorporating a recommended framework presented in [3], we have developed mathematical models for optimal placement of RNs for wireless indoor positioning systems using a BILP. It is an efficient approach widely applied in the facility layout problems due to its low complexity and requiring short time to solve the problem [13]. Specifically, we have developed two models for optimal placement of RNs in wireless indoor positioning systems which are the minimize-number of RN model and the maximize-sum of maximum RSS model. However, when search space is larger such as the problem of multi-story buildings, BILP cannot find the answer because of time limitations. In this case, we proposed a heuristic optimization algorithm based on Simulated Annealing (SA) that can yield near-optimal solution for the placement of reference node (RNs) for indoor positioning system because SA has simple procedures that can effectively find near optimal solutions for the case of complex problems like the multi-story scenarios. Table 1 defines notations used in the proposed models.

2.1 Minimize-Number of RN Model

We denote this model as MNR. The proposed model aims to minimize the number of RNs and determine the optimal locations to install them in the target service area of the wireless indoor positioning systems. This can be written as the objective function (1). The problem involves selecting locations from a set of predetermine candidate location such that the obtained wireless indoor positioning system meets the requirements recommended in [3] such as the level of signal quality and the number of RNs required to provide high accuracy in positioning systems. These requirements are incorporated into the model via a set of constraint (2) - (4).

MNR objective function:

$$Minimize \quad \sum_{\forall j \in R} c_j \tag{1}$$

Constraints:

$$S_{ij}(P_{ij} - P_T) \geq 0 \quad \forall i \in T, \forall j \in R \tag{2}$$

$$S_{ij} \leq c_j \quad \forall i \in T, \forall j \in R \tag{3}$$

$$\sum_{\forall j \in R} S_{ij} \geq N_R \quad \forall i \in T \tag{4}$$

Table 1: *Notations.*

Sets:	
R	A set of candidate sites to install reference node (RNs)
T	A set of signal test points (STPs)
Decision variables:	
c_j	A binary {0, 1} variable that equals 1 if the RN is installed at site $j, j \in R$; 0 otherwise
S_{ij}	A binary {0, 1} variable that equals 1 if the STP i is assigned to RN $j, i \in T$ and $j \in R$; 0 otherwise
Constant parameters:	
P_{ij}	The signal strength that a STP i receives from RN j, $i \in T$ and $j \in R$
P_T	The received signal strength threshold
N_R	The minimum number of RNs recommended
N_S	Sufficient number of RNs or an optimal number of RNs obtained from MNR model

The objective function (1) aims to minimize the number of RNs needed for the specified service area of the indoor positioning system. Constraint (2) states that STP i is in coverage of RN j if the signal strength received at STP i from RN j (Pij) is greater than the threshold PT. Constraint (3) specifies that STP i can receive signal from RN j if a RN j is installed. Constraint (4) enforces that each STP must be able to communicate with at least a minimum number of RNs, specified with a parameter N_R.

2.2 Maximize-Sum of Maximum RSS Model

We denote this model as MSMR. The proposed model aims to determine the optimal locations to install RNs so that we can achieve high quality of radio signal propagation from RNs across the target service area of the wireless indoor positioning systems. This can be mathematically modeled as maximizing summation of the maximum RSS at STPs as written in an objective function (5). MSMR model also incorporates the requirements of the indoor positioning systems as recommended in [3] via the constraints (2) - (4) as described previously. Moreover, the MSMR model includes the constraint (6) which enforces the minimum number of RNs (NS) to be utilized in the service area. Note that NS is an optimal number of RNs obtained from the MNR model.

MSMR objective function:

$$Maximize \quad \sum_{\forall i \in T} \max_{\forall j \in R} (S_{ij} P_{ij}) \tag{5}$$

Constraints:

$$\sum_{\forall j \in R} c_j = N_S \tag{6}$$

2.3 MSMR for Multi-floor Building

We proposed a heuristic optimization algorithm based on Simulated Annealing (SA) to solve optimal placement of reference node (RNs) for indoor multi-floor positioning system. The proposed technique is called MSMR for multi-floor building (MSMR-M) which is extended from our preliminary work presented in [20]. The MSMR-M is based on SA which is a heuristic optimization technique that mathematically mirrors the vulcanization process. SA is a simple and popular method that has been applied to various optimization problems [18]. Here we apply SA to solve the optimal placement of reference nodes for indoor positioning systems in multi-floor buildings. Note that in this work the optimal placement is done each floor as a time. It is not a joint optimization in which optimal placement of all RNs is derived simultaneously. The proposed optimization formulation consists of the objective function (5) and the constraints (2) - (4) and (6). Table 1 defines notation used in the proposed formulation.

Table 2 illustrates the pseudocode of MSMR-M technique to determine the optimal placement of RNs for each floor of the multi-floor buildings. The first step involves entering the input to the Simulated Annealing algorithm (SA) [18]. Then SA starts by generating a random set of initial placement of RNs and evaluates the cost values with objective function (5). Then set this as a current state (S_c).

Next a set of neighbor solutions will be evaluated and the best neighbor will be selected. Neighbor solutions are generated by randomly selecting adjacent locations to the current locations of RNs. Note that the selected adjacent locations need to satisfy constraints (2) - (4) and (6). Then the new state (S_n) will be obtained. The cost values of the objective function (5) will be evaluated and be compared with that of the current state. Those locations are selected by the decision function. Then the current state (S_c) will be updated. This process repeats until reaching the stopping criteria. Finally, the near-optimal placement for RN installation can be obtained. We apply temperature reduction function written in (7) to simulate temperature reduction of SA. The initial temperature (T_0) is set 100 Celsius and the temperature reduction constant (K) written in (8)

Temperature reduction function:

$$\alpha(t) = T_0 e^{-0.9k} \tag{7}$$

$$K = K + 0.02 \tag{8}$$

Table 2: *The Pseudo Code of MSMR-M Technique.*

Input: R, T, N_R, P_T, N_S	
Output: Optimal placement of RN$_s$	
1.	Select an initial temperature (T_0)
2.	Select a temperature reduction function t = $\alpha(t)$
3.	Repeat
4.	Select an initial solution ($S_c \in R$) with random sample
5.	Verify constraints
6.	Until according to the conditions
7.	E(S_c) = Objective Function (S_c)
8.	Repeat
9.	Generate a set of neighbor solutions of S_c according to the conditions and select the best neighbor, S_n
10.	E(S_n) = Objective Function (S_n)
11.	ΔE = E(S_c) - E(S_n)
12.	If ΔE < 0
13.	Then $S_c = S_n$
14.	Else generate random (x), uniformly in the range (0, 1)
15.	If x < exp(-ΔE/t)
16.	Then $S_c = S_n$
17.	End if
18.	End if
19.	Set t = α(t)
20.	Until stopping criteria

3. EXPERIMENT ON OPTIMAL RN PLACEMENT

In this section, we present an implementation and experiments demonstrating performance of the proposed technique. First, in this section we will apply our proposed technique to determine optimal placement of RNs for single-floor building and multi-floor building as described in the section 3.1 and 3.2, respectively. In this phase of determining the RN placement location, the signal strength is simulated by using the path-loss model.

After we obtained the location to install the RNs in the service area, then in the section 4 the experiments with real signal measurement were conducted to evaluate the accuracy of the indoor positioning systems in which the RNs were installed at the locations found from the RN node placement phase. The performance results will be compared with other node-placement techniques found in the literature.

3.1 Single-floor Building

In this section we present experimental study and analysis demonstrating the optimal RN placement using the proposed MNR and MSMR models. We aim to compare the positioning systems designed by our models with other systems reported in [14] and [15]. First, in this section we will apply our models to determine optimal placement of RNs in two service environments described below. Then in Section 4 we will analyse the positioning performance of the positioning systems obtained by our models and will compare with the positioning performance of the systems presented in [14] and [15].

In the experiment of optimal RN placement, we consider two environments of the wireless indoor positioning systems which were used in the study of [14] and [15]. The first environment from [14] considers the service area of size 63m × 10m as shown in Fig. 1. In this case, a set of STPs with grid spacing of three meters and a set of 43 candidate locations to install RNs are located along the building as depicted in Fig. 1. The second environment from [15] considers the service area of size 23m ×37m as shown in Fig. 2. In this case, a set of STPs is also distributed at grid spacing of three meters and a set of 45 candidate location to install RNs are selected uniformly over the service area as depicted in Fig. 2.

The wireless transceivers with IEEE 802.15.4 standards are applied in our experiments. The received signal strength threshold to ensure the radio communication between RNs and the target node (P_T) is set to -100 dBm [16] and the transmit power is set to 18 dBm (60mW) [14]. In addition, a guideline of the positioning framework in [3] recommends that each STP should be able to receive signal from at least four RNs. Therefore, we set the value of N_R equals to 4.

We apply the path-loss model written in (9) to simulate the signal strength that STP i receives from RN j (P_{ij}). This path-loss model considers obstruction and building materials in the signal attenuation [17].

$$P_{ij}(dBm) = P_t + L_0 - 10\alpha\log(d_{ij}) - \sum m_{type} w_{type} + X \quad (9)$$

Where P_t is the transmitted power (in dBm), L_0 is the free space loss at distance one meter, α is the path-loss exponent. For this path-loss model which considers the building materials, $\alpha = 2$. d_{ij} is the distance between STP i and RN j in meters, and m_{type} refers to the number of partition of that type and w_{type} refers to loss in dB attributed to such partition. X is a random variable with a distribution that depends on the fading component. In this study, we apply the log-normal distribution to the random variable X. We conducted preliminary signal measurements using wireless transceivers with IEEE 802.15.4 standards and obtained mean value of the received signal strength $\mu = 0$ and the standard deviation σ = 5.678 dBm.

We apply MNR model to find minimum number of RNs (NMNR) required for both service environments described earlier. Next we apply MSMR model to determine optimal locations to install RNs. In solving MSMR model, the input parameters include the value of NMNR obtained from MNR model, a set of candidate locations to install RNs (R), a set of STPs (T), a set of simulated signal strength (Pij) and a received signal strength threshold (PT). We implement the problems with the ILOG-OPL development studio and solve them with CPLEX Optimization Studio Academic Research 12.2 optimization solver. Computations are performed on an Intel Centrino Duo Processor 2.0 GHz and 2 GB of RAM.

Fig. 3 and Fig. 4 depict the optimal number and locations of RNs for the first and second service environment compared with those deployed in [14] and [15], respectively. In Fig. 3 we can see that our models require the use of four RNs whereas the deployment in [14] uses three RNs. In Fig. 4 the positioning system designed by our models deploys four RNs which are the same as that used in [15]. However, the locations of RNs obtained by our models are different from those locations in [15]. In the next section, we will analyse and compare the positioning performance of the positioning system designed by our models with those deployed in [14] and [15].

3.2 Multi-floor Building

In this section, we present an implementation and experiments demonstrating performance of the proposed technique. First, in this section we will apply our proposed technique to determine optimal placement of RNs in the service area ranging over two floors of the building as described below. Then in Section 4 we will analyze the positioning performance of the positioning systems obtained by our models and will compare with the systems obtained by using the uniform placement technique in [10].

In the experiment of optimal RNs placement, we considered two-story library building at Suranaree University of Technology which was used as a test bed. Size of each floor of the service area is approximately 35m×35m as shown in Fig. 5 and Fig. 6. A set of candidate locations to install RNs are distributed at the same location as those of Signal Test Points (STPs) as depicted by the symbol '+' in Fig. 5 and Fig. 6. We consider different sizes of the grid spacing to study how the grid size affects the optimal solutions and the performance of the obtained indoor positioning systems. In particular, we consider the grid spacing of 2m×2m and 4m×4m.

We implemented the system of IEEE 802.15.4 wireless transceivers using Freescale MC13224V third generation chipset with built-in ARM7TDMI processor. The antennas of wireless transceivers are the inverted F-shape antennas and operate at 2.480 GHz (i.e. channel 26 of IEEE 802.15.4 standard). The signal strength that STP i receives from RN j (P_{ij}) is generated based on RSS data measured from the real service area. The received signal strength threshold to ensure the radio communication between RNs and the target node is set to -110dBm [13] and the transmit power is set to 4 dBm [13]. In addition, a guideline of the positioning framework in [11] recommends that each STP should be able to receive signal from at least four RNs. Therefore, we set the value of NR equals to 4. To provide sufficient coverage over the service area, we defined the value of N_S equals to 4 on each floor.

Fig. 7 depicts a set of RNs which were installed

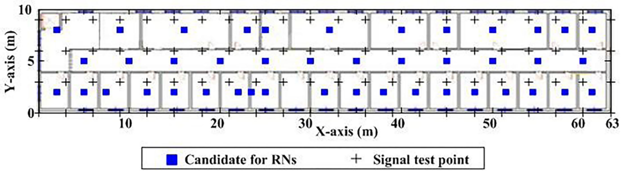

Fig.1: *The First Service Area of Our Experiments.*

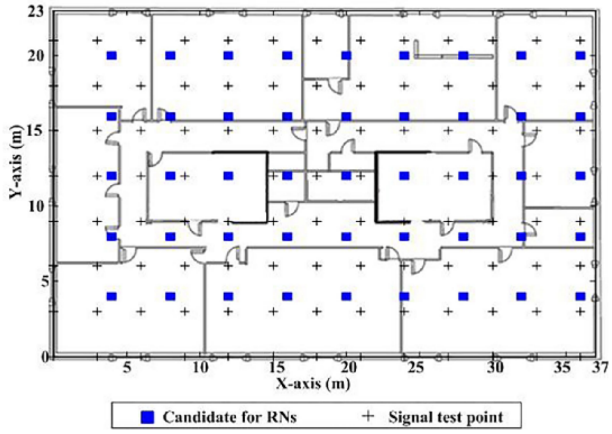

Fig.2: *The Second Service Area of Our Experiments.*

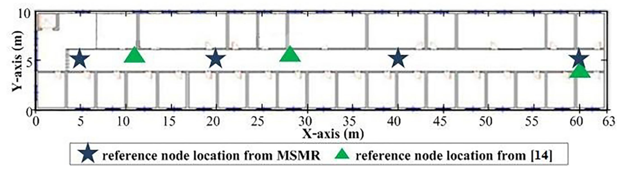

Fig.3: *Comparison of RN Placement in the First Service Area.*

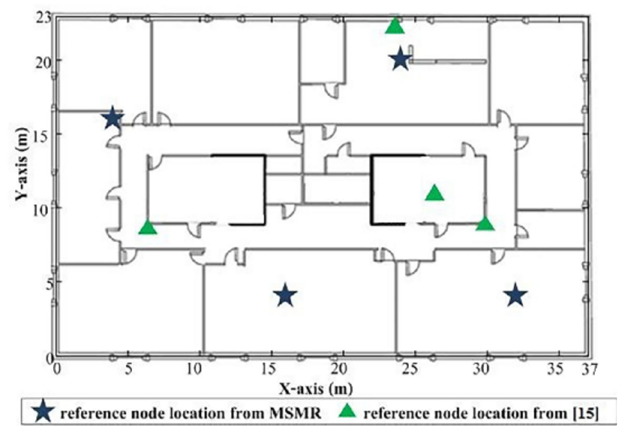

Fig.4: *Comparison of RN Placement in the Second Service Area.*

within the service area the height of RNs is at 2 meters. The target node used in our experiments is a mobile node consisting of the wireless transceiver connected to a computer notebook, which is used to calculate positions of the object. The height of the wireless transceiver of the target node is 0.8 meters.

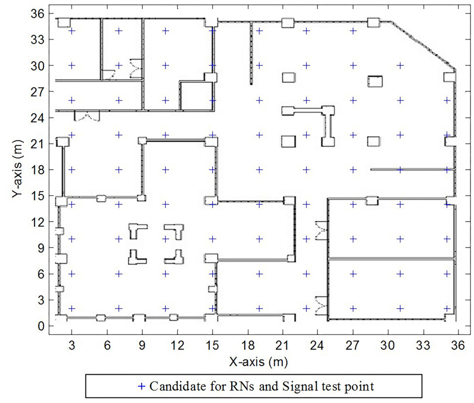

Fig.5: *The Third Service Area on 1st Floor of Our Experiments .*

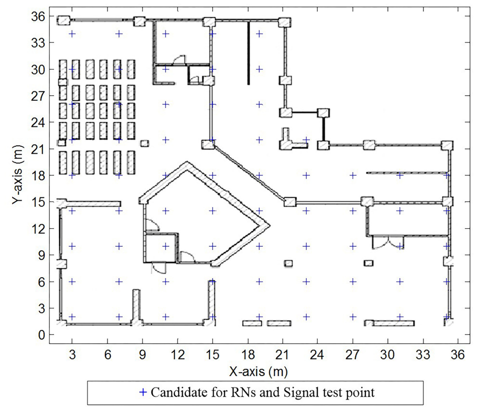

Fig.6: *The Third Service Area on 2nd Floor of Our Experiments .*

Finding optimal locations to install RNs for indoor positioning in the multi-floor environment is more complicated than that of the single floor scenario. We could not use CPLEX to solve the RN placement problem. The program could not yield feasible solutions after running for 72 hours. But we could obtain near optimal solution by using our proposed SA technique implementing on MATLAB R2012b solver running on an Intel Core i5-2450M Processor 2.5 GHz and 4 GB of RAM.

Fig. 8 illustrates run-time of finding solution for the multi-floor positioning systems obtained by MSMR-M using the proposed SA technique in which the search process converged within about 100 iterations (less than 2 minutes). Fig. 9 and Fig. 10 depict the optimal locations of RNs for the first and second floor of the service area, respectively (denoted by green star symbols). The figures also show the locations of RNs based on the uniform placement technique in [10] (denoted by blue triangle symbols). In the next section, we will analyze and compare the accuracy performance of the positioning system designed by our proposed method with those design used in [10].

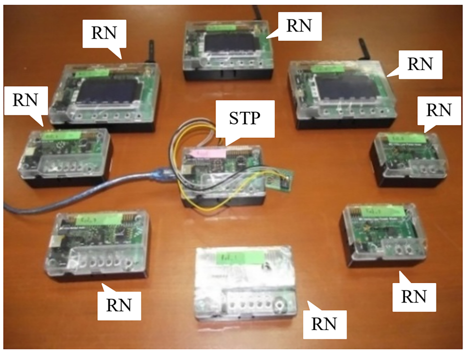

Fig.7: *Experimental Equipment in This Work.*

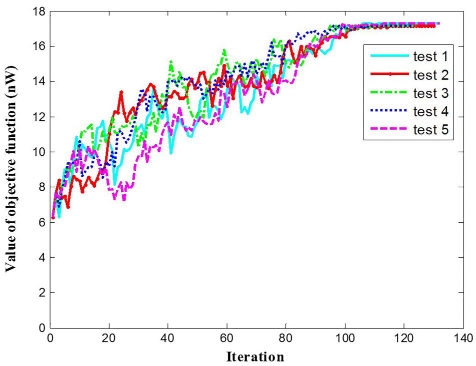

Fig.8: *Run-time of MSMR.*

4. ANALYSIS OF POSITIONING PERFORMANCE

In this section, we present an analysis of the accuracy of the positioning systems presented in the last section. In order to test the positioning systems based on the location fingerprinting, first, in this section we will analyse our proposed technique to determine optimal placement of RNs for single-floor building and multi-floor building as described below. Then in Section 5 we will conclude the positioning performance of the positioning systems obtained by our models and will compare with other node-placement techniques found in the literature.

4.1 Single-floor Building

In this section, we will present an analysis of the accuracy of the positioning systems presented in the last section. In order to test the positioning systems based on the location fingerprinting, first in the offline phase we need to create a fingerprinting database. The radio map of the received signal strength at STPs is simulated by using the path-loss model as written in (9). Then in the online phase, during which the location of the target node is determined, the sample signal strength that the target node receives from RNs is also simulated by using the same path-loss model as written in (9) but this time incorporating a sample standard deviation of the log-normal distribution. Then the Euclidean distance technique [5] is applied to determine a location of the target node by matching the target's sampled signal strength with those signal strength in the fingerprinting database.

We conducted three sets of tests to determine locations of the target node. In each set of tests, twenty locations were randomly selected as the actual locations of the target node. Then the location of the target node was determined based on the positioning systems obtained by our models compared with other systems deployed in [14]

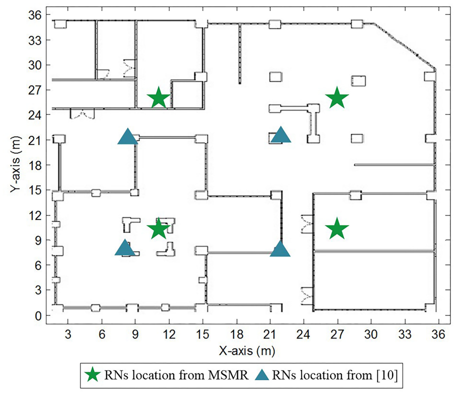

Fig.9: *Comparison of RN Placement on 1^{st} Floor in the Third Service Area.*

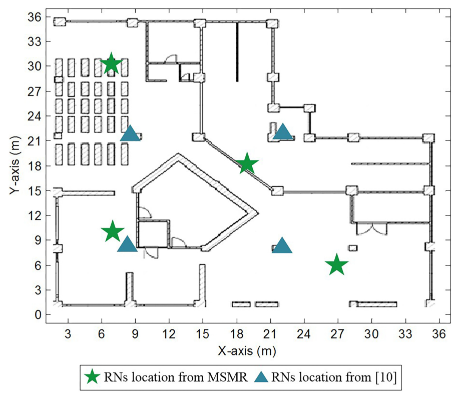

Fig.10: *Comparison of RN Placement on 2^{nd} Floor in the Third Service Area.*

and [15]. Fig. 11 and Fig. 12 compare the actual locations and the estimated locations of the target node in the first and second service area, respectively.

Table 3: *Accuracy Comparison of Two Service Areas.*

Experiment	**First Service Area**						**Second Service Area**					
	MSMR-M			Positioning system deployed in [14]			MSMR-M			Positioning system deployed in [15]		
	Min, Max (m,m)	Average (m)	SD (m)	Min, Max (m,m)	Average (m)	SD (m)	Min, Max (m,m)	Average (m)	SD (m)	Min, Max (m,m)	Average (m)	SD (m)
Test 1	1, 5.38	2.99	1.35	1, 15	3.56	2.95	1, 5.39	2.76	1.34	1.4, 13.15	5.66	4.1
Test 2	1, 7.07	3.64	1.62	1.41, 17	4.86	3.74	1.41, 6.1	3.61	1.61	1.4, 13.15	4.87	3.38
Test 3	1, 6.08	2.69	1.58	1, 17.46	3.86	4.18	0, 5.1	2.88	1.52	1, 16.28	4.93	3.7

The figures show positioning results obtained by using the positioning systems designed by the proposed MSMR-M model.

Table 3 summarizes the positioning performance in term of the error distance from the three sets of tests and compare results from the positioning systems designed by the proposed MSMR-M model with those from the positioning system deployed in [14] and [15], respectively. We can observe that the positioning systems designed by MSMR-M model yield the highest accuracy. The optimal placement of RNs obtained from the proposed models can reduce the positioning error up to 18% and 16% compared with the positioning system deployed in [14] and [15], respectively.

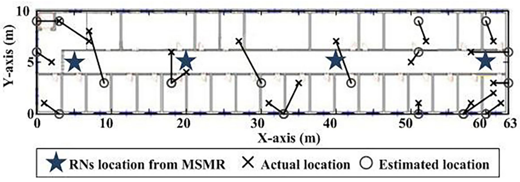

Fig.11: *Position Estimation Error of Test 1 in the First Service Area.*

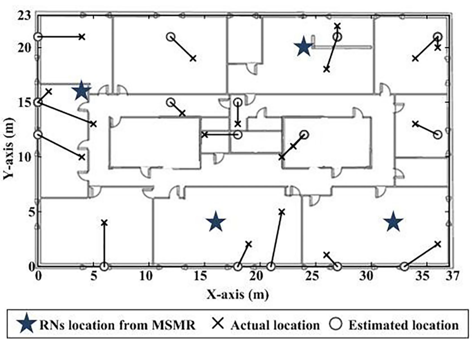

Fig.12: *Position Estimation Error of Test 1 in the Second Service Area.*

Different environments of positioning systems yield different accuracy of the location determination. Fig. 13 depicts the Cumulative Density Function (CDF) of the error distances resulting from the positioning systems designed by the proposed MSMR-M model and those from the positioning systems deployed in [14] and [15], respectively.

We can see that the positioning systems designed by MSMR model yield higher positioning accuracy, i.e. less error distances, compared with those of the other systems in [14] and [15]. Particularly, 90% of tests using the positioning system designed by MSMR model result in error distance less than 5m whereas the other systems in [14] and [15] result in error distance up to 7.5m and 10m, respectively.

4.2 Multi-floor Building

In this section, we present an analysis of the accuracy of the positioning systems model for multi-floor building using the locations of RNs as obtained in the last section. We conducted five sets of tests to determine locations of the target node. In each set of tests, thirty locations were randomly selected as the actual locations of the target node. Then the location of the target node was

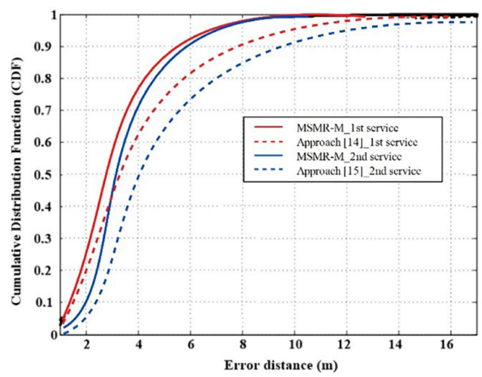

Fig.13: *CDF of Error Distance of First and Second Service Areas.*

determined based on the positioning systems obtained by our proposed technique compared with the other system obtained by using the uniform placement technique in [10]. Fig. 14 and Fig. 15 compare the actual locations and the estimated locations of the target node on the first and second floor of the third service area, respectively (in the case of grid spacing of four meters). The figures show positioning results obtained by using the positioning systems designed by the proposed MSMR-M model.

Table 4 summarizes the positioning performance in term of the error distance from the five sets of tests and compare results from the positioning systems designed by the proposed MSMR-M model with the uniform placement technique in [10]. We can

Table 4: *Accuracy Comparison for Multi-floor Building of the Third Service Area at Two Grid Spacing.*

Experiment	2m × 2m						4m × 4m					
	MSMR-M			Uniform Placement [10] deployed in [14]			MSMR-M			Uniform Placement [10] deployed in [15]		
	Min, Max (m,m)	Average (m)	SD (m)	Min, Max (m,m)	Average (m)	SD (m)	Min, Max (m,m)	Average (m)	SD (m)	Min, Max (m,m)	Average (m)	SD (m)
Test 1	0, 5	1.57	0.94	0, 8.94	2.11	1.55	0, 4.24	2.01	0.77	0, 6.50	2.40	1.20
Test 2	0, 4.03	1.45	0.77	0, 6.10	1.71	1.15	0, 5.22	2.23	0.97	0, 7.43	2.33	1.20
Test 3	0, 3	1.42	0.70	0, 5	1.66	0.95	0, 4.24	2.21	0.87	0, 5.39	2.41	0.93
Test 4	0,4.61	1.49	0.94	0, 6.78	1.81	1.15	0, 4.03	1.93	0.76	0, 7.76	2.32	1.30
Test 5	0, 6.40	1.57	1.11	0, 5.39	1.72	1.04	0, 5.41	2.37	1.06	0, 9.12	2.78	1.51

observe that the positioning systems designed by MSMR model yield the highest accuracy. The optimal placement of RNs obtained from the proposed models can improve the positioning error up to 20% compared with the positioning system deployed in [10]. Fig. 16 compares the cumulative distribution function (CDF) of error distances resulting from the positioning systems for 2-story building at grid spacing of two and four meters, respectively.

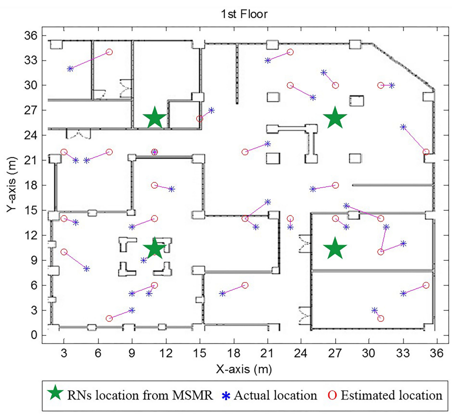

Fig.14: *Position Estimation Error of Test 1 on 1^{st} Floor of the Third Service Area.*

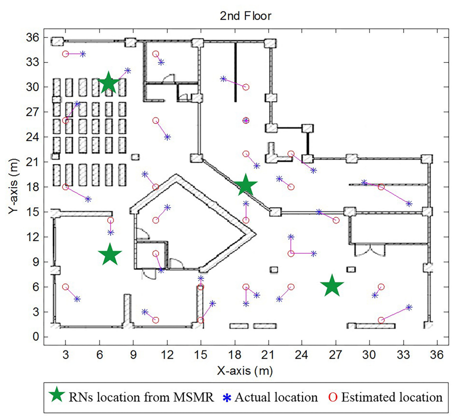

Fig.15: *Position Estimation Error of Test 1 on 2^{nd} Floor of the Third Service Area.*

We can observe that the positioning systems designed by our MSMR-M model yield the higher accuracy than other model in both situations. MSMR-M model could yield positioning accuracy at the minimum average error distances of 1.42 and 1.93 meters for the case of grid spacing two and four meters, respectively, whereas the system designed by the uniform placement technique yields the positioning accuracy at the minimum average error distances of 1.71 and 2.32 meters for the case of grid spacing two and four meters, respectively. Particularly, 90% of test using the positioning systems designed by MSMR-M model result in error distance of 2.68 and 3.30 meters at grid spacing of two and four meters, respectively whereas the other model result in error distance of 3.36 and 4.05 meters at grid spacing of two and four meters, respectively. Therefore, the optimal placement of RNs obtained by the proposed model outperforms the other technique up to 20% and 18.5% for the case of grid spacing of two and four meters, respectively.

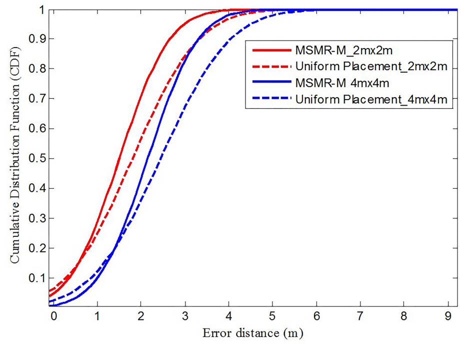

Fig.16: *CDF of Error Distance of the Third Service Area at Two Grid Spacing.*

5. CONCLUSIONS

In this paper, the optimal placement problems of reference nodes (RNs) in wireless indoor positioning systems are investigated. We propose a novel mathematical formulation using a Binary Integer Linear Programming (BILP) approach that can determine optimal number and locations to install RNs in the target service area of the indoor positioning system. The proposed models incorporate essential factors suggested in the deployment framework for wireless indoor positioning systems. Experimental results and comparisons illustrated that the proposed models yield positioning systems that can operate at higher precision compared with other positioning systems for single-floor building. In addition, the optimal placement problems of reference nodes (RNs) in wireless indoor positioning systems for multi-floor building are investigated. We propose a novel mathematical formulation using a Simulated Annealing algorithm (SA). Experimental results and comparisons illustrated that the proposed models yield positioning systems that can operate at higher accuracy compared with other model. The proposed model yield the positioning accuracy at the minimum average error distances of 1.42 meters and outperform the other technique up to 20%.

Our future works will consider parameters of the indoor environment. We aim to develop indoor positioning systems for multi-floor building by finding optimal locations of RNs on every floor simultaneously

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