공학석사학위논문

산업 환경에서 안정적인 WiFi 연결을 위한 효율적인 AP 배치 방법

An Effective AP Placement Scheme for Reliable WiFi Connection in Industrial Environment

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이한얼의 공학석사 학위논문을 인준함

2020 년 8 월

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Abstract

An Effective AP Placement Scheme for Reliable WiFi Connection in Industrial Environment

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As the wireless communication systems provide higher data rates and extended services, especially for mobile users/devices, they replace rapidly the wired ones. However, for some mission-critical applications in industrial environments, the engineers are unwilling to adopt the wireless system because of the low reliability of wireless link in comparison of wired link. A solution for increasing the reliability of wireless system is using backup wireless link(s). In this case, the adequate locations of access points (APs) of the wireless network can be different from those of the single link case. In this paper, we consider mobile devices/systems carrying out very critical missions, by using WiFi in the hostile indoor radio propagation environments (for example, mobile robots in the automated factories). We propose an effective scheme for placing the APs for a given service area, which aims (1) to ensure that a mobile user can maintain at least two simultaneous links with different APs, respectively, on every point of its moving path and; (2) to lessen the number of APs installed in a whole service area. We design a heuristic scheme based on the optimization approach. A practical merit of the proposed scheme is that the channel model and/or the AP coverage are not need to be pre-assumed or pre-measured. For evaluating the performance, the scheme is implemented and tested in a real environment. The experimental results show that the proposed heuristic scheme successfully achieves the design goals and its performance is comparable with that of the theoretically optimal placement.

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Keywords : Mobile WiFi user/device, Mission-critical application, Reliable WiFi connection, AP placement, Optimization, Heuristic algorithm

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Chapter 1

Introduction

The IEEE 802.11 wireless local area network (WLAN), also known as WiFi, has become a *de facto* standard for providing the wireless connection, particularly in the indoor environment. That is, the WiFi replaces rapidly the wired communication links in office and home. However, this is not the case for some mission-critical applications in industrial environments. The metal facilities and objects in the working area of a factory become serious obstacles in radio propagation. Thus, in the factory with a lot of metal objects, there can be many positions where WiFi channel quality is extremely poor. Moreover, because of the movement of users and obstacles, the channel quality varies with time. As a result, the reliability of wireless link is usually lower than that of wired link and this prevents the wireless system for very critical missions from using in such factories.

To increase the reliability of wireless link from the physical layer viewpoint, a higher order of modulation and channel coding can be used. From the system level viewpoint, for example, the backup link(s) can be used. When the active link suffers from channel quality degradation, the mobile user/device (MU) can change a backup link with higher quality as the new active link. Moreover, if the backup link is activated in a make-before-break manner, the link switching time can be greatly reduced. It is noted that, to use this strategy, an MU should be able to make and maintain at least two simultaneous links with different access points (APs).

In a company or in a factory, the use of APs is tightly regulated for security reasons in usual. In this situation where all APs in a service area are managed by a single organization, the organization needs to provide high quality WiFi services by using the minimum number of APs [1]. An engineering issue of special importance is the placement of APs for covering full service area by using the minimum number of APs. To tackle this problem, many schemes have been suggested until recent years. For example, in [2], a joint method for WiFi access point placement and channel assignment has been proposed. Lin, et al., [3] consider the AP placement problem in realistic deployment environments, so they propose realistic propagation modeling in an urban scenario. In [4], the optimal density of APs and the optimal channel assignment problem are treated with the same problem formulation, in terms of maximizing the overall network capacity. Fang, et al., [5] present a framework for linking the placement of APs and the positioning performance. Their algorithm aims to maximize SNR (signal-to-noise ratio) so as to reduce the positioning errors. Recently, the AP placement is investigated for many purposes. For example, [6], [7], and [8] have studied the problem, respectively, for supporting the indoor positioning system, the vehicular communication system, and the train communication system.

In this paper, we design an AP placement scheme for the MUs carrying out some mission-critical jobs in industrial environments (especially, in factories). In the existing schemes, the design goal is no hole of WiFi service in the entire service area. That is, the objective of the existing schemes is to guarantee at least *one* link to AP at any point in the service area. However, as discussed before, we herein consider the system where each MU keeps two or more links to APs in the service area. To this end, we propose an effective scheme for placing the APs for a given service area, which aims (1) at ensuring that each MU can maintain at least two simultaneous links with different APs, respectively, on every point of its moving path and; (2) at minimizing the number of APs installed in whole service area.

In designing the AP placement scheme, we consider practical restrictions in AP deployment. The existing schemes use the channel model or the AP coverage data as an input for the AP placement algorithm. This means that the channel model or the AP coverage is known a priori. However, to get a useful channel model/AP coverage information for every possible AP location is very hard in practice. We propose the AP deployment scheme which does not require such kind of priori information.

On the other hand, even though many existing schemes assume that AP can be located at any point within the service area, it may be impossible in practice. The feasible positions of AP placement are typically limited to some subareas (not a whole area), because of several factors such as the prior plan of the service area, the availability of power source and network cabling, etc. In designing the proposed scheme, we also take account of this restriction, as well as no priori information on AP coverage or channel model. Specifically, we consider the deployment of not only APs but also passive repeaters (PRs). Since the PR can receive the WiFi signal from one direction and repeat to another direction without power source [9], [10], it can be used to remove shadow spots in the service areas characterized by the highly complex structure and the lack of the power source and network cabling in places. Note that the typical service areas with such characteristics can be found in factories.

Hereafter, we assume that each MU has two WiFi interfaces, which means an MU has two simultaneous links with different APs, for the convenience of the description of the proposed scheme. The rest of the paper is organized as follows. The next section describes the system model and problem formulation. The proposed AP placement algorithm is discussed in Section 3. Section 4 presents the performance evaluation. Finally, Section 5 concludes this paper.

Chapter 2
System Model and Problem Formulation

Chapter 2.1

System Model

In this paper, we assume without loss of generality that the service area for placing APs is divided into small discrete areas, each of which is referred to as a tile. Let A denote the set of all available tiles. We consider an MU of which moving path is predefined on the given service area. Let the ordered set $M \coloneqq \{m_1, m_2, \dots, m_n\}$ $(M \subset A)$ be tiles on the moving path of MU. It is assumed that APs can be installed only on some locations in the service area. This assumption reflects the real situation in practical industrial environments. Let z_i be a binary indicator which indicates the installability of AP on tiles-i: if an AP can be placed on tile-i, $z_i = 1$; otherwise $z_i = 0$. We also consider the use of PR to serve an area which cannot be served by the AP due to the deep fading condition. The PR can be installed at any location because it does not require the power source.

The main goal of the problem is to select the appropriate location of APs and PRs. To this end, we introduce a binary variable a_i which represents whether an AP is installed on tile-i: if an AP is installed on tile-i, $a_i = 1$;

otherwise $a_i = 0$. In addition, a binary variable b_i represents whether a PR is installed on tile-*i*: if a PR is installed on tile-i, $b_i = 1$; otherwise $b_i = 0$. The variables a_i and b_i will be the decision variables for the placement problem.

Chapter 2.2

Problem Formulation

The main goal of the AP deployment technique is to minimize the total number of installed AP and PR, while satisfying all the given constraints. The AP deployment problem is formulated as in (1) – (4).

$$\min \sum_{i=1}^{|A|} (w_1 a_i z_i + w_2 b_i) \tag{1}$$

$$s.t. \sum_{i=1}^{|A|} \left(\beta_{ij} a_i z_i + (1 - \beta_{ij}) \sum_{k=1}^{|A|} \gamma_{ijk} a_i z_i b_k \right) \geq 2$$

$$\forall m_j \in M \tag{2}$$

$$a_i, b_i \in \{0,1\}, \qquad \forall i \in A \tag{3}$$

$$w_1 + w_2 = 1, \tag{4}$$

where $|\cdot|$ is the cardinality of the given set.

The objective function in (1) minimizes the total number of AP and

PR. The weights of preference for AP and PR are represent by w_1 and w_2, respectively. Since an AP can likely offer more stable WiFi signal than a PR, we assign the weights such that $w_1 \ll w_2$, which implies much higher preference to AP. The constraint in (2) says that any area in the moving path of MU should be covered by at least two APs. In (2), β_{ij} and γ_{ijk} are the indicators for the coverage area of AP and PR, respectively, which are given as follows:

$$\beta_{ij} = \begin{cases} 1, & \text{if } m_j \text{ is covered by AP on tile i.} \\ 0, & \text{otherwise.} \end{cases}$$

$$\gamma_{ijk} = \begin{cases} 1, & \text{if } m_j \text{ is covered by PR on tile k and} \\ & \text{tile k is covered by AP on tile i} \\ 0, & \text{otherwise.} \end{cases}$$

where we say "be covered" if the received signal strength (RSS) of WiFi is larger than a predefined minimum RSS threshold value (δ).

The formulated problem in (1) – (4) is a nonlinear integer programming problem, which is known to be NP-hard. The nonlinearity is caused by the definition of β_{ij}, γ_{ijk}, and the constraint in (2). If β_{ij} and γ_{ijk} are given for every possible combination, we can transform the original problem into equivalent integer linear programming (ILP) problem, by introducing a new variable $v_{ij} = a_i b_j$ and new constraints as in (5) – (8).

$$v_{ij} \le a_i, \qquad \forall i,j \in A \qquad (5)$$

$$v_{ij} \le b_j, \qquad \forall i,j \in A \qquad (6)$$

$$v_{ij} \geq a_i + b_j - 1, \qquad \forall i, j \in A \tag{7}$$

$$v_{ij} \in 0, 1, \qquad \forall i, j \in A \tag{8}$$

It is well known that the ILP problem can be efficiently solved using the branch-and-bound technique to get the solution. Moreover, there are many solvers available to solve the ILP problem, for example, such as CPLEX [11] and lp_solve [12].

However, in a practical situation, it may be difficult to get the value of β_{ij} and γ_{ijk}, since (1) it may be very expensive to measure the RSS in the environment for every possible combination of AP location and moving path of MU; (2) alternatively, it is not practical also to predict the coverage of AP and PR because of the lack of the general channel model applicable in these cases. In addition, the optimal solution may not exist for some given constraints. To overcome these difficulties, we suggest a heuristic technique which is more practical.

Chapter 3
Heuristic AP Placement Algorithm

Recall that the goal of the AP placement technique in this paper is to deploy a minimum number of APs, while ensuring that all tiles in the moving path of MU are covered by at least two APs. Let us consider a simple moving path of MU in Fig. 1, where APs can be installed only at given specific locations, not a whole area. A basic idea for deriving a solution of this problem, as shown in Fig. 1, is to deploy APs so that, for each AP, the coverage areas (circles) of its two neighboring APs are tangent to each other on the moving path. We design the heuristic AP placement scheme, based on this concept.

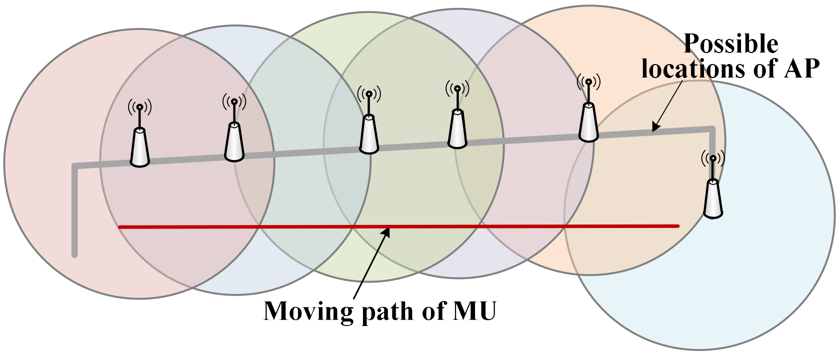

Figure 1: Basic concept of heuristic algorithm

The overview of the proposed heuristic AP placement scheme is described below, of which block diagram is depicted in Fig. 2. Prior to the beginning, we first define some notations. *Z* denotes a set of tiles representing possible installation locations of APs. When determining a position of next AP, the scheme needs to consider only some part of moving path being able to be covered by one AP, not a whole moving path. Let L represent such part of moving path. Accordingly, L contains a part of moving path being not yet covered by two or more APs and the part in L cannot exceed the maximum coverage length of AP. Now, let us describe the proposed scheme step-by-step.

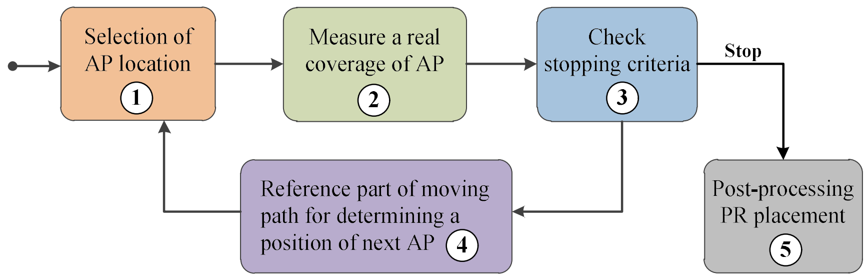

Figure 2: Block function diagram of the proposed scheme

(1) **Determining a position for AP placement**: As the position of next AP, the proposed scheme selects a point $p \in Z$ located closest to the part of moving path in L. On the other hand, since the set L is not defined until the location of the first AP is determined, the proposed scheme determines the position of the first AP, as follows. While assuming that the coverage radius of AP is R_{AP}, when the largest part of moving path is covered by an AP at a point $p \in Z$, the p is selected as the installation position of the first AP.

(2) **Identifying the part of moving path really covered by a new AP**: Since R_{AP} is merely an imaginary coverage radius for AP positioning,

the real coverage radius of AP can be quite different from R_{AP}. To identify the part of moving path covered by a real AP at p, after really placing a test AP at position p, we directly measure the received signal strength of the test AP at each tile of moving path.

(3) **Checking the termination criterion**: When all tiles of moving path are covered by two or more APs or all possible locations for AP placement are checked, the process is terminated and we go to the Step (5). Otherwise, i.e., when there still exist both the part of moving path being not covered by two or more APs and possible locations of AP placement being not yet checked, the process is continued to the Step (4).

(4) **Setting *L* for the next AP**: Among the part of moving path which is not yet covered by two or more APs, the scheme selects the reference part, L, for determining the position of next AP and then goes back to the Step (1). We will describe the specific method for making L (the Algorithm 2) later.

(5) **Checking possible locations of PR placement**: We can check whether the communication reliability can be improved, by additionally installing passive repeaters (PRs). Especially, when some part of moving path is not covered by at least two AP, the PRs may be placed

at proper locations where APs are hard to be installed.[1]

The proposed AP placement scheme is described by Algorithm 1 and Algorithm 2, in more detail. Fig. 3 is presented to help the readers understanding the steps of the proposed algorithm.

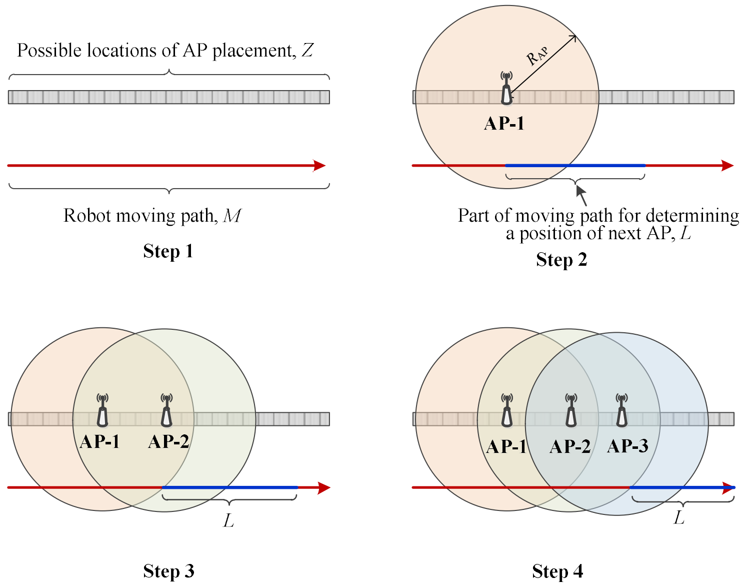

Figure 3: Step-by-step example of the proposed algorithm

Let us define the symbols newly introduced in Algorithm 1 and Algorithm 2. Remind that *M*, *Z*, and *L* respectively denote a set of all tiles on moving path, a set of the tiles on possible AP placement area, and a set of the

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[1] Since the possible positions of PRs depend greatly on the real structure and topology of service area, it can be more efficient that the PR placement work is based on measurement in ad-hoc manner. Thus, we will not treat the Step (5) specifically in this paper.

tiles on moving path part considered to determine the position of next AP. Additionally, M_0 denotes a set of the moving path tiles being not yet covered by any AP, M_1 is a set of the moving path tiles being covered by just one AP, and M_2^+ is a set of the moving path tiles being covered by two or more APs. Obviously, $M = M_0 \cup M_1 \cup M_2^+$. P denotes a set of the tiles where APs are placed and $P \subseteq Z$. The Algorithm 1 takes M and Z as input parameters and returns P as a final result. Another parameter R_{AP} is set to a value typically suggested as AP coverage radius.

Algorithm 1 AP Placement Algorithm

$\mathcal{M}_0 \leftarrow \mathcal{M}$; $\mathcal{M}_1 \leftarrow \emptyset$; $\mathcal{M}_2^+ \leftarrow \emptyset$; $\mathcal{P} \leftarrow \emptyset$
stop $\leftarrow$ *false*
while stop = *false* **do**
  if $\mathcal{M}_1 = \emptyset$ **then**
    Select a point p $\in \mathcal{Z}$ which covers the largest number of points in $\mathcal{M}_0$, assuming that the AP coverage radius is R_{AP}.
  else
    $\mathcal{L} \leftarrow$ **PathPart_ToBeCovered**($\mathcal{M}_0, \mathcal{M}_1, \mathcal{M}_2^+$)
    p $\leftarrow \arg\min_{z \in \mathcal{Z}} \sqrt{\frac{1}{|\mathcal{L}|} \sum_{l \in \mathcal{L}} \|z - l\|}$
  end if
  $\mathcal{I}_{\text{p}} \leftarrow$ a set of moving path tiles within the measured coverage of the test AP really placed at p
  $\mathcal{M}_0' \leftarrow \mathcal{M}_0$; $\mathcal{M}_1' \leftarrow \mathcal{M}_1$
  Update $\mathcal{M}_0, \mathcal{M}_1, \mathcal{M}_2^+$, based on $\mathcal{I}_{\text{p}}$
  if $\mathcal{M}_0' \neq \mathcal{M}_0$ or $\mathcal{M}_1' \neq \mathcal{M}_1$ **then**
    $\mathcal{P} \leftarrow \mathcal{P} \bigcup \{\text{p}\}$
  else
    $\mathcal{M}_0 \leftarrow \mathcal{M}_0 \setminus \mathcal{L}$; $\mathcal{M}_1 \leftarrow \mathcal{M}_1 \setminus \mathcal{L}$
  end if
  if $\mathcal{M}_0 \bigcup \mathcal{M}_1 = \emptyset$ **then**
    stop $\leftarrow$ *true*
  end if
end while
return Set of AP locations, $\mathcal{P}$

Figure 4: Algorithm 1 – AP placement algorithm

In the Algorithm 1, the position of the first AP is determined in the lines 4 – 5 (Step 2 in Fig. 3). From the second AP, when determining the position of AP, the scheme considers not a whole path but merely a part of moving path which it wants to cover with the next AP, called the reference tiles. The Algorithm 1 gets a set of reference tiles, L, by calling a function **PathPart_ToBeCovered** (Algorithm 2) and, as the position of next AP, it selects a tile p $\in$ Z, which has the minimum root mean square distance to all tiles in L (lines 7 – 8, refer to Step 3 and Step 4 in Fig. 3). Then, we can expect that the AP being placed at p covers more tiles in L than the AP at any other position in Z. If two or more candidates are found, one of them is randomly selected.

The next step of the algorithm is to identify the part of moving path covered by a real AP at p. To do this, after really placing a test AP at position p, we directly measure the RSS of the test AP at each tile of moving path. Based on the measured coverage of a test AP at p, the scheme updates the M_0, M_1, and M_2^+ (lines 10 – 12) Note that the change of M_0 or M_1 means that the AP at p newly covers some part of moving path being covered by no AP or just one existing AP. Then, the scheme adds p to the set of AP placement points (lines 13 – 14). If the members of M_0 and M_1 are not changed, since it implies that there is no possible AP location to cover any tiles in L, we remove the tiles in L from the M_0 or M_1 (lines 15 – 16). This is because there is no way to cover the tiles in L. After that, the algorithm checks the termination criterion (lines 18

– 19), i.e., whether all tiles in moving path have been covered by at least two APs ($M_0 \cup M_1 = \emptyset, M_2^+ = M$) or the part of moving path covered by two or more APs cannot be increased any more ($M_0 \cup M_1 = \emptyset, M_2^+ \neq M$). Note that, for all of two cases, $M_0 \cup M_1 = \emptyset$. The above work (lines 3 – 21) is repeated until the termination criterion is satisfied.

Algorithm 2 PathPart_ToBeCovered($\mathcal{M}_0, \mathcal{M}_1, \mathcal{M}_2^+$)

Select a point q from $\mathcal{M}_1$ such that its neighbor belongs to $\mathcal{M}_2^+$. If such point is not found, select a middle point q from $\mathcal{M}_1$
$\mathcal{L} \leftarrow \{q\}$; $\Upsilon \leftarrow \mathcal{M}_0 \bigcup \mathcal{M}_1$;
stop $\leftarrow$ *false*; *ctr* $\leftarrow 1$
while stop = *false* & *ctr* $< |\Upsilon|$ **do**
  $q \leftarrow \arg\min_{u \in \Upsilon \setminus \mathcal{L}} \|q - u\|$
  $maxV \leftarrow \max_{\ell \in \mathcal{L}} \|q - \ell\|$
  if $maxV > 2R_{\text{AP}}$ **then**
    $stop \leftarrow true$
  else
    $\mathcal{L} \leftarrow \mathcal{L} \bigcup \{q\}$
  end if
  $ctr \leftarrow ctr + 1$
end while
return Set of reference tiles, $\mathcal{L}$

Figure 5: Algorithm 2 – PathPart_ToBeCovered(M_0, M_1, M_2^+)

The Algorithm 2 selects the reference tiles, i.e., a part of moving path which should be covered by the next AP. Thus, the reference tiles are selected from M_0 and M_1, i.e., the tiles of moving path which has been not covered by two or more APs yet. If M_2^+ is empty, the scheme selects a tile in M_1 which has the minimum sum of the distance to each other tile in M_1 (a middle point) as a starting point (the case of Step 2 in Fig. 3). Otherwise, we can select a tile in M_1 whose neighbor is in M_2^+ as a starting point (the case of Step 3 or Step 4 in Fig. 3). From the given starting point, the consecutive tiles in M_0 and M_1 following the moving path are selected one-by-one, until the number of selected tiles does not exceed the maximum coverage of AP ($2R_{\text{AP}}$) or there are no more tiles to be selected (lines 4 – 13).

Remark: The proposed scheme well operates although various multiple moving paths coexist within the service area. Then, *M* becomes a set of all tiles on multiple moving paths and the Algorithm 1 determines the installation positions of APs so that all path areas are covered by as few APs as possible while any location on all paths can be covered by at least two APs. We will present the results of the proposed scheme for various cases with multiple moving paths, in Figs. 9 and 10.

Chapter 4
Performance Evaluation

We first check the feasibility of the heuristic scheme and assess its performance, based on real experimental results. Then, we present the efficiency of the heuristic scheme by comparing its results with the optimal solution of the problem (1)–(8), under various conditions of moving paths.

Chapter 4.1
Experimental Results

Chapter 4.1.1
Experiment Settings

To validate the feasibility of the proposed heuristic scheme, we implemented the heuristic algorithms and conducted the experiment in the parking lot located on the basement floor of student dormitory area in Seoul National University campus. Note that the implemented heuristic algorithm is a kind of software program tool for finding a proper placement location of AP. The experiment environment is depicted in Fig. 6, where a whole area is divided into small sub-areas (so-called tiles) with the size of 1m × 1m. The moving path of MU is marked with a red line and the possible installation locations of APs are marked with the shadowed-purple rectangle area in Fig. 6.[2] In the experiment, we took account of channel bonding, up-to 80 MHz in 5 GHz band and up-to 40 MHz in 2.4 GHz band. It is noted that the maximum possible channel bonding is allowed up to 40 MHz in 2.4 GHz band. The received signal strength (RSS) threshold value, δ, for determining the coverage area of an AP depends on channel bandwidth. The WiFi standard specifies different δ value for different channel bandwidth. In our experiments, the values of δ for a channel with bandwidth of 20 MHz, 40 MHz, and 80 MHz are -82 dBm, -79 dBm, and -76 dBm, respectively. In addition, the value of R_{AP} is set to 45 m and 40 m for channel bandwidth of 20 MHz and 40 MHz in 2.4 GHz band, respectively. Also, when a channel with bandwidth of 20 MHz, 40 MHz, and 80 MHz in 5 GHz band is used, R_{AP} is set to 35 m, 30 m, and 25 m, respectively. We repeated the experiment three times for each setting and measured the average on the total number of APs as the performance metric.

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[2] Under given experimental environment in Fig. 6, the moving path can be covered by installing APs without any PRs. Thus, PRs were not used in our experiment.

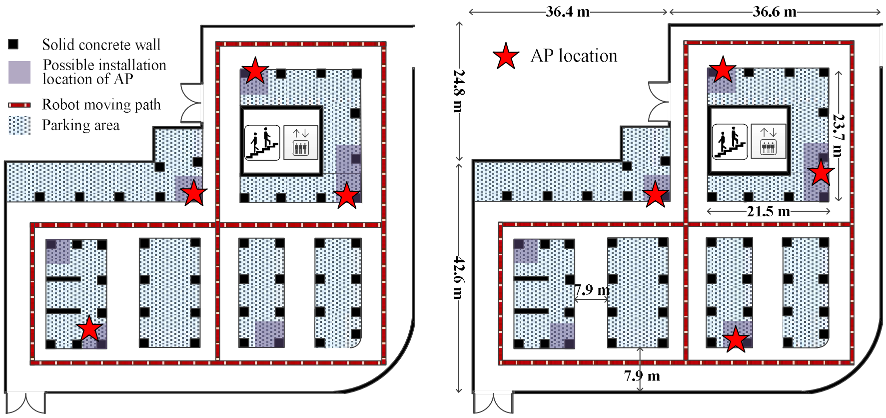

Figure 6: Experiment environment and two different AP installation locations due to randomness property

Chapter 4.1.2

Experiment Results

Table 1 shows the total number of APs used to serve the given area after running the proposed algorithm. It is obvious that with higher minimum RSS (higher bandwidth), more APs are needed to serve the area due to the reduced coverage area of APs. Moreover, the total number of APs required for 2.4 GHz frequency band is much smaller than that for 5 GHz band. This is because a channel in 2.4 GHz band has better propagation property so that the coverage of AP is much larger as compared to that in 5 GHz band.

	20 MHz δ = -82 dBm	40 MHz δ = -79 dBm	80 MHz δ = -76 dBm
2.4 GHz	3	4	NA
5 GHz	5	7	9

Table 1: Total number of APs

Next, we present the installation locations of APs for the case of a channel with 40 MHz bandwidth in 2.4 GHz band. Note that the proposed algorithm has a randomness property which may affect the final installation locations of the APs, because the proposed scheme randomly selects one of several candidates. Fig. 6 depicts two different results on the AP installation location for the abovementioned setting. We can observe in Fig. 6 that the total number of APs is the same for this setting i.e., four APs, although their locations are different. This implies that the randomness property of the proposed scheme indeed affects the installation location of AP, but it does not affect the total number of the installed APs. This is because the total number of APs is likely to be mainly affected by the structure of possible AP placement area and moving path. We actually observed a similar trend for different settings, although we did not depict the results herein. Thus, we can expect that the total number of APs will be the same for the same setting.

Chapter 4.2

Comparison with Optimal Solution

We compare the solution of the proposed heuristic algorithm with an optimal solution, which is got by solving the problem (1) - (8) using CPLEX solver [11]. It is noted that the optimal solution may be less practical since it needs the pre-knowledge on channel environment (i.e., $\forall\beta_{ij}, \forall\gamma_{\mathrm{ijk}}$ in (1), (2)) and requires a lot of computation.

Chapter 4.2.1

Comparison in Various Coverage Conditions

The number of APs installed within the service area is greatly affected by the size of AP coverage area as well as the structural environment of service area. We evaluate the performance of the proposed scheme according to the coverage radius of AP, under the service area environment of Fig. 6. Two cases, which are different from each other only in possible installation locations of AP, are considered. One case (Case I) is the same as that in Fig. 6, i.e., APs can be placed only within the shadowed area of Fig. 6; In the other case (Case II), the constraint regarding possible AP placement locations is relaxed, i.e., APs are allowed to be installed at any location of the entire area in Fig. 6.

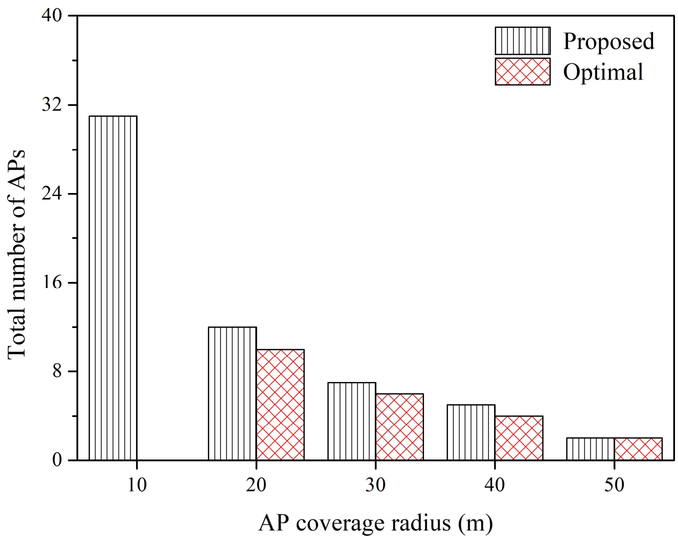

Figure 7: Performance comparison in Case I (APs can be placed at shadowed area of Fig. 6)

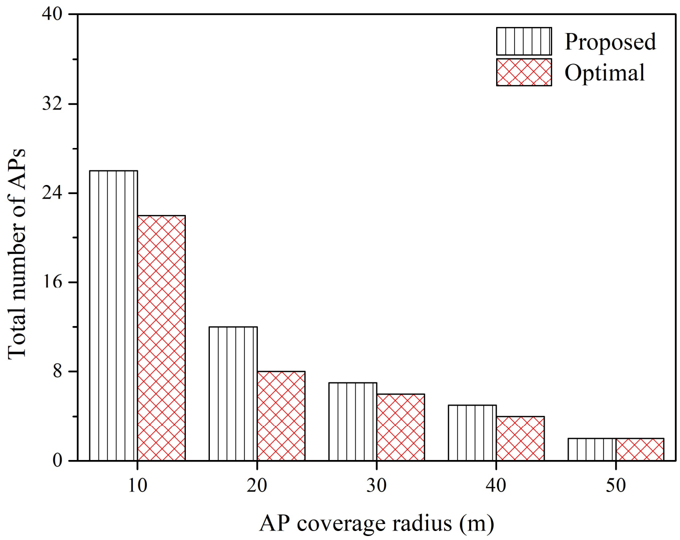

Figure 8: Performance comparison in Case II (APs can be placed at a whole area of Fig. 6)

Fig. 7 depicts the result of Case I. The graph shows that the total number of APs decreases as the AP coverage increases. It is obvious because, with a larger coverage area of AP, the fewer APs are needed to cover the path area. Moreover, the results of the proposed algorithm are not greatly different from optimal solutions. This confirms the effectiveness of the proposed heuristic scheme. Especially, when an AP covers the small area with low transmission power (for example, like the AP coverage radius of 10 m in Fig. 7), the optimal solution may not exist. This is because there is no combination of AP location which can satisfy the given constraints. Meanwhile, although all tiles of moving path are not covered by two or more APs, the proposed scheme stops with the intermediate results when there remains no tile in M_0 and M_1 (lines 18 – 19 of Algorithm 1). The intermediate results of the proposed heuristic algorithm for the AP coverage radius of 10 m covers merely about 80 % of moving path by two or more APs. Note that such a partial solution can be better than no solution. Then, the operators can decide whether they again run the proposed algorithm with higher transmission power (i.e., the wider AP coverage), or additionally install the passive repeaters (Step 5 in Fig. 2). Next, the results of Case II are presented in Fig. 8. Even though the APs are allowed to be placed at any location of the area, the difference in the total number of APs between the solution of the proposed scheme and the optimal solution is not large (compare Fig. 7 and Fig. 8). The proposed scheme still produces the result which closes to the optimal solution. When considering that the preliminary WiFi signal measurement for every possible combination of AP location and MU moving path is required to derive the optimal solution, Figs. 7 and 8 justify the merit of the proposed scheme, which is not only simple but also produces a reasonably good solution.

Chapter 4.2.2

Comparison in Various Path Situations

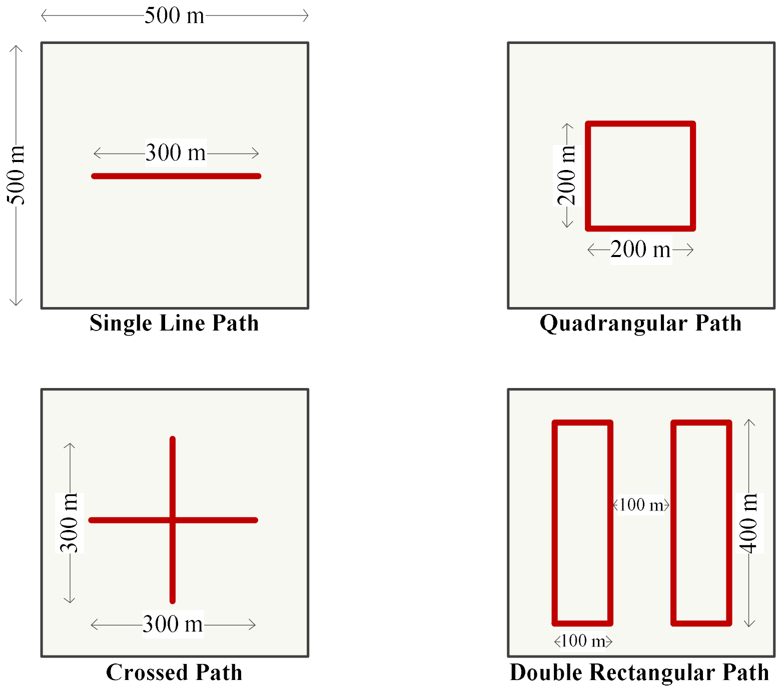

Figure 9: Moving paths

In this subsection, we want to present that our scheme yields good solutions in various path conditions, although the moving path of Fig. 6 is also not simple. To do this, we compare the solution of the proposed scheme and the optimal solution, under four different cases of MU moving path as shown in Fig. 9. The coverage radius of an AP is set to 60 m. The deployment environment is in the form of square area which size is 500m×500m and the size of a tile is 1m×1m. The MU moving path is marked with red line inside the area and the APs can be placed at any position.

Although the selected paths do not represent all possible real-life conditions, they can represent typical paths that may exist in practical situations. For instance, the Single Line path represents a very simple straight moving path, the Quadrangular path represents a condition where a moving path of MU forms certain shape, the Crossed path represents a condition where multiple straight moving paths intersect with each other, and the Double Rectangular path may represent a situation where there exist multiple independent moving paths of MU. Note that there can be one or more MUs on each moving path.

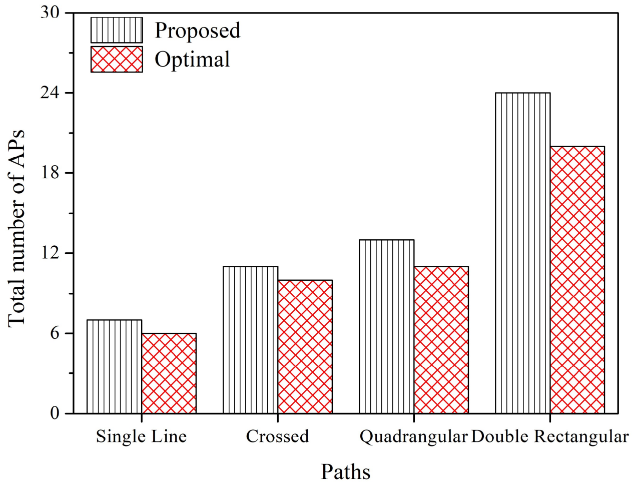

Figure 10: Performance comparison for various moving paths

It is observed in Fig. 10 that the total number of APs depends on the layout of MU moving path. Among paths of similar shape, more APs are required for multiple paths, i.e., Single Line vs Crossed and Quadrangular vs Double Rectangular. For the same number of paths, more complex paths need more APs, i.e., Single Line vs Quadrangular and Crossed vs Double Rectangular. We can also see in the figure that the difference between the optimal solution and the solution of the proposed heuristic scheme is still not large and is reasonably acceptable even for the most complex Double Rectangular path.

Chapter 5
Conclusion

In this paper, we have proposed a heuristic AP placement algorithm for supporting a reliable WiFi connection. This is done by introducing a constraint that any location on the moving path of MU should be covered by at least two APs. We also have considered that the possible installation location of AP is limited, which can be a typical condition in practical situations. The proposed scheme does not require *any priori* information on either channel model or AP coverage. According to the experiment results in a real environment, the proposed scheme successfully achieves the design goal, which is to deploy as few APs as possible while ensuring that all moving paths of MU are covered by two or more APs, and its performance is close to that of the optimal solution. Therefore, the proposed technique can be a practical guide in deploying the APs to provide a reliable WiFi connection for supporting mission-critical application in the industrial environment.

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요 약

무선 통신 시스템이 모바일 유저와 디바이스에 더 높은 데이터 속도와 확장된 서비스들을 제공하면서, 유선 시스템을 빠르게 대체하고 있다. 그러나 공학자가 산업 환경 내에서 몇몇 미션 크리티컬 애플리케이션을 지원하는 시스템을 설계하는 경우, 무선 통신 시스템의 이점에도 불구하고 무선 링크가 유선 링크보다 안정성이 떨어지기 때문에 무선 통신 시스템을 채택하는 것을 꺼리게 된다. 따라서 무선 통신 시스템의 안정성을 높이는 것은 산업 환경에서 미션 크리티컬 애플리케이션을 지원하는 무선 통신 시스템을 설계하는데 필수적이다. 무선 통신 시스템의 안정성을 높이는 방법 중의 하나로 백업 링크를 사용할 수 있는데, 이러한 방식을 사용하는 경우 단일 링크 만을 지원할 때의 AP 배치와 다른 배치가 요구된다. 본 논문에서는 적대적인 실내 무선 전파 환경에서 와이파이(WiFi)를 사용하여 모바일 장치/시스템이 매우 중요한 임무를 수행하는 상황(예: 자동화된 공장의 모바일 로봇)을 고려하여, (1) 모바일 유저가 이동하는 경로의 모든 지점에서 각각 다른 AP와 적어도 2개 이상의 링크를 유지할 수 있도록 하고, (2) 전체 서비스 영역에 설치되는 AP의 수를 최소화하도록 주어진 영역에서 AP를 배치하는 효율적인 체계를 제안한다. 이러한 체계는 최적화 접근법에 기반한 휴리스틱 알고리즘으로 설계되었다. 제안된

방식은 채널 모델이나 AP 커버리지를 사전 정의하거나 사전 측정하지 않기 때문에 비용 측면에서 효율적이면서 실제 환경을 잘 반영한다. 제안된 체계는 실제 환경에서 구현되었으며, 실제 환경에서 실험에 의해 성능 평가가 이루어졌다. 실험 결과를 통해 제안된 휴리스틱 AP 배치 체계가 디자인 목표를 달성할 뿐만 아니라 이론상 최적의 배치 결과와 큰 차이가 없다는 것을 보였다.

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주요어 : 모바일 와이파이 유저/디바이스, 미션 크리티컬 애플리케이션, 안정적인 와이파이 연결, AP 배치, 최적화, 휴리스틱 알고리즘
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