Joint Design of Density of Access Points and Partially Overlapped Channel Assignment for Capacity Optimization in Wireless Networks

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Joint Design of Density of Access Points and Partially Overlapped Channel Assignment for Capacity Optimization in Wireless Networks

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***Abstract*—The design of a wireless network is often critically affected by issues such as determining the optimal density of Access Points (APs) and optimal channel assignment by exploiting partially overlapped channels (POCs) for significantly improving the network performance in terms of maximizing the overall network capacity. Contemporary research works have traditionally dealt with these two problems in an isolated manner though they should be considered within the same problem formulation. Furthermore, though deployment of additional APs can improve the network capacity in case there are a few APs in a given area, the APs cannot be indefinitely added to the wireless network. This means that there is an upper bound to the network capacity maximization with respect to the number of APs. In fact, the network capacity starts to dramatically decrease when the number of deployed APs becomes excessive. This performance decrease can be accredited to the substantial interference among the high number of deployed APs. A more fundamental insight into the joint issue and its affect on capacity, in signal to interference plus noise ratio (SINR) is required. In order to address this challenge, in this paper, we propose an approach to jointly optimize the number of APs and POCs assignment. Our proposal derives the existence of the upper bound of the density of APs with POCs, and models the POC assignment to the deployed APs from a novel perspective. Computer-based simulations are conducted to demonstrate the effectiveness of our proposal.**

I. Introduction

The wide acceptance and easy deployment of the IEEE 802.11 WLAN technology has been gaining high popularity to provide communication service to areas, such as airports, shopping malls, office buildings, and university campuses. In many situations, WLAN planning is needed. For example, how to make a network design is critical for the disaster area beforehand so that it can be deployed promptly after a disaster, (e.g., the earthquake, tsunami wreck out communication). The channel assignment and AP density are needed to be done at the initial phase of network planning, setting aside user consideration.

Due to the broadcast nature of wireless signals and scarcity of available channels, the crucial issues of determining the optimal density of APs and channel assignment have to be considered in the planning phase to maximize the network capacity as the optimization objective. Though deployment of additional APs can improve the network capacity in case there are a few APs in a given area, APs cannot be indefinitely added to the wireless network due to a limited number of channels (e.g., only 3 orthogonal channels are available in the IEEE 802.11b/g).

Additionally, for extended coverage and higher capacity support in the high density of planned networks, POCs, which have been indicated to be able to facilitate interference mitigation and improve the network capacity, are used for the communication between users and APs. There are about 11 POCs in the IEEE 802.11b/g with center frequency separated by about 5 MHz while each channel occupies a spread of about 30 MHz as presented in Fig. 1.

Among adjacent channels there are some overlapped frequencies-referred to as the channel interference. The channel interference decreases with the channel separation (CS). With sufficient separation (not less than 5 channels in the IEEE 802.11b standards), no interference occurs. Currently, either one or three orthogonal channels are employed in WLAN networks. Recent work shows that a careful design of POC assignment can often lead to significant improvement in spectrum utilization and network performance [1][2][3].

While plenty of work is already presented in certain areas, it is still unclear how these networks need to be planned and tuned to optimally address the interplay between density of APs and POC assignment. In our work, we are focusing on the combination of the optimal number of APs and POC assignment to cover a particular geographical area. In the phase of network planning, the network performance can not be guaranteed to be optimized if the number of APs and POC assignment are optimized individually. The network capacity is decreased under the poor scheme of POC assignment in spite of deploying the optimal number of APs. Likewise, the best scheme of POC assignment can not lead to the maximal network capacity if the number of APs is not optimized.

The remaining of the paper is structured as follows. Section II introduces related research papers and their basic drawbacks. Section III presents the network assumptions, analysis of the existence of the upper bound of the density of APs, proposed scheme of POC assignment and the algorithm to solve the problem. Next in Section IV, the result of the performance evaluation by simulation is discussed. At last, Section V concludes this paper.

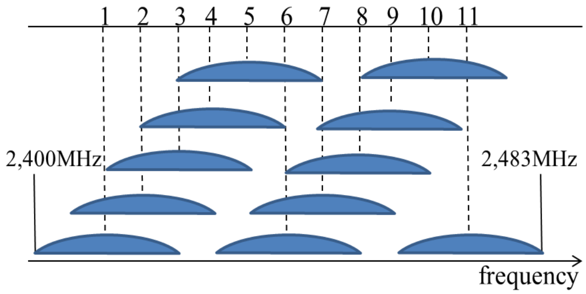

Fig. 1: Frequency spread of various channels in the IEEE 802.11b/g standard [9]. The number $1, 2, ..., 11$ are channel indices. There is overlapping area in frequency between two channels nearby (e.g., channels 2 and 4), which is called channel interference.

II. Related Work

Several methods for network planning in WLAN can be found in the literature, mostly in terms of candidate positions [4][5]. Given multiple candidate positions for APs, select some positions so that the network performance is maximized. This method can not determine the optimal density of APs in the sense that it can be seen as a NP-complete problem. Also, measurement driven design [6][7] performed extensive measurements to study the impact of parameters, which has real statistics but hard to be employed and scaled in the planning phase. Besides, in [8], the authors analyzed the relationship between MAC parameters and the density of APs. Furthermore, the afore-mentioned works just took into consideration one single channel or the orthogonal channels.

Recent studies has been done in improving the network performance by exploiting POCs. In [10][11], the authors measured the interference between different APs when POCs are used. Some works proposed channel assignment algorithms with POC for APs aiming at minimizing the interference among different APs, mostly from the viewpoint of graph theory [12], such as directed graph [13]. In [14] derived a novel interference model that considered both the interference among POCs and the physical distance between two APs. By defining the model of 'node orthogonality', they proposed an approximate algorithm to minimize the cumulative interference for throughput maximization. Unfortunately, these methods usually provided the way to assign channels to maximize the network capacity, without consideration of the optimal density of APs in the phase of network planning.

In [2], researchers formulated the problem of POC assignment into (0-1) optimization to study the improvement using POCs compared with using the orthogonal channels. Mathematical formulation for POC assignment to optimize the network performance. However, the work just gave the necessary condition of optimization. The work also studied the density of APs using POCs and concluded that POC can improve the network performance with the high density of APs, without indication of the optimal density of APs. Moreover, it is impossible to apply the approach in the phase of network planning in practice, since the proposal considered irregular deployments (e.g., the random deployment).

TABLE I: Channel Interference [11] F: CS is the separation of two channels $CS = |c_i - c_j|$, c_i, c_j are channel indices.

CS	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
F	1	0.73	0.27	0.03	0.005	0	0	0	0	0	0

III. Upper bound of Ring Levels and Optimal POC Assignment

In this section, we first make some reasonable assumptions to simplify the model. The primary objective of network planning is to provide the greatest capacity at the worst case, under which it results in the severest interference in the given area. Both the network capacity based on SINR and the POC assignment are considered in the analytical studies. Then, the algorithm is designed to solve the problem.

A. Assumptions

We assume the following conditions concerning the interference at the worst case in the network.

We first use the interference model in literature [11] to measure the channel interference degree among POCs. For example, the channel interference F for different channel separation CS is depicted in Table I. Later, we propose a new interference model due to the hardness of F and CS based methods to assign POCs.

Furthermore, the received power for the communication from the user to its associated AP is assumed unvaried with the cell size since the high density of APs is considered.

Since it is impossible to determine the optimal density in irregular deployments (e.g., random deployment), optimization in the regular deployment is studied. The definition of the regular deployment is that there only exists one result of AP placement for the deployment given the number of APs. We study the network performance in the hexagonal deployments, which usually is applied in the network planning in practice. For the regular hexagonal deployment, we can deploy $f(n) = 3n^2+3n+1$ APs uniformly in the circular area with the radius of r, where n is the number of ring levels of APs as shown in Fig. 2. Approximately, the radius R_n of each cell is $\frac{2r}{\sqrt{3(2n+1)}}$. However, it is hard to calculate the network capacity because there are numerous placement methods for other numbers of APs.

On the other hand, the users at the edge of the coverage area of its associated APs lead to the severest interference to others [15], which is the worst case to calculate $SINR$. Additionally, we assume the area is large enough so that the border effect can be ignored. The probability of being interfered by the users associated to other basic service sets (BSSs, a set of all stations that communicate with the same AP) is the same.

B. Upper Bound of Ring Levels Using POCs

Given the deployment of APs, we can calculate the received power P_{ij} at the worst case when using the same channel in

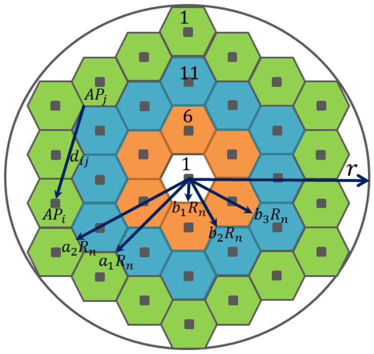

Fig. 2: Hexagonal deployment and the worst case for $SINR$: users at the edge of coverage of AP_j interfere with AP_i; d_{ij}: distance when the severest interference exists from the users associated to AP_j to AP_i; the number of ring levels is, $n = 3$.

two-ray ground propagation model [16] as follows:

$$P_{ij} = \frac{P_t * g_t * g_r * h_t^2 * g_r^2}{d_{ij}^{\beta}} = A * d_{ij}^{-\beta}, \tag{1}$$

where P_t is the transmitting power; g_t, g_r, h_t, g_r are constant system values, which are measured by A as a whole; d_{ij} is the distance to calculate the interference at the worst case; β is the path loss exponent and typically $2 \leq \beta \leq 4$. Since the received power for the communication between the user and its associated AP is assumed fixed and the path loss exponent just has a significant impact on the interference, a new term, i.e., environment interference factor, is used to describe the path loss exponent to avoid confusion. Thus the interference H_{ij} of AP_i from the users associated to AP_j with POC is:

$$H_{ij} = F(c_i, c_j)P_{ij}, \tag{2}$$

where c_i and c_j are channels at AP_i and AP_j, respectively; $F(c_i, c_j)$ is channel interference as described in Table I. $SINR$ is equal to

$$SINR_i = \frac{P_r}{P_0 + I_i}, \tag{3}$$

where P_r is the received power of AP_i from its users; $I_i = \sum_{j \neq i}^{f(n)} H_{ij}$ is the cumulative interference for AP_i. P_0 is the ambient noise power. In our analysis, assume $I_i \geq P_0$ and using Shannon Capacity formula, the achievable aggregate capacity is:

$$C(n) = B \sum_{i}^{f(n)} log(1 + SINR_i) = B \sum_{i}^{f(n)} log\left(1 + \frac{P_r}{I_i}\right), \tag{4}$$

where B is the channel bandwidth. In order to maximize the network capacity, the optimal number of APs is:

$$N_{opt} = \arg\max_{n} C(n). \tag{5}$$

Given the deployment area, when n is small, $C(n)$ increases along with n since that the increase in capacity dominates that in interference. When n is large, it results in substantial interference due to a limited number of channels such that the increase in interference dominates that in capacity. Thus, there is an optimal value of n to maximize the network capacity. In order to find the optimal number of APs, initially, the upper bound of the number of APs is derived as the following proposition.

Proposition 1. *There exists an upper bound of ring levels of APs N_u to maximize the network aggregate capacity given the optimal POC assignment in the regular hexagonal deployment that is:*

$$\exists N_u, C(n+1) - C(n) < 0, \forall n \geq N_u. \tag{6}$$

The following two claims are provided to support Proposition 1.

Claim 1. *Given the number of ring levels of APs, there exists an upper bound of overall network capacity that the following claim always holds:*

$$B * f(n) * \log\left(1 + \frac{P_r}{S_n} * f(n)\right) \leq C(n), \tag{7}$$

where P_r is the received power of the communication from the user to its associated AP; $S_n = \sum_{i=1}^{f(n)} I_i$ is the cumulative interference in the network.

Proof: Network aggregate capacity is $C(n) = \sum_{i=1}^{f(n)} C_i = B * \sum_{i=1}^{f(n)} \log\left(1 + \frac{P_r}{I_i}\right)$, where C_i is the capacity of i^{th} AP. Recall that C_i is a convex function of I_i, which implies Inequality (8).

$$\frac{1}{f(n)} * \sum_{i=1}^{f(n)} \log\left(1 + \frac{P_r}{I_i}\right) \geq \log\left(1 + \frac{P_r}{\sum_{i=1}^{f(n)} I_i / f(n)}\right). \tag{8}$$

So proof. ■

Claim 2. *Given the number of ring levels of APs, there exists an lower bound of overall network capacity that the following claim always holds:*

$$C(n) < B * f(n) * \log\left(1 + \frac{P_r}{I^K(n)}\right), \tag{9}$$

where $I^K(n)$ is the lower bound of cumulative interference when there are at most K orthogonal channels among POCs. E.X., $I^3(n) = 12 * P(a_1 R_n) + 6P(a_2 R_n), a_1 = \frac{\sqrt{52}}{2}, a_2 = \frac{5\sqrt{3}}{2}$ for $K = 3$ in the IEEE 802.11b/g WLAN in which $P(d)$ is the received power for the transmitting distance d in Equation (1).

Proof: It is interesting to note that for the simple string deployment where the APs are deployed in a line, the optimal channel assignment is just to use the orthogonal channels and the distance between two APs with the same channel is K levels away. This is intuitively reasonable. By Equation (2), the interference between AP_i and AP_j $H_{ij} \propto F(c_i, c_j) * d_{ij}^{-\beta}, 2 \leq \beta \leq 4$. Since channel interference $F(c_i, c_j)$ is a hardware-based value, $F(c_i, c_j)$ is fitted as a quadratic function or a linear function as shown in (III-C). Note that $d_{ij}^{-\beta}$ is a power function of distance d_{ij}, $d_{ij} \geq D_{Thresh}$, as an example,

$D_{Thresh} = 50\ \ meters$ where radius of the coverage area of an AP is $25 meters$. For example, in the string deployment one of the optimal channel assignment patterns is $1, 6, 11$ as shown in Fig. 2 for $K = 3$ in the IEEE 802.11b/g. As explained above, it can minimize the interference if there is an approach of POC assignment in which the optimal channel assignment is just to use the orthogonal channels and the distance between two APs with the same channel is K levels away for each AP. Consequently, in such assignment the interference is minimized for each AP that is $I^K(n)$ and $I^3(n) = 12 * P(a_1R_n) + 6P(a_2R_n)$ illustrated in Fig. 2. Note that in fact there is no such orthogonal channel assignment for the hexagonal deployment. So proof. ■

The key implication behind Claims 1 and 2 is to support Proposition 1. Introduce $k(n)$ as the efficiency of POC assignment that is $k(n)$ times less than that in random POC assignment with respect to cumulative interference in the network. In addition, since I^K is depended on the exact value of K, the analysis below is based on the case of $K = 3$ in the IEEE 802.11b/g, which is valid for other cases. By Claims 1 and 2,

$$C(n+1) - C(n) < f(n+1)\log\left(1 + \frac{P_r}{I^K(n+1)}\right) - f(n)\log\left(1 + \frac{P_r}{S_n}f(n)\right). \tag{10}$$

Roughly speaking, the interference is dominated by the closest two levels of interfering APs for the random POC assignment and the cumulative interference,

$$\begin{aligned} S_n^{ran} &= 6F_{exp}\left(P(b_1R_n) + P(b_2R_n) + P(b_3R_n)\right)f(n) \\ &= 6AF_{exp}\left(\frac{2r}{2n+1}\right)^{-\beta}(b_1^{-\beta} + b_2^{-\beta} + b_3^{-\beta})f(n), \end{aligned} \tag{11}$$

where $F_{exp} = \frac{\sum_{c_j}^{M} F(c_i, c_j)}{M}, \forall c_i \le M$, M is the total number of channels as described in Table. I; b_1, b_2 and b_3 are the distances as shown in Fig. 2 to calculate interference at the worst case. For the reuse patter of orthogonal channel assignment in [8], the cumulative interference is given by:

$$\begin{aligned} S_n^{ort} &= f(n-2) * 6 * P(2R_n) + 6(n-1) * 4 * P(2R_n) \\ &\quad + 6n * 2 * P(2R_n) \\ &= 6A * 2^{-\beta} * \left(\frac{2r}{2n+1}\right)^{-\beta} * (3n^2 - 3n + 3). \end{aligned} \tag{12}$$

From (11) and (12),

$$\begin{aligned} k^{ort}(n) &= \frac{S_n^{ran}}{S_n^{ort}} \\ &= \frac{F_{exp} * (b_1^{-\beta} + b_2^{-\beta} + b_3^{-\beta}) * (3n^2 + 3n + 1)}{2^{-\beta} * (3n^2 - 3n + 3)}. \end{aligned}$$

Referring to (10), it follows that

$$\begin{aligned} & f(n+1)\log\left(1 + \frac{P_r}{I^K(n+1)}\right) - f(n)\log\left(1 + \frac{P_r}{\frac{S_n^{ran}}{k^{ort}(n)}}f(n)\right) \\ &= (3n^2 + 9n + 7)\log\left(1 + \frac{P_r}{I^K(n+1)}\right) \\ &\quad - (3n^2 + 3n + 1)\log\left(1 + \frac{k^{ort}(n)P_r}{S_n^{ran}}f(n)\right). \end{aligned} \tag{13}$$

Given the reasonable parameters values as evaluated in Section IV, since $\exists n_{up}$, such that $((13)) \le 0, \forall n \ge n_{up}$. Furthermore, for the optimal POC assignment $k^{poc}(n) \ge k^{ort}(n)$. This, in turn, implies that $C(n+1) - C(n) \le 0, \forall n \ge n_{up}$. So proof Proposition 1.

C. POC Assignment in Hexagonal Deployment

We have already introduced the existence of upper bound of ring levels of APs to maximize the aggregate capacity. This result stems from the dependency that the efficiency in POC assignment which is better than using the orthogonal channels. This basically states that the optimal POC assignment is needed to maximize the aggregate capacity within the range of upper bound of ring levels. Usually, it is a NP-complete problem for POC assignment due to integer assignment of channel index in terms of interference model F and CS in subsection III-A. Most of them are from the viewpoint of graph theory and partly from the viewpoint of game theory [17]. In this section, a novel POC assignment is developed and will be used in the combination of optimal number of APs in the next subsection.

There is a fixed standard channel center frequency f_s^i corresponding to the channel i as shown in Fig. 1. The POC assignment is identical with the channel center frequency selection. The basic idea is, firstly, to relax the channel center frequency from the standard channel center frequency to arbitrary frequency to obtain the optimal selection of channel center frequency. Then place the constraint on the result to assign POCs. In this paper, we simplify the channel power distribution as a rectangle. The channel interference degree model is, then, formulated as follows.

$$F(f_i, f_j) = \begin{cases} 1 - \frac{|f_i - f_j|}{B}, |f_i - f_j| < B \\ 0, \quad\quad otherwise, \end{cases} \tag{14}$$

where f_i is the channel center frequency in the range of $[f_{low}, f_{up}]$; B is the channel bandwidth. If the channel center frequencies of two channels are within interfering separation, their channel interference is $(1 - \frac{|f_i - f_j|}{B})$; otherwise, it is 0. The selection problem of channel center frequency to minimize the interference can be formulated as follows with the new model of channel interference.

$$\boldsymbol{min.} \sum_{i}^{n-1}\sum_{j=i+1}^{n} H_{ij} \tag{15}$$

$$\boldsymbol{s.t.} \quad H_{ij} = F(f_i, f_j)P_{ij}, \forall i, j \tag{16}$$

$$F(f_i, f_j) = \begin{cases} 1 - \frac{|f_i - f_j|}{B}, |f_i - f_j| < B \\ 0, \quad otherwise. \end{cases} \quad, \forall i, j \tag{17}$$

$$f_{low} \le f_i \le f_{up}, \forall i \tag{18}$$

The optimization problem can be solved as a Mixed Integer Linear Problem (MILP) as follows.

$$\boldsymbol{min.} \sum_{i}^{n-1}\sum_{j=i+1}^{n} F(f_i, f_j) * P_{ij} \tag{19}$$

$$\textbf{s.t.}\quad f_i - f_j + W * y_{ij}^1 \geq 0, \forall i, j \leq n \tag{20}$$
$$B - (f_i - f_j) + W * y_{ij}^1 \geq 0, \forall i, j \tag{21}$$
$$F(f_i, f_j) - (1 - \frac{f_i - f_j}{U}) + W * y_{ij}^1 \geq 0, \forall i, j \leq n \tag{22}$$
$$f_i - f_j + B + W * y_{ij}^2 \geq 0, \forall i, j \leq n \tag{23}$$
$$-(f_i - f_j) + W * y_{ij}^2 \geq 0, \forall i, j \leq n \tag{24}$$
$$F(f_i, f_j) - (1 + \frac{f_i - f_j}{U}) + W * y_{ij}^2 \geq 0, \forall i, j \leq n \tag{25}$$
$$f_i - f_j - B + W * y_{ij}^3 \geq 0, \forall i, j \leq n \tag{26}$$
$$F(f_i, f_j) + W * y_{ij}^3 \geq 0, \forall i, j \leq n \tag{27}$$
$$-B - (f_i - f_j) + W * y_{ij}^4 \geq 0, \forall i, j \leq n \tag{28}$$
$$F(f_i, f_j) + W * y_{ij}^4 \geq 0, \forall i, j \leq n \tag{29}$$
$$y_{ij}^1 + y_{ij}^2 + y_{ij}^3 + y_{ij}^4 = 3, \forall i, j \leq n \tag{30}$$
$$y_{ij}^k = 0, 1, \forall i, j \leq n, k = 1, 2, 3, 4 \tag{31}$$
$$f_{low} \leq f_i \leq f_{up}, \forall i \leq n, \tag{32}$$

where W is a constant, which value should be large enough. By introducing (0-1) variables y_{ij}^k, we reduce the problem to MILP. Constraints (20)-(22), (23)-(25), (26)-(27) and (28)-(29) describe cases $0 \leq f_i - f_j < B$, $-B \leq f_i - f_j < 0$, $B \leq f_i - f_j$ and $f_i - f_j < -B$ in (17), respectively. There are multiple (0-1) variables in MILP formulation, which is not efficient to solve when the number of APs becomes large. Since the interference mainly is from BSSs nearby, the problem complexity can be reduced by associating BSSs in just the closest three levels of interfering BSSs, for example.

Denote $f^* = (f_1, f_2, ..., f_n)$ as the solution of channel center frequency assignment from MILP. Place the constraint of standard channel center frequency f_s^k on f^* to assign POCs. Since there exists k, $f_s^k \leq f_i \leq f_s^{k+1}$, the most simple method is to choose POCs from $\{c_k, c_{k+1}\}$ corresponding to channel frequencies $\{f_k, f_{k+1}\}$ for each AP.

Let c^* be the result of POC assignment in the aforementioned proposal, c_{opt} the optimal POC assignment, which is usually impossible to obtain. It results in deviation when placing the constraint on the result of MILP formulation. The definition of deviation is how far it is from the channel frequency corresponding to c^* obtained in the proposal to that in the optimal POC assignment corresponding to c_{opt}. The worst case of solution in the proposal is $\exists k, f_i = f_s^k + \frac{B}{2}, \forall i$ and the corresponding POC assignment of AP_i with standard channel center frequency f_s^k or f_s^{k+1}. So the deviation $dev = \frac{|c^* - c_{opt}|}{B} \leq \frac{|f_s^k - f_i|}{B} = \frac{1}{2}$. The main merit of our POC assignment is that it can be regarded as the reference with minimal interference to compare.

D. Algorithm for Determining Optimal Number of Ring Levels

Now, we propose Algorithm 1 for determining the optimal number of ring levels and POC assignment based on the analysis and MILP formulation.

In order to cover the entire area, the minimal number of ring levels is given in the line 1; r_0 the maximal radius of coverage area of an AP. As investigated in Section III-B, the optimal number of ring levels can be found within the range of upper bound of ring levels in Proposition 1. The steps from line 3 to 9 in the algorithm explore the characteristics to find the optimal number of ring levels while locating the optimal channel center frequency in line 4. Once the optimal number of ring levels is obtained with optimal channel center frequency, the algorithm places the necessary constraint of standard channel center frequency to assign POCs to APs.

Algorithm 1

1: Init number of levels: $N = argmin_n(n - \frac{r}{r_0}), n \geq \frac{r}{r_0}$;
2: solve MILP formulation given the number of levels N;
3: **while** $N < n_{up}$ **do**
4:     solve MILP formulation given the number of levels $N + 1$;
5:     **if** $C(N) \leq C(N+1)$ **then**
6:         $N + 1$ is the optimal number of levels;
7:     **end if**
8:     $N = N + 1$;
9: **end while**
10: Place the constraint of standard channel center frequency to assign POCs.

TABLE II: Center Frequency Selection and POC Assignment

#AP	Result in MILP Formulation	POC Assignment
3	2413.8, 2441.8, 2469.8	1, 6, 11
4	2414.5, 2442.1, 2469.8, 2413.8	1, 6, 11, 1
5	2442.1, 2469.8, 2413.8, 2441.5, 2469.2	6, 11, 1, 6, 11

IV. Performance Evaluation

A. Environment

In this section, we evaluate our proposal presented in Section III with the radius of 1000 and 2000 meters, respectively. The transmitting power is set to $15dbm$. The environment interference factor β is varied from 2 to 3. The communication range can be calculated as 270 meters for the rate of $11Mbps$. The channel bandwidth is about $27.67MHz$. The channel center frequency is in the range of $[2413.8, 2469.8]MHz$. We use Lingo [18] to solve the MILP formulation.

B. Study of Hexagonal Deployment

Recall the upper bound based on the fact that the optimal POC assignment for the string deployment is just to use the orthogonal channels as listed in Table II. The second column of the table is the result in MILP formulation when deploying APs in a line and the corresponding POC assignment is in the last column. From the table, the POC assignment only lies in the orthogonal channels, that are channels 1, 6 and 11, irrelevant to POCs as analyzed in Claim 2. In the investigation of the upper bound of ring levels, the parameter β has a significant impact on the interference from one cell to other cells as described in Claim 2. Logically, as β increases, the interference becomes less harmful as illustrated in Figs. 3 and 4. The y axis is the upper bound of normalized capacity increment that is $\frac{C(n+1) - C(n)}{C_0}$, where C_0 is the capacity of

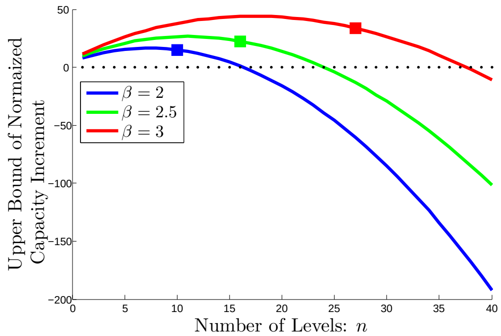

Fig. 3: Simulation result in the area with radius of 1000 meters: cross-points between the curves and the zero-dotted lines are the upper bounds of ring levels; square points are the corresponding optimal numbers of ring levels..

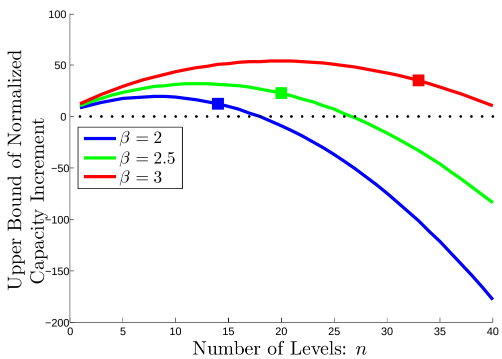

Fig. 4: Simulation result in the area with radius of 2000 meters.

one AP without interference. Given the exact value of β, there exits an upper bound of ring levels at the crosspoint between the curve and the zero-dotted line for reference. Using the proposed algorithm, the optimal number of ring levels at the square point in the curve is found within the upper bound.

It is intuitively reasonable that the capacity increment drops sharply for the big n in Figs. 3 and 4 since interference increases quickly in high density of APs. Remark that in figures the capacity increment decreases infinitely, which seemingly contrasts with the fact that the network capacity achieves at least a threshold since there are K orthogonal channels. The key premise behind the threshold capacity is that some of APs in high density almost do not work due to heavy interference to make sure there is little interference for other APs with the threshold capacity. This, in turn, implies that the deployment is not the regular hexagonal deployment.

V. Conclusion

In this paper, we addressed the critical issue of combining the density of APs and POC assignment that aims at maximizing the overall network capacity. There is certainly a maximal network capacity by optimizing the combination issue, but may not occur in individual optimization scenarios. In particular, we analyzed the characteristics of the problem, which suggests an upper bound of ring levels in the context of POC assignment. Roughly speaking, the optimal number of ring levels can be found within the upper bound.

Based on our conducted analysis, we also proposed an algorithm based on a novel scheme of POC assignment. We developed the model of POC assignment from the perspective of frequency distribution. Through both analysis and simulation, we demonstrated the effectiveness of our proposed algorithm for regular hexagonal deployment.

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