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Optimal Design of Reference Node Placement for Wireless Indoor Positioning Systems in Multi-Floor Building

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***Abstract*—**In this paper, we propose an optimization technique that can be used to optimize the placements of reference nodes and improve the location determination performance for the multi-floor building. The proposed technique is based on Simulated Annealing algorithm (SA) and is called MSMR-M. The performance study in this work is based on simulation. We compare other node-placement techniques found in the literature with the optimal node-placement solutions obtained from our optimization. The results show that using the optimal node-placement obtained by our proposed technique can improve the positioning error distances up to 20% better than those of the other techniques. The proposed technique can provide an average error distance within 1.42 meters.

***Keywords*—**Indoor positioning System, Optimization System design, Multi-Floor Building, Wireless Sensor Networks.

I. Introduction

THE applications of wireless communication technology standard IEEE 802.15.4 for indoor positioning systems has gained more attention recently because it is small, lightweight and low power consumption [1]. The technology has widespread applications, such as location detection of the patient or equipment in hospital, product inspection in a manufacturing plant, identifying location of visitor in large museum, etc. [2]. The optimal design for the placement of wireless transceivers in the system is needed to ensure high service performance of the indoor positioning systems.

The techniques used for indoor positioning systems can be classified into three groups. The first group is based on Triangulation properties. Particularly, the geometric features of trigonometry are applied [3], [4]. The second group is based on proximity of known objects or symbolic location [5]. Finally, the third group is called scene analysis. It infers the location based on off-line observation of features of a scene [6]–[8]. This technique has gained more attention due to it is provided high accuracy, high precision and less complexity.

Procedures of the scene analysis techniques are divided into two phases [9]. The first phase is called an off-line phase. In this phase, the fingerprint database is created. This database collects parameters of interest in the service areas and is used to determine the coordinates of objects.

The second phase is call an online phase. In this phase, a set of reference nodes (RNs), which are installed in the building, send out referencing signal for the indoor positioning systems. Each RN has different name or Media Access Control address (MAC address) which is used as a reference for the measured signal strength. The target node, which is a device that is attached to an object or something that needs to know the location, measures the parameters of the system such as the received signal strength (RSS), the temperature, etc. Then, the measured parameters are used to determine the location of objects.

One of the key factors that affects the accuracy and precision of the scene analysis based indoor positioning systems is the placement of reference nodes [10].

Several works in literatures have shown interest in the placement design for reference nodes in the indoor positioning systems. The research work in [10] studied the effect of the access point (APs) placement on the performance of localization in WLAN based indoor positioning system. This work interested in the number and pattern of APs placement in both symmetric and asymmetric in service area. Such areas are complicated and could influence the accuracy of the indoor positioning systems. In [11], the authors studied the factors affecting the design of indoor positioning systems based on location fingerprinting such as path loss exponent, number of access point, grid spacing and methods used in estimating the location which affects the performance metric of indoor positioning systems. In [12], the authors presented a technique for reference nodes placement in a single story building base on Binary Integer Linear Programming (BILP) for a single plane. In Research [13], 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.

Based on our literature review above, existing studies are interested on the accurate and precise indoor positioning systems. There has been little interest on the placement design of reference nodes for indoor positioning systems. Existing work has not considered the optimum placement of reference nodes for multi-story buildings. Therefore, this paper focuses on the study and development of optimal reference nodes placement techniques for multi-story buildings. We aim to increase accurate and precision of indoor positioning services in multi-story buildings by installing reference nodes in the most suitable locations.

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The rest of this paper is organized as follows. In section II, we formulate the RNs optimization model in detail. Section III presents experimental study and analysis demonstrating the optimal RN placement. Section IV presents an analysis of accuracy of the positioning systems. Finally, Section V concludes our work and provides directions for future research.

II. Methodology

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 [14]. 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 [12]. 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 (1) and the constraints (2) - (5). Table I defines notation used in the proposed formulation.

Objective function:

$$Maximize \sum_{\forall i \in T} \max_{\forall j \in R}(S_{ij}P_{ij}) \qquad (1)$$

Constraints:

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

$$\sum_{\forall j \in R} S_{ij} \geq N_R \qquad \forall i \in T \qquad (3)$$

$$S_{ij} \leq c_j \qquad \forall i \in T, \forall j \in R \qquad (4)$$

$$\sum_{\forall j \in R} c_j = N_S \qquad (5)$$

TABLE I
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.
Constraint parameters:	
P_{ij}	The signal strength that a STP i receives from RN j, $i \in T$ and $j \in R$ (dBm).
P_T	The received signal strength threshold (dBm).
N_R	The minimum number of RNs recommended [5].
N_S	Sufficient number of RNs.

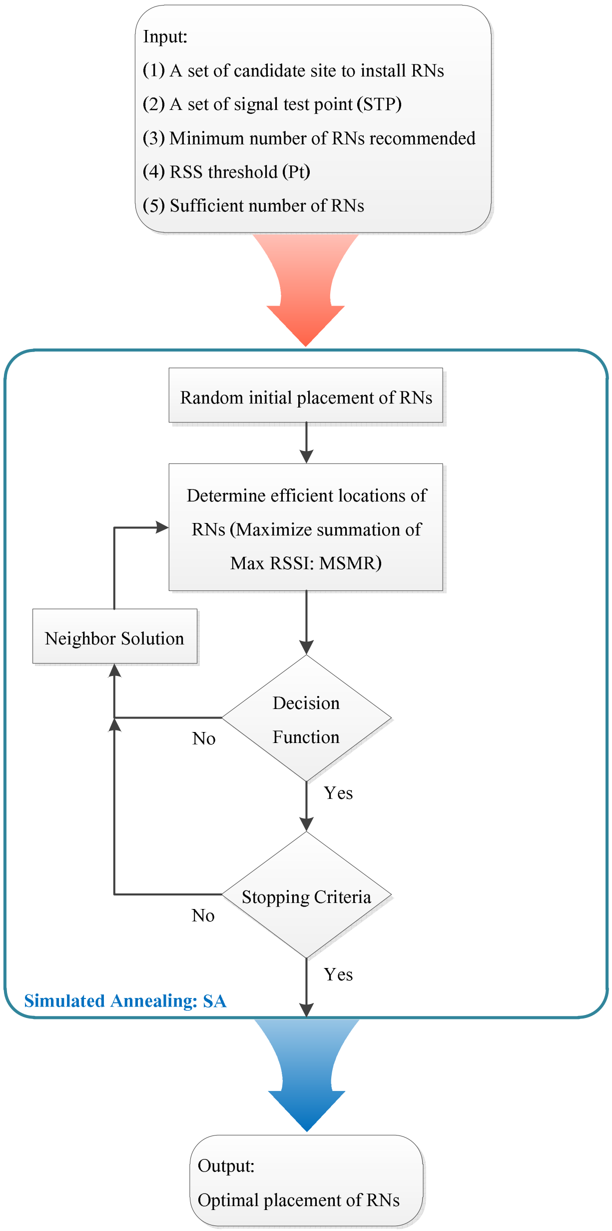

Fig. 1 The process of MSMR-M technique

The objective function (1) aims to maximizing summation of the maximum RSS at STPs or MSMR objective function. Constraint (2) is the condition for guaranteeing the quality of the radio coverage of RNs in the target service area of the building. Constraint (3) enforces that each STP must be able to communicate with at least a minimum number of RNs, specified with a parameter NR. Constraint (4) specifies that STP i can receive signal from RN j if a RN j is installed. And constraint (5) defined the number of nodes used in the installation must have an equal sufficient number of RNs.

Fig. 1 illustrates the process 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) [12]. Then SA starts by generating a random set of initial placement of RNs and evaluates the cost values with objective function. Then set this as a current state.

Those locations are selected by the decision function. If not selected, the neighbor solutions will be searched by applying the constraints of the problem. The cost values of the objective function will be evaluated and be compared with that of the current state. Then the new state will be obtained. This pattern repeats until reaching the stopping criteria. Finally, we will obtain the optimal placement for RN installation.

III. Implementation and Experiments

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 IV 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 approximately35×35m^2 as shown in Fig. 2 and Fig. 3. 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. 2 and Fig. 3. 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 2×2 m^2 and 4×4 m^2.

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 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 N_R equals to 4. To provide sufficient coverage over the service area, we defined the value of N_S equals to 4on each floor.

Fig. 4 depicts a set of RNs which were installed within the service area. The height of RNs is at 2meters. 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 0.8meters. We implement the proposed optimization technique by using the MATLAB R2012b solver. Computations are performed on an Intel Core i5-2450M Processor 2.5GHz and 4GB of RAM.

Figs. 2 and 3 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].

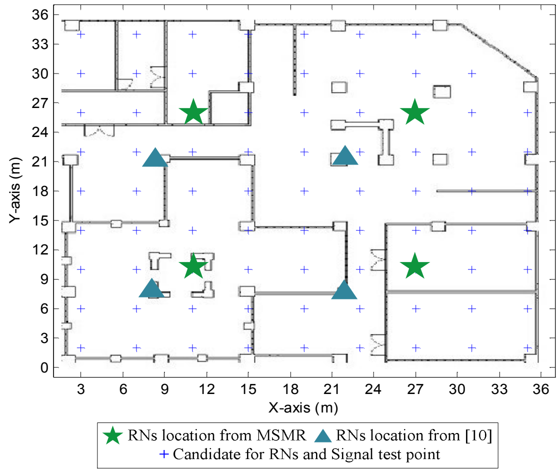

Fig. 2 1st floor of the service area

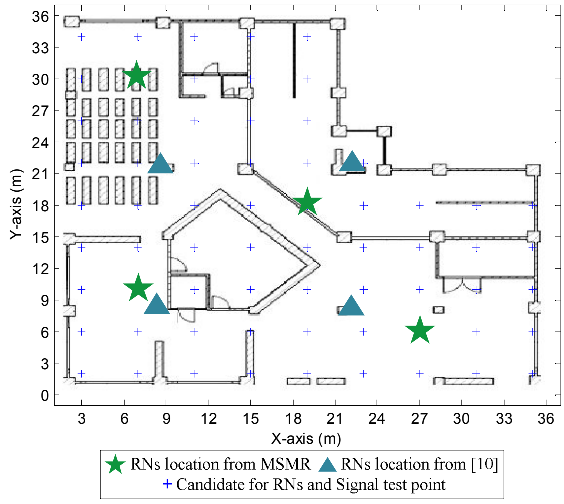

Fig. 3 2nd floor of the service area

Fig. 4 Experimental equipment in this work

IV. Performance Comparison and Analysis

In this section, we present an analysis of the accuracy of the positioning systems modeled 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 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].

Figs. 5 and 6 compare the actual locations and the estimated locations of the target node on the first and second floor of the service area, respectively (in the case of grid spacing of four meters). Figs. 7 and 8 compare 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.

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.

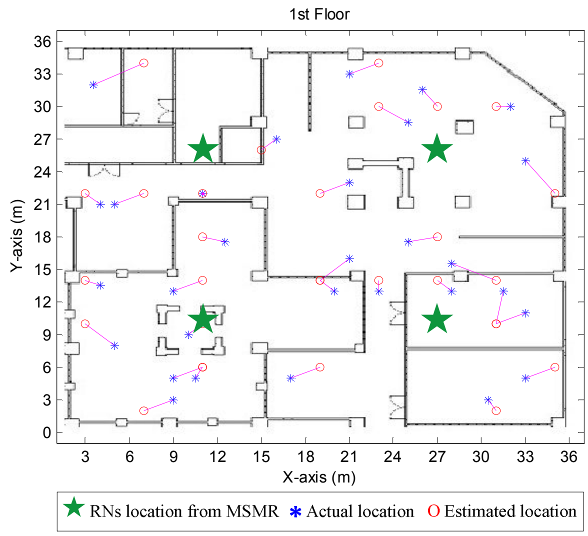

Fig. 5 Position estimation error of test 1 on 1st floor

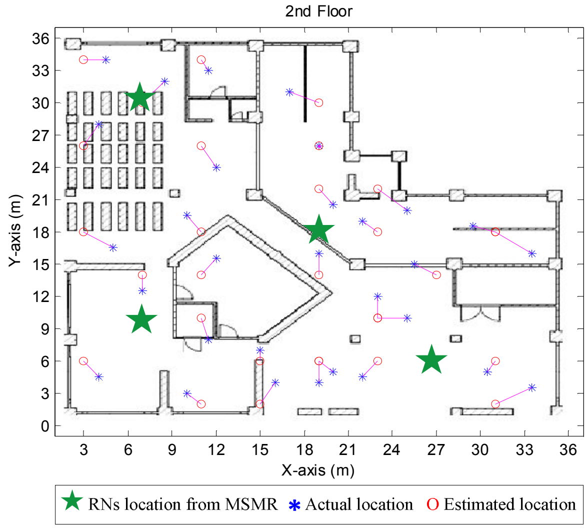

Fig. 6 Position estimation error of test 1 on 2nd floor

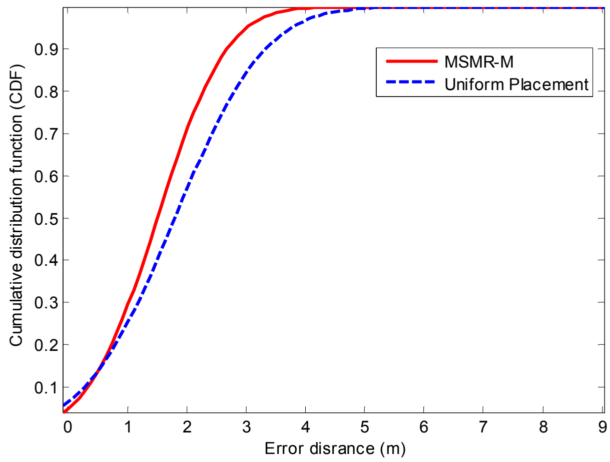

Fig. 7 CDF of error distance of the service area at grid spacing $2x2m^2$

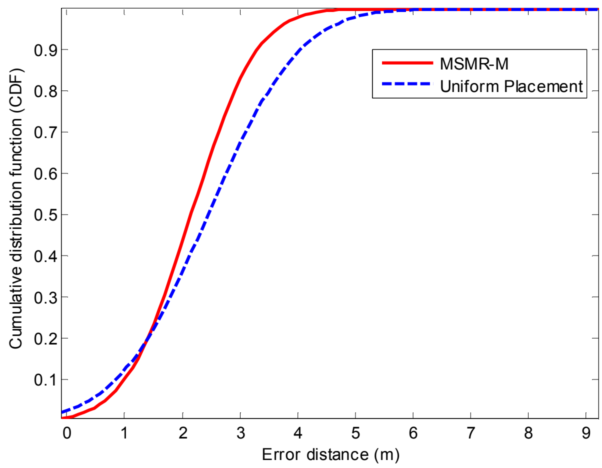

Fig. 8 CDF of error distance of the service area at grid spacing $4x4m^2$

V. Conclusion

In this paper, 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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