BalloonNet: A Deploying Method for a Three-Dimensional Wireless Network Surrounding a Building

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***Abstract*—Aiming at fast establishment of a wireless network around a multi-level building in a disaster area, we propose an efficient method to determine the locations of network nodes in the air. Nodes are attached to balloons outside a building and deployed in the air so that the network can be accessed from anywhere in the building. In this paper, we introduce an original radio propagation model for predicting path loss from an outdoor position to a position inside a building. In order to address the three-dimensional deployment problem, the proposed method optimizes an objective function for satisfying two goals: (1) guarantee the coverage: the target space needs to be covered by over a certain percentage by wireless network nodes; (2) minimize the number of network nodes. For solving this problem, we propose an algorithm based on a genetic algorithm. To evaluate the proposed method, we compared our method with three benchmark methods, and the results show that the proposed method requires fewer nodes than other methods.**

***Keywords*-Genetic Algorithm; disaster; radio propagation model; mobile ad hoc networks,**

I. INTRODUCTION

Recently, the world has experienced a succession of large-scale natural disasters such as earthquakes, volcanic eruptions and extreme weather conditions. In disaster rescue areas, systems with cutting-edge IT technologies like the Electric Triage System and the Advanced Health and Disaster Aid Network (AID-N)[1] have been developed for utilizing electronically acquired vital information on life and location of victims. Since these systems require access to a wireless network, restoration of communications infrastructure is an urgent task in a disaster area. As a means to build communications infrastructure quickly, wireless ad-hoc networks are attracting attention, and many methods have been studied in recent years. A wireless ad-hoc network is a technique for building a wireless network, using only network nodes and without a base station, where each node can communicate directly with other nodes that exist within the communication range or indirectly with distant nodes through intermediate nodes. This technique is expected to become an effective help for communication in major disaster areas, because it does not require a dedicated infrastructure, advanced knowledge or expensive devices.

Many methods for building a wireless ad-hoc network in an indoor environment have been proposed [2] disaster rescue operations, it is necessary for a wireless network to cover an entire building so as to support first responders. And in the search and rescue of victims, it is also required to deploy a large number of nodes in order to cover a building which is in risk of collapse. Bread crumb [4] is a method for constructing a wireless ad-hoc network inside a building in a challenged environment. Basically, this method entails placing network nodes one by one by rescue members as they move inside the building. But a problem here is that the additional work of node deployment can interfere with rescue operations. Therefore, we need a method to quickly cover an entire building with wireless nodes deployed outdoors and without having to enter the building.

In this paper, we propose a three-dimensional node deployment method for setting up a wireless network that covers an entire building from the outside. We place small battery-driven network devices suspended from balloons in the air. Since radio waves penetrate window glass with little attenuation, the network nodes can provide wide coverage in a horizontal direction, and their performance is comparable to access points deployed inside a building. In addition, some floors of the building may receive radio waves more efficiently from outside than from an AP inside the building, since the radio attenuation is high when penetrating thick ceilings and floors. In order to enable indoor localization service and improve the fault tolerance, our method guarantees k-coverage of a wireless network. The problem of positioning the network nodes outside a building is NP-hard [5], so we propose a heuristic method based on a genetic algorithm. Although several existing radio propagation models [8] have been studied for outdoor or indoor environments, we found those models unsuitable for our method, which requires calculating outdoor-to-indoor attenuation. For this reason, we use an original radio propagation model that takes account of the diffracted distance and the obstacles inside a building in order to calculate the

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communication range of network nodes in our method.

Our evaluation showed that our algorithm can reduce the number of nodes by up to 50%, compared with other methods. We compared the simulated received signal strength(RSS) at each point and the measured RSS in the real environment, and we found that the RSS and the overall radio coverage in a real building are very close to the simulated results. As a result of computing complexity, the computing finished within 10 minutes in the most complex case. We also conducted a real-world experiment for triangulation based indoor positioning based on RSS. The average error was within 3.86m, which is considered to be practical.

II. RELATED WORK

Deployment methods for wireless network nodes are studied for various purposes, such as maximizing the lifetime of network and communication speed. When deploying wireless network nodes in an environment like a disaster area, maximizing the coverage or minimizing the number of nodes to cover the target space is required since the resources are limited. Dhillom et al proposed a method for covering a space with wireless nodes by approximating a communication range with a hexagonal shape[9]. If there are no obstacles in the target space, this method finds near-optimal positions for deployment. Wang et al proposed a method that takes into consideration the obstacles[10]. If an obstacle exists within the communication range of the network nodes, the area beyond the obstacle is treated as an out-of-radio-range region for the node, and thus communication area varies significantly depending on the positions of the nodes. They find efficient deployment positions by dividing the target space into regions susceptible to the obstacles. Lin et al proposed a method[12] using GASA[11] in which the communication range of network nodes is treated as a circular shape. This method searches for the combination of the minimum number of nodes by alternately applying simulated annealing and a genetic algorithm. Since these are studies for deployment in a two-dimensional space without considering height, network nodes have to be deployed on each floor if an entire multi-story building is to be covered; and this requires many nodes.

Some methods for three-dimensional deployment are studied. Carle, Decayeux and Nazrul likened communication range to rhombic dodecahedron[13], hexagonal[14] and truncated octahedron shapes[15]. Since this problem belongs to the NP-hard class, these methods find heuristic solutions as a packing problem. However, these methods did not allow for the existence of obstacles. Since the communication range of all network nodes is considered to be a sphere, these methods operating in only two dimensions are difficult to apply to a real world environment.

As a way of providing a wireless network in a disaster area, Shibata et al have proposed a method to launch network nodes and antennas using balloons in the sky[16]. The balloons are launched at intervals of several kilometers. In this way each network node provides wide range coverage. Moreover, additional functions such as video cameras and atmosphere sensors can also be added. However, this approach requires specialized devices and enormous time for installation, and does not cover the inside of buildings.

We assume that a wireless network is to be used for exchanging data and for indoor positioning in disaster area rescue operations. Due to the unstable environment in a disaster, fault tolerance is a very important requirement for such a network. In this paper, we propose a method intended to improve positioning accuracy and fault tolerance by ensuring k-coverage. Since network nodes are deployed outside of the building using balloons, we have two advantages: (1) low installation cost; (2) low injury risk during deployment, because there is no need to install devices inside the building. The proposed method minimizes the number of nodes needed to guarantee k-coverage of the building.

III. PROBLEM STATEMENT

In this section, we first give an overview of our method. We then explain our assumptions and formulate the problem of determining the positions of the nodes.

A. Overview of the Proposed Method

Fig.1 pictures a deployed balloon network. In order to cover the entire multi-story building, network nodes attached to balloons are deployed in the air around the building.

B. Assumptions

Balloons

The heights of balloons are easily changed by adjusting string length. Each balloon is moored from three ground points. Preliminary experiments confirmed that balloons at a height of 20m do not swing excessively in the wind .

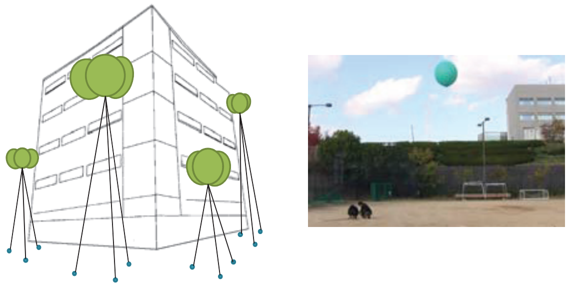

Fig. 1. Image of Deployed Balloon Network and Preliminary Experiments

Network Node

Network nodes are battery-powered devices with ad-hoc communication function capability. Transmission power and receiver sensitivity are assumed to be constant until the battery of the network node runs out. We define the minimum signal strength that can communicate with other network nodes as T[dBm]. The area R_a covered by network node A is defined as the area where received signal strength from node A is greater than T.

Target Building

We assume that the building is in a disaster area. The building is represented by a set of cubic cells having a length

l on each side. Each cell has a unique ID that corresponds to its position. Each cell has one attribute of material that is either air, inner wall, outer wall or ceiling (floor). A cell is the smallest unit of coverage.

C. Problem Formulation

We formulate the problem to minimize the number of nodes needed to satisfy the k-coverage of the building.

Input

- Geometry: A floor plan of the target building; locations where balloons can be placed.
- Propagation prediction formula L: a formula that calculates the propagation loss between a transmitter and a receiver.
- Number k of coverage
- Ratio s of covered cells

Output

- Location and the number of network nodes.

Constraint

Suppose that N is a set of deployed network nodes, M is a set of cells, and the number of nodes of coverage is k. Let ap_i and c_j be the ith network node ($ap_i \in N$) and the jth cell ($c_j \in M$). $p(i,j)$, are defined as follows. They show whether ap_i covers c_j or not.

$$p(i,j) = \begin{cases} 1 & L(i,j) \geq T \\ 0 & otherwise \end{cases} \tag{1}$$

Function $kp(j)$ shows whether c_j is covered by k nodes or not. Function $kp(j)$ is defined as follows.

$$kp(j) = \begin{cases} 1 & \sum_{i=1}^{|N|} p(i,j) \geq k \\ 0 & otherwise \end{cases} \tag{2}$$

The constraint is expressed by the following formula.

$$\frac{\sum_{j=1}^{|M|} kp(j)}{|M|} \geq s \tag{3}$$

Objective function

Minimizing the number of nodes needed to satisfy the constraint is the purpose of this study; the objective function is represented by following formula.

$$\textbf{minimize}(n) \textbf{ subject to constraints } (3) \tag{4}$$

IV. RADIO PROPAGATION MODEL

In order to realize our method for node deployment, we need to calculate outdoor-to-indoor radio attenuation. We also need to take account of obstacles like floors and walls which may interfere with radio wave propagation. There are several attenuation models including the ECC-33 model[6], the SUI model[7], the COST-231 model[8], the model proposed by Okamoto et al[17] and the model proposed by Kitao et al[18]. These models are based on the Euclidean distance between an access point and a receiver, and some of the models also consider obstacles between those two points. However, diffraction of radio waves is not usually considered. Our observation suggests that radio waves tend to go through corridors in indoor environments, and thus we can get more accurate results by taking account of detours. Therefore, we propose a model which takes into account diffraction of radio waves in addition to attenuation due to obstacles. In general, detailed data of a building's structure is needed to calculate the diffraction of radio waves, but it is usually difficult to get a detailed floor plan in a disaster area. So, we propose a new model which only requires parameters obtained from a simple floor plan.

Some models including [19] and [20] take account of floor height gain, which expresses the reflection of radio waves from the ground and the character of non-uniform emission from the antennas. We did not consider this in our model since there was no correlation between signal strength and floor height in our experiment.

A. Construction of a Radio Propagation Model

Prediction Formula of Reference

The model proposed by Okamoto et al. is based on measured radio strength at points outside and inside the building[17]; and this model represents the attenuation due to the outer wall of a building. They suggest that their model can be used to construct an outdoor-to-indoor attenuation model by combining their model with the model proposed by Kitao, et al.[18]. Equations (5) and (6) represent the model for outer-wall attenuation and the model proposed by Kitao, et al, respectively. d, d_{in} and h denote the distance between an access point and an outer wall, the distance between window to receiver, and the height from ground, respectively; and f is frequency.

$$Loss_{out} = 54 + 40\log d - 30\log h + 21\log f \tag{5}$$
$$Loss_{in} = 0.6d_{in} - 0.6h + 10 \tag{6}$$
$$Loss = Loss_{out} + Loss_{in} \tag{7}$$

Construction of a Radio Propagation Model

Equation (8) represents our model for signal attenuation between access point A and receiver B. The model of attenuation is addition of attenuation $Loss_{distance}$ by distance and attenuation $Loss_{obstacle}$ by obstacles. The parameters are shown in Table I.

$$L(A,B) = Loss_{distance} + Loss_{obstacle} \tag{8}$$

The model for attenuation by distance takes account not only of the distance d_1 between A and B, but also of detour distance d_2 with the least number of obstacles. If there is no obstacle between A and B, d_1 is equal to d_2. Otherwise, d_2 is greater than d_1. The constants α, β, γ and δ are obtained by the multiple regression method from the measurement results described in IV-B.

$Loss_{obstacle}$ represents the attenuation by obstacles placed between A and B. O_i represents the number of obstacles of

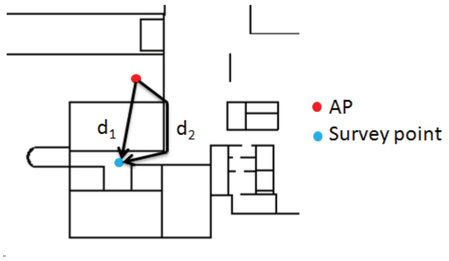

Fig. 2. Example of d1,d2

TABLE I
PARAMETERS OF PROPAGATION MODEL

Term	Description
$L(A,B)$	The function returns the attenuation between positions A and B, which is addition of attenuation by distance and obstacles
$Loss_{distance}$	Denotes the attenuation due to Euclidean distance (d_1) and diffracted distance (d_2)
$Loss_{obstacle}$	Denotes the attenuation due to obstacles
$\alpha = 36.37$	Coefficient for attenuation due to Euclidean distance d_1
$\beta = 0.12$	Coefficient for attenuation due to $d_2 - d_1$
$\gamma = -69.13$	Coefficient for attenuation due to diffraction
$\delta = -28.51$	Constant

each kind (e.g., the number of walls between A and B), and ρ is the attenuation by each kind of obstacle.

$$Loss_{obstacle} = \sum \rho_i O_i \tag{9}$$

Fig.2 shows an example of the target environment. The red dot and the blue dot show an access point and a survey point, respectively. d_1 is the Euclidean distance and d_2 is the diffracted distance between A and B. There is only a single outer wall in the diffracted path. Attenuation by obstacles is calculated by the two obstacles in the straight path between A and B, which are an outer wall and an inner wall.

B. Measurement

We classify the obstacles into the three kinds shown here.

- Inner wall
- Outer wall
- Floor

In order to determine the coefficients α, β, γ and ρ, and the coefficients for each kind of obstacle, we carried out an experiment in measuring in the Department of Information Science Building of Nara Institute of Science and Technology. We used a notebook PC with Atheros AR9280 IEEE 802.11g NIC, a BUFFALO WZR-HP-G300NH access point, and inSSIDer[21] for measurement software. We placed the access point outside the building, and measured signal strength from 150 points inside the building. At each point, we faced in the direction of the access point with the PC in front of us in order to avoid attenuation due to the human body. We recorded the median value of the values measured over each 15 seconds. Fig.3 shows some of the measurement points. Measurements were also made on floors different from the floor where the access point was placed.

We found the coefficients in the model formula shown as Eq.10 by regression analysis from the measured signal strength. For comparison, we also calculated coefficients for a formula shown as Eq.11, which does not take account of a diffracted path. Table II shows, for the two models, the coefficients for calculating attenuation due to obstacles.

Fig. 3. Example of measured location

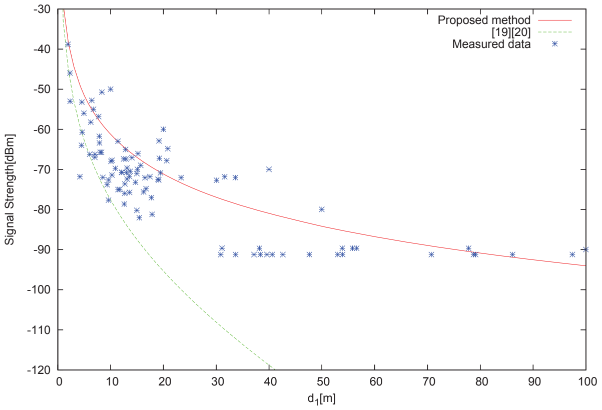

Fig. 4. Comparison of proposed model and the model in [19][20]. The proposed model and the model in [19][20] are plotted respectively in the case of $d_1 = d_2$ and $d_1 = 0.95d_{in} + 0.05d, h = 20, f = 2400$.

$$\begin{aligned} Loss_{distance} &= 36.67\log(d_1) + 0.12(d_2 - d_1)\log(d_2) \\ &\quad -69.13\log(d_2) - 28.51 \quad (10) \\ Loss_{distance} &= -29.34\log(d_1) - 37.66 \quad (11) \end{aligned}$$

Fig.4 shows the comparison between the measured attenuation due to the distance and the $Loss_{distance}$ terms calculated by the two models. We subtracted the $Loss_{obstacle}$ value from the measured data to find the measured attenuation by distance. Fig.5 shows the absolute error for each model, and Table III shows the statistical errors of the two formulas and Okamoto's formula. ME, RMS, SD and R^2 express the average of the prediction errors, the mean square root, the standard deviation and the determination coefficient, respectively. Although fig.5 shows little difference between the proposed model and the model without d_2, the detailed values of table III show that SD and RMS for the proposed model are better than SD and RMS for other formulas. The average of the prediction errors is 4.06dBm, which is considered to be accurate enough to be used for range based indoor positioning methods.

$$\begin{aligned} Loss_{distance} &= \alpha\log(d_1) + \beta(d_2 - d_1)\log(d_2) \\ &\quad +\gamma\log(d_2) + \delta \quad (12) \end{aligned}$$

V. PROPOSED METHOD

The problem of deploying wireless sensor nodes in a three-dimensional space is NP-hard[5], and it is therefore hard to

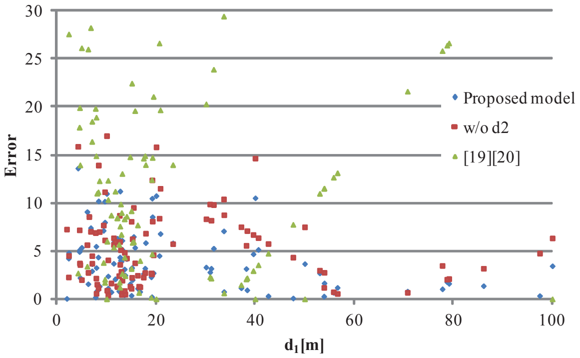

Fig. 5. Error in each model

TABLE II
OBSTACLE COEFFICIENTS

	Inner wall	Outer wall	Ceiling or Floor
Proposed model	-0.72	-6.44	-3.41
w/o d_2	-1.59	-7.17	-7.25

find the optimal solution in a practical time. In this paper, we propose a heuristic algorithm based on Genetic Algorithms.

A. Overview

In the proposed method, multiple network nodes are positioned to satisfy k-coverage of the building according to the required ratio of s. The method starts with a sufficient number of nodes and positions them to satisfy the coverage condition. If it finds a solution, then it decreases the number of nodes and continues until it cannot find a solution with the resulting number of nodes. The initial population is generated randomly, and when the number of nodes is decreased, the result of a previous search is reused to improve the search speed of the subsequent searches. Pseudocode for the proposed algorithm is shown in Fig.6.

B. Details of the Algorithm

n, P, N, P' and L denote, respectively, the number of network nodes, population (a set of solution candidates, or chromosomes), population size ($|P|$), an interim population and a set of available locations for deployment. In this method, a chromosome (a solution candidate) is a list of vectors, where a vector is a set of three integers representing the coordinates of a node. The order of the vectors in a chromosome does not affect the corresponding deployment pattern or the evaluation of the chromosome.

Function InitialPopulation() generates N solutions where the number of nodes is n. Coordinates for each node are determined at random from the location L. Function Search() performs the search described above, which finds positions of nodes to satisfy the coverage condition. Function DecreaseNode() decreases the number of nodes so that the population can be used for subsequent searches. It removes one of nodes at random.

Function Search() determines the positions of the given number of nodes with a GA-based algorithm. It continues the

TABLE III
STATISTICS OF ERROR IN MODEL PREDICTIONS

	ME	RMS	SD	R^2
Proposed model	4.06	5.36	3.51	0.86
w/o d_2	5.27	6.63	4.04	0.79
[17][18]	13.27	16.62	10.07	n/a

```
Parameter : $N$ = Number of elements
Input :
$n$ = Number of nodes in a solution candidate
$L$ = Set of deployable location

//Generate set of initial solution candidates
$P = InitialPopulation(n, N, L)$
//Search better solution candidates until convergence
while true do
  //Generate population of the next generation
  $P' = Search(P)$
  //if Search() returns $\emptyset$, convergence is detected
  if $P' = \emptyset$ then
    break
  end if
  //generate a new candidate set by randomly removing a node from each solution candidate in $P'$
  $P$ =DecreaseNode($P'$)
end while
return the best solution in $P$
```

Fig. 6. Pseudocode for the Proposed Algorithm

search for the given number of generations, and if the solution does not converge, the entire population is returned. Otherwise, it returns $\emptyset$. The algorithm for this function is shown in Fig. 7.

Details of each function used in Search() are described below.

- **Mutate()**
  In order to avoid converging to local optima, a random change of population is needed in the search process. Function Mutate randomly moves the coordinates represented by a gene (a vector that represents the coordinates for a single node). This function changes each gene with 3% probability.
- **LocalSearch()**
  In order to find better solutions not present in P, with little computing complexity, we added a local search to the GA process. This is only applied to the best 5 chromosomes in the population. It replaces a chromosome with a new one, if a new chromosome with a better evaluation is found.
- **Crossover()**
  Crossover function creates new chromosomes from a pair of existing chromosomes. Usually, the probability of crossover is constant. In our method, we tried to dynamically change this probability to speed-up convergence. We let the chromosomes with a higher score be selected

```
Input :
$P$ = Population
$M$ = Set of all cells that need to be covered in the building

while Number of generations $\leq$ 50 do
    //Solution candidates are randomly changed to prevent convergence to local optima
    Mutate($P$)
    //Local search is performed to speed-up convergence
    LocalSearch($P$,5)
    Crossover($P$)
    Evaluate($P, M$)
    //If no new candidate with a higher score appears for 10 generations, finish the search
    if Converged($P$,10) then
        return $\emptyset$
    end if
    //Tournament selection is performed to the set of solution candidates
    Select($P$)
    if the best pattern in $P \geq s$ then
        return $P$
    end if
end while
//no solution
return $\emptyset$
```

Fig. 7. Pseudocode for Search function

more easily as parent chromosomes. More concretely, the probability of crossover is determined by the number of cells covered by the node. Suppose that ap_{cover} and M, respectively, are the number of cells covered by a network node and a set of cells, and the probability is set to $ap_{cover}/|M|$.

- **Evaluate()**
  In the Evaluate function, the k-coverage rate is assigned to each chromosome as its evaluation.
- **Converged()**
  If the evaluation score is not updated for 10 generations, the search is considered to be converged, and the search is ended.
- **Select()**
  Tournament selection is conducted between two randomly selected chromosomes in P, and the chromosome with worse evaluation is removed.

VI. EVALUATION

In order to evaluate the proposed method, we compared our method to other methods. We also investigated the validity of the proposed method through experiments in a real environment.

A. Environmental Configuration

We conducted our experiments in the Department of Information Science building, Nara Institute of Science and Technology. The length, width and height of the building are 110m, 80m and 28m, respectively. All access points were deployed outside of the building, and the radio coverage was measured on all floors (1F-7F) of the building. We set the cell width to 0.96m, and the radio sensitivity threshold T of RSS was set to -86dBm, the level required to maintain 6Mbps communication according to a product specification for an access point[22]. The environment for running our programs to optimize the node positions is shown in the following:

TABLE IV
EXECUTION TIME[MIN]

	$s = 85$	$s = 90$	$s = 95$
$k = 1$	3.23	3.74	3.76
$k = 2$	4.33	4.91	5.61
$k = 3$	6.81	7.56	8.93

- CPU: Intel Core i7 920 (2.66GHz)
- Memory: 12 GB
- OS: Windows 7 Professional x64
- Language: Java SE 1.6
- Runtime Environment: Build 1.6.0 _ 24-b07

We first conducted a simulation-based comparison with other methods of the number of nodes required to satisfy the given coverage condition.

We then verified the performance of the proposed method through experiments in a real experiment in the environment. In these experiments, all network nodes were deployed at the positions derived by the programs. We compared the simulated received signal strength(RSS) at each point and the measured RSS.

We also conducted a real-world experiment for triangulation based indoor positioning based on the RSS, which was described in Section IV.

B. Compared Methods

We used three methods for comparisons with the proposed method. We executed all methods for the same execution time, shown in Table IV. We changed the required number of coverages k from 1 to 2, and then from 2 to 3. The required coverage rate s was also set to 85%, 90% and 95%. We performed 50 trials for each combination of the settings.

Below, we explain the compared methods.

Repetitive Random Search (RS)

This method continues to generate random solutions until the given time is up. This method starts the search with a sufficient number of nodes to cover the entire building, and when it finds the positions of nodes which cover the building with that number of nodes, it searches further by continually decreasing the number of nodes.

Local Search (LS)

This method generates a set of node positions randomly, and then it generates another five sets of positions by applying to the positions the mutation method used in our method. If none of these sets satisfies the required coverage, the method is repeated until it finds a set of positions that satisfy the requirement. If it finds a solution, it decreases the number of nodes and continues the search until it runs out of time. Then it returns the best position.

Bread Crumb (BC)

Bread Crumb[3][4] is a two dimensional node deployment method, by which network nodes are deployed inside a building. Network nodes are placed one by one at the entrance of the building and inside at equidistant intervals. If nodes are placed on all floors and the coverage requirement is not met, additional nodes are added until the conditions are satisfied. Deploying intervals are 30m, 25m and 20m, for each k, 1, 2, 3, respectively.

C. Experimental results

Comparison with Other Methods by Simulation

The results for each case are shown in Fig.8-10. The graphs represent the results with the proposed method, LS, RS, BC from left to right. Each bar shows the average value, and each line segment shows the maximum/minimum values for the corresponding method. Since the result by BC was always same, there are no maximum/minimum values for this method. We can see that the number of nodes for the proposed method is the smallest in all cases, and there are significant differences when k and s are high. In the case that k=3 and s=95%, the network nodes required by the proposed method are 43%, 45% and 73% less than RS, LS and BC, respectively. We see notable, large differences in the case of k=3, where the differences in number of nodes are 27%, 31%, 53%, respectively, for each method. The results clearly show that the proposed method outperforms other methods in complicated conditions. For the BC method, the large number of nodes is required because of the characteristics of that method. Since the proposed method deploys nodes in the air, radio waves reach multiple floors, reducing significantly the number of network nodes required. We can also see that the standard deviation of the results with our method is smaller than with other methods, indicating that our method gives more consistent results.

Evaluation of Validity in a Real Environment

We performed experiments in the real environment based on results obtained by simulation with $k = 1$, $n = 3$, which has 92.6% coverage. We measured the difference between the results obtained by simulation and the RSS measured in the real building. Fig.11 shows the results of the comparison. Dots and x marks represent measurement points and the network nodes, respectively. The colors of the dots represent the difference between the simulation results and the measurements. The average errors are shown for measurement points that have reception from multiple network nodes.

In this experiment, the average error was 11.08[dBm] and the coverage was 86.6% for 300 measurement points. Although the average error is higher than the estimation given by our model, described in section IV, the coverage value is close to the simulation result. The RSS errors measured at most of the measurement points were within 10dBm. The space which is not covered by radio waves is almost the same as the prediction by simulation. Therefore, we can say that the proposed prediction model and simulation are practical.

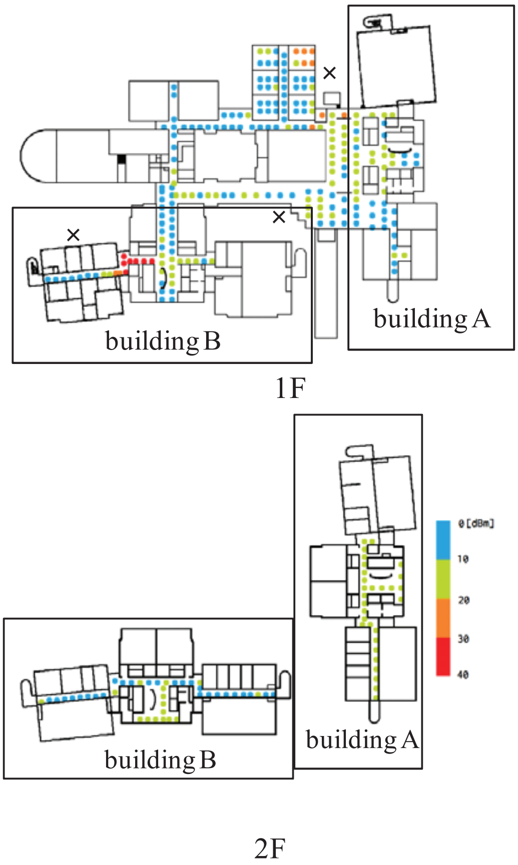

Fig. 11. Measurement results

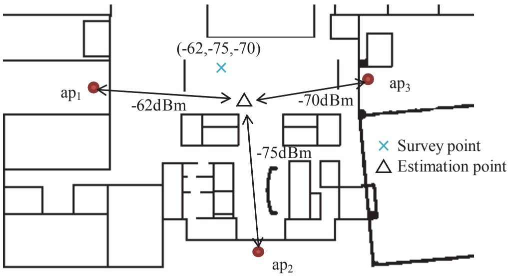

Fig. 12. Experiment for indoor positioning

Indoor Positioning Based on RSS

We investigated the accuracy of position estimation by giving a 3-coverage requirement to our method. An example of applying triangulation is shown in Fig.12. Measurements are taken inside the building. The location is estimated by comparing the values predicted by the proposed model and the measured results of the real experiment. Estimation error is obtained by calculating the distance between the actual measurement point and estimated point.

The average error for 70 survey points was 3.86[m]. Location estimation can be used to identify the locations of

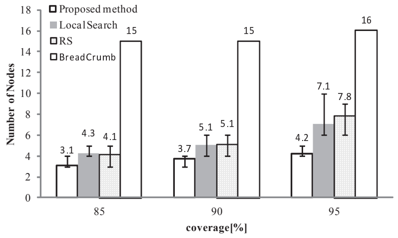

Fig. 8. Result with $k = 1$

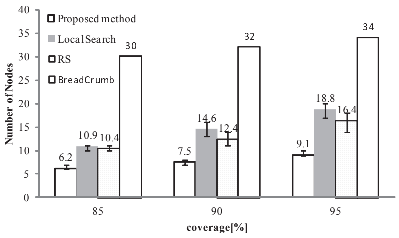

Fig. 9. Result with $k = 2$

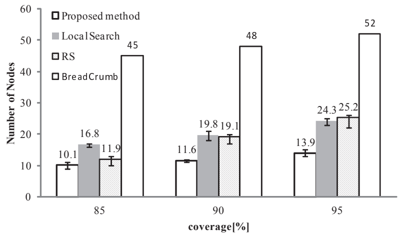

Fig. 10. Result with $k = 3$

victims in the system for rescue operations like AID-N[1]. These results are accurate enough to determine which rooms victims are in.

VII. CONCLUSION

Aiming at quickly building a wireless network surrounding a multi-level building in a disaster area, we proposed an efficient method to determine the location of network nodes locations in the air. The proposed method minimizes the number of nodes and guarantees k-coverage for indoor positioning. We constructed a new radio propagation model that takes account of diffracted distance. Our evaluation shows that our algorithm can reduce the number of nodes by up to 50%, compared with other methods. We compared the simulated received signal strength(RSS) at each point and the measured RSS and found that the RSS and the overall radio coverage in the real building are very close to the simulated results. We also conducted a real-world experiment for triangulation based indoor positioning based on RSS. The average error was within 3.86m, which is considered to be practical.

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