WLAN Access Points Channel Assignment Strategy for Indoor Localization Systems in Smart Sustainable Cities

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Abstract. The idea of smart and sustainable cities is incomplete without using information and communication technologies. Wireless Local Area Network (WLAN) plays a vital role in connecting different services, transferring data and providing indoor localization. WLAN fingerprinting technique has become the most common approach for indoor localization in smart cities. This technique utilizes received signal strength (RSS) and channel status from the installed WLAN Access Points (AP). Currently, WLAN planning relies on the site survey, which is laborious and uneconomical for large areas. The WLAN has a limited number of channels assigned in the frequency reuse strategy. An inefficient channel assignment strategy will lead towards increased interference, thus degrading the overall service. This paper proposes a WLAN channel assignment strategy for large and crowded indoor areas. The proposed scheme assigns the channels to installed APs for indoor localization in fingerprinting framework. The proposed technique ensures that the proposed AP channel assignment algorithm in our network-planning scheme mitigates interference.

1. Introduction

The demand for smart and sustainable cities is increasing day by day. The smart city concept includes smart services for its residents using recent technological advancements. Some examples of these smart services are smart homes, intelligent transportation, smart healthcare and applications demanding real-time services \cite{1,2}. Smart cities greatly depend on information and communication technologies. Internet of Things (IoT) is one of the most exciting developments of the century. It has a wide range of applications ranging from industrial to everyday use. IoT enables many smart city applications to monitor and manage numerous activities, including services with real-time data. For many of these applications to work, they need to know where the devices are. Received data with no or inadequate location information is either of no or limited use in various instances.

Many technologies have been used to meet the requirements of indoor positioning, with their pros and cons \cite{3}. The issues related to localization services for IoT devices also have received a lot of attention \cite{4}. WLAN has evolved as the most popular indoor communication method. It works on the unlicensed Industrial Scientific and Medical (ISM) spectrum and is accessible to everyone and anyplace. The hardware requirements are uncomplicated and cheap; almost every smart device has a built-in module to support it. WLAN APs can be seen everywhere in indoor environments, making it the best choice for indoor localization services. These days, WLAN has been widely used for not just internet access but
also indoor location-based services. The RSS fingerprinting-based localization systems have drawn considerable attention towards itself because of its better localization accuracy and range-free approach [5,6].

The rapid expansion of this technology for indoor localization and internet connection demands careful design and installation strategy. The planning and optimization is an important research topic that has received much attention in the literature related to wireless communication and networks. A lot of work has lately been done to ensure quality of service and network performance [7,8]. Still, the optimal WLAN configuration for localization services is an unsolved problem. Providing adequate signal coverage, localization accuracy, and channel assignment are all critical factors to consider while planning a WLAN APs configuration.

Interestingly, only optimizing AP deployment can result in improved performance. It can also help to remove dead zones, reduce interference, and provide maximum signal coverage with a limited number of APs. Therefore, we consider that AP optimization is an important topic to research. In our previous work [9], we developed a WLAN APs optimization algorithm enhancing the localization accuracy and coverage, but the interference problem among the closely placed APs was not discussed. Co-channel interference is a critical issue to be considered in WLAN networks. WLAN contains a limited number of non-overlapping channels leading towards interference. The Frequency-reuse phenomenon is used for interference mitigation. We propose a channel assignment scheme to mitigate interference between APs and improve network performance.

The work on network planning is extensive; here, we discuss some recent and closely related work. The authors of [10] proposed a network-planning scheme for high-density WLANs based on Interference Alignment. To avoid interference, the proposed scheme divides the area into sub-regions and utilizes non-overlapping channels. The work in [11] is devoted to determining the optimal number of APs and allocation of partially overlapped channels to cover a given area. By combining these two factors, the proposed DAPA scheme optimizes the network. The proposed solution in [12] makes use of radio propagation models and meta-heuristics for simulated annealing.

Jaiyeola et al. [13] propose a wireless network planning method for areas with a large dimension or many APs. The proposed method includes estimating the sufficient number of APs using a coarse-grained modeling approach and calling it an NP-complete problem. If a problem’s solution can be estimated and verified in polynomial time, it is referred to as NP (nondeterministic polynomial). The problem of optimum placement of APs is studied in [14]. An unplanned network design may lead to degraded performance. The paper considers two parameters concurrently, the transmission power and partially overlapping channel assignment, using integer linear programming. The objective of the proposed technique is to maximize the users served and network throughput. An optimization algorithm is presented in [15]; the algorithm considers external interference, which can degrade the performance. The proposed algorithm optimizes AP resource allocation to users using a centralized potential game developed in an SDWN Software-Defined Wireless Networking framework. In [16] an AP transmission power reduction algorithm is proposed. The proposed algorithm reduces WLAN power consumption for IoT applications using PI feedback control. The lack of non-overlapping channels leads to high interference, which is vital to consider in dense WLAN environments. Motivated by this problem, the authors in [17] propose an optimization algorithm, mixed-integer programming, using the Lyapunov approach. Among all these studies and researches, non have been conducted particularly for AP configurations from a localization point of view. The AP deployment for indoor localization has different requirements and includes deliberate overlapping regions. This paper fills the gap by providing a channel assignment strategy for WLAN APs installed for localization point of view.

This paper extends our previous work and enhances the algorithm leading to a more refined and complete AP optimization algorithm. This work takes a more complex and broad environment than the previous work. The area of interest is divided into rooms with the presence of a certain number of
people, not distributed uniformly. This work also uses the wall and people's presence algorithm from our previous paper. The proposed algorithm avoids interference among the neighboring APs in a dense installation; the channels are assigned to APs based on their hearability and mutual distance. The proposed algorithm is implemented on the configuration obtained for the fingerprinting-based WLAN localization system.

The rest of the paper is structured as follows, Section 2 covers the related work, and Section 3 explains the proposed channel assignment strategy. In Section 4 Simulation Model is presented, and Section 5 concludes the paper.

2. Proposed Channel Assignment Strategy
In this work, we propose a channel assignment strategy for WLAN APs of an indoor localization system. There are 14 channels in the WLAN 2.4 GHz band, as shown in Table 1. Only sets of three channels can be used as non-overlapping frequency space. The most commonly used channels are (1, 6, 11) as shown in Figure. 1; these channels are repeated as frequency reuse so that APs having similar frequency bands should not overlap to avoid interference. It is a valid problem in indoor localization systems because it requires a point to be covered by multiple APs at the same time. There is a great possibility of two APs using similar channels and causing interference. As the number of non-overlapping channels in WLAN is very limited, a proper channel assignment strategy can help reduce interference and increase system efficiency.

| Table 1. WLAN 2.4GHz Band Channels and Frequencies |
|---------------------------------------------------|
| Channel | Frequency Range (GHz)  |
|---------|------------------------|
| 1       | 2.412                  |
| 2       | 2.417                  |
| 3       | 2.422                  |
| 4       | 2.427                  |
| 5       | 2.432                  |
| 6       | 2.437                  |
| 7       | 2.442                  |
| 8       | 2.447                  |
| 9       | 2.452                  |
| 10      | 2.457                  |
| 11      | 2.462                  |
| 12      | 2.467                  |
| 13      | 2.472                  |
| 14      | 2.484                  |
An indoor environment having three or fewer APs will not have any problem, as these channels are sufficient for them. However, for environments having a large number of APs as one in our scenario, we develop a simple strategy to reduce interference. The first three APs will be assigned the three non-overlapping channels; for the next AP, its distance from all other APs is calculated. The AP with the largest distance will have the lowest interference influence, so its channel is assigned to the fourth AP. For the fifth and onwards APs, both the nearest and farthest APs are recorded, as there is a possibility both of these APs have been assigned the same frequency because of the repetition of channels.

If APs having maximum and minimum distance do not have the same WLAN channel, the new AP is assigned the AP channel having maximum distance. If both the APs with maximum and minimum distance have the same channel assigned to them because of frequency reuse, the distances are sorted, and the channel from the second farthest AP is assigned to the new AP. This process is shown in the flowchart presented in Figure. 2.

3. Simulation Model
In this paper, a two-dimensional indoor space is considered as our area of interest (AoI). It is partitioned into grids with equal spacing across them. These grid points are also called as reference points (RPs). RSS from APs are measured at these RPs and are then used in the optimization and localization processes to further refine the results. As shown in Figure 3, the AoI is divided into several rooms by walls that serve as partitions between them. We assume that our AoI is large enough for a single AP; it cannot offer complete coverage to all RPs, resulting in many RPs being left as wireless dead zones. Multiple access points are installed to ensure complete signal coverage, and these form overlapping zones. Overlapping on one side creates interference, but it is essential for positioning purposes on the other side. This issue will be addressed by our algorithm, which will also guarantee signal coverage.
Diff(AP₄;APᵢ) where (ᵢ = 1; 2; 3)
Max(Diff) = Dᵢ
AP₄ = channel(APᵢ)

For APᵢ, (j = 5, 6, ... N)
Diff(APⱼ;APᵢ), (ᵢ = 1, 2, 3, ......, M)
Max(Diff) = D₁
Min(Diff) = D₂

IF
D₁ ≠ D₂;
channel with Max distance is assigned

D₁ = D₂;
[Ac,Bc]=sort (Diff)
K=Bc(end-1)
APⱼ = Channel(K)

Figure. 2. Flowchart of the channel assignment algorithm.
The fingerprinting-based systems generate a radiomap by utilizing RSS from the deployed APs. The fingerprints and RPs, or a radio map, can be expressed mathematically as:

$$RP_i = [(x_i, y_i)] j = (1, ..., N)$$

$$\Theta = \begin{bmatrix}
    x_1 & y_1 & (\Omega_{1,1}, \Omega_{1,2}, \Omega_{1,3}, \Omega_{1,4}, ..., \Omega_{1,M}) \\
    \vdots & \vdots & \vdots \\
    x_N & y_N & (\Omega_{N,1}, \Omega_{N,2}, \Omega_{N,3}, \Omega_{N,4}, ..., \Omega_{N,M})
\end{bmatrix}$$

where \((x, y)\) are the coordinate points of the RPs, \(N\) and \(M\) are the total numbers of RPs and APs, respectively, and \(\Omega\) = samples of RSS from APs.

The main factors causing attenuation in this indoor signal propagation are the distance, noise, material obstacles and human presence. These attenuators must be included in the model to relate our simulation to a realistic environment. The environmental dynamics vary from RP to RP, making the values of these factors differ for each RP. The extended log-normal path loss model used for this purpose in our work is given as:

$$P(d) = P(d_0) + 10 \cdot n \cdot \log \left(\frac{d}{d_0}\right) + \vartheta + \sum_{i=1}^{j} \gamma + \sum_{k=1}^{l} \rho$$

where \(P(d)\) denotes the RSS at a point \(d\) in the \((x; y)\) coordinate system, \(P(d_0)\) denotes the RSS at a reference distance (1m from the AP), \(n\) denotes the path loss coefficient, and \(d\) denotes the distance between the AP and the RP; noise \(\vartheta\), material obstacles \(\gamma\) and human presence \(\rho\). The summation adds the attenuation effect caused by each wall and person in the path between transmitter and receiver. The simulation parameters can be seen in Table. 2.
Table 2. Simulation Parameters

| Parameter                        | Value |
|----------------------------------|-------|
| Path loss coefficient (n)        | 3     |
| Wall Attenuation Factor (γ)      | 4     |
| People Attenuation Factor (ρ)    | 3     |
| Reference Distance (d₀)          | 1     |
| Power at Reference Distance (P(d₀)) | -30   |

Our previously established AP optimization technique [9] is used to determine the ideal AP design. The APs are deployed using an RSS-based threshold, and their selection is based on minimising geometric dilution of precision (MinGDOP) and maximising fingerprint difference (MaxFD). The proposed selection algorithm is a hybrid technique, that combines MaxFD and MinGDOP. Both of these values are in different ranges, hence needs to be normalized to have an equal influence of both factors. Mathematically it can be seen be represented as follows:

\[
\text{Hybrid} = \arg\max(\text{MaxFD} + \frac{1}{\text{MinGDOP}})
\]  

(4)

However, as discussed previously, the work did not present any policy for channel assignment. The details of the selected AP configuration can be seen in Table 3. The optimal configuration obtained had 6 APs, which are deployed in the AoI as shown in Figure 4. The channel assignment process considers the positions of the APs; frequency reuse is applied for APs more than 3. The fourth and onward APs are assigned the channel by keeping in view the hearability and positions of previously assigned APs. Figure 4 shows the results of channel assignment after applying the proposed technique. It can be seen that the nearby APs have been assigned different channels, and frequency reuse is applied for the APs, avoiding interference by RSS hearability.

Table 3. AP configuration details.

| Coordinates of installed APs | Mean Error (m) | Max Error (m) |
|------------------------------|----------------|---------------|
| [25,25]                      |                |               |
| [37,25]                      |                |               |
| [25,19]                      |                |               |
| [28,13]                      |                |               |
| [16,25]                      |                |               |
| [7,13]                       | 2.5104         | 9.5           |
4. Conclusion
Indoor localization systems are an important part of the smart cities concept. It involves a large number of WLAN APs, which are deployed in a way creating overlapping regions. This overlap causes interference; this paper addresses this problem by an efficient channel assignment strategy. The proposed strategy uses APs hearability and mutual distance between the APs to avoid interference without changing the optimal configuration obtained for localization. The simulations prove that any two APs are not assigned the same frequency band if they lie in the each other’s proximity. The proposed channel assignment strategy will provide a promising solution for WLAN fingerprinting localization systems.

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