Interference Mitigation in Co-Working IEEE 802.11n WLANs

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Abstract: - In a densely deployed Wireless Local Area Network (WLAN) environment, Access Points (APs) could be so close to cause significant channel interference. In the next generation IEEE 802.11n WLANs, inter-cell interference decreases spectral efficiency. By applying common transmission weight vectors in all sub-carriers at a set of users, the paper proposes a new distributed algorithm that permits interfering APs to select appropriately their operating frequency and suppress interference in co-working IEEE 802.11n WLANs. Our method increase system performance and significantly reduces implementation complexity and power consumption. Simulation results in a strong interference environment show substantial gain for our proposed strategies.

I. INTRODUCTION

Given the unlicensed nature of WLAN technologies and decreasing cost of IEEE 802.11 WLANs, the number of APs has multiplied to improve the wireless cove range. Additionally, independent WLANs co-work in the same region. Wireless networks are unplanned resulting variable AP densities and independently managed due to manual setting of AP at the factory. This deployment is refer in [1] as chaotic and suffer from throughput and latency degradation, essential requirements for multimedia applications. 802.11 Task Group n proposes modifications to physical and MAC (Medium Access Control) layer in order to achieve higher data rate than the existing WLANs [2]. IEEE 802.11n put forward technologies such Orthogonal Frequency Division Multiplexing (OFDM), Quadrature Amplitude Modulation (M-QAM) and Multiple Input Multiple Output MIMO [2,3,4].

The access to the same channel by multiple APs is coordinated by the MAC protocol CSMA/CA (Carrier Sense Multiple Access with Collisions Avoidance). When high interference level is dominated, Ready To Send (RTS) / Clear To Send (CTS) collision is very frequently, which drives APs to the back-off state more often. After a collision, back-off window is increased before next re-transmission. In case of being able to guaranteeing a prescribe SINR, contention periods and collisions within 802.11 MAC operation are eliminated. RTS/CTS mechanism can't be used and the maximum theoretical throughput obtained will be increased up to 85% for any number of stations [5].

The problem of assigning channels to APs can be characterized as a graph-coloring problem. The goal is to cover APs with the minimum of channels (color), such that no two adjacent APs use the same channel. In [6], the weight at graph-coloring problem indicates the importance of using different colors taking into account co-channel interference as well as the impact of interference between overlapping channels. Distributed algorithms in a high node density deployments for channel selection and user association is proposed in [7]. APs are recommended to select channels which minimize total interference. The proposed algorithms are probabilistic (synchronization is required since initialization of the network) and long-term efficient. The same optimization philosophy based on Gibbs sampler is proposed in [8]. In this work, power control and CSMA/CA thresholds are jointed to maximize the sum of long term throughput for all users in the network. Mechanisms such automatic frequency selection and CSMA/CA are based on interference avoidance. In a densely WLAN environment, the above solutions will result low throughput or a state of no synchronization between AP and users. Therefore interference needs to be suppressed. Transmit power and channel band are often set without taking account the number and the position of users in the cell. Such situation increases interference among APs.

The goal of this paper is to greatly improve the frequency utilization efficiency and at the same time to keep low implementation complexity, while focusing on IEEE 802.11n standard. The key idea is to minimize interference and simultaneously to keep Quality of Services (QoS) at an acceptable level even for overlapping co-working networks. Therefore, RTS/CTS operation could be off. Space Division Multiple Access technique (SDMA) and common weight vectors applying in all sub-carriers belong to a set of users is proposed. According their locations, the users are divided in g sets. Downlink beamformers are designed for the co-channel sets of users under QoS (minimum attained Signal to Interference plus noise ratio at each receiver). We minimize total transmission power and thus leakage to neighboring cells. Operation frequency of AP a f_a is defined at the center of band. From the set of fixed number of available channels used by AP a and K users, we select the channel that gives the minimum transmit power after beamforming optimization. Following the optimal beamformers at AP, the different sub-carriers of each set of users can be allocated to different users (OFDMA). By adaptively employing different modulation modes on the sub-carriers according to SINR, we enhance the system performance.

Such optimization design suffers from the fact that the receivers are found at different locations and therefore different levels of interference are induced. The constraint of minimum SINR for each receiver must be satisfied. Multiple antennas at the receiver are used to increase diversity gain by combining the different paths of propagation and reduce strong interference from neighboring cells.

The integration of our solution offers decreased complexity since only the addition of an RF beamforming module between Power Amplifier (PA) and antenna elements is needed. The RF beamformer applies the complex weights for each antenna element by controlling phase shifters and attenuators. In IEEE 802.11n standard, beamforming for each sub-carrier is proposed and implementation can be realized only with digital beamforming architecture. In digital beamforming, the operation of phase shifting and amplitude scaling are implemented digitally. Either general-purpose Digital Signal Processing (DSP) or dedicated beamforming chips are used. Therefore, this technique suffers from high power consumption. Our implementation reduces the number of signal processed. Also, digital integration places tough performance criteria on Analog –to-Digital (A/D) converter at the receiver and D/A at the transmitter in order to provide accurate delay. The linearity and dynamic range of the Intermediate Frequency (IF) stage and A/D converter will also have to be substantially higher, leading to higher power consumption and cost hardware.

The fundamental idea of our approach is the following: a WLAN can obtain better performance if all neighbors APs steer transmit and receive beams appropriately, choice suitable channel band and minimize transmitted power than all AP behaves in selfish manner by maximizing transmitted power. Our algorithm works without coordinate by other APs. In IEEE 802.11 WLANs, interference on the same channel can be directly detected through the contention mechanism. Contrarily, adjacent channel interference often contributes to background noise and cannot be handled in an explicit manner. Our design take account adjacent channel interference since transmit masks are not ideal band-pass filters.

The paper is organized as follows: in the next section, we define the system model. In section III, downlink SDMA-MIMO algorithms with common weight vectors are developed. Section IV studies sub-carriers assignment problem. In section V, performances of proposed algorithms are extensively simulated and section VI concludes this article.

II. SYSTEM MODEL

In IEEE 802.11n draft, the 20 MHz channel bandwidth is divided into 48 data sub-carriers. The network operates into UII unlicensed band at 5 GHz. The largest amount of spectrum is 300 MHz with 4 indoor, 4 outdoor and 4 indoor or outdoor available channels. The outer 12 sub-carriers are zeroed in order to reduce adjacent channel interference. At 2.4 GHz, ISM band with available bandwidth 83.5 MHz is designed. Taking account that channels are spaced by 20 MHz, 3 indoor or outdoor channels are used [9].

Let's a geographical area where there is a set $\mathcal{A}$ of available APs forming non-cooperative co-working WLANs IEEE 802.11n. Consider $\mathcal{C}$ the set of a fixed number of available channels to be subsequently used for AP $a \in \mathcal{A}$ where frequency of operation $f_a \in \mathcal{C} = \{1, 2, \ldots F\}$ with $F = 3$ for ISM band and $F = 8$ for UNII band. Interference depends on the traffic load. If most APs are involved in occasional transmission, then no degradation in performance occurs. We focus on the downlink, where data is send by APs to users that is the majority of wireless traffic. We assume that the networks are fully saturated, i.e. the APs always have data to send to all the users. We study a cell with a single AP $a \in \mathcal{A}$ and K users. Both AP and users are equipped with M_t and M_r array antennas respectively. Consider a total of $1 \le G \le K$ sets $\{G_1 \ G_2 \ \ldots \ G_G\}$, where G_g contains the indices of receivers participating in set g, $g \in \{1 \ 2 \ \ldots \ G\}$. Each receiver belongs to a single set $G_g \cap G_m = \{ \ \}$ with $g \ne m$ and $\sum_{g=1}^{G} |G_g| = K$. Let the channel for user k at operation frequency f_a is frequency-flat; propagation loss and phase shift are described by $H_k^{f_a}$ $M_r \mathrm{x} M_t$ channel matrix. The operation frequency of our downlink beamforming optimization problem is defined at the center of band, where according IEEE 802.11n sub-carrier is null. Multipath delays cause frequency selective fading consequently the estimated channel matrices $H_k^{f_a}[1]$ to $H_k^{f_a}[N]$ correspond from sub-carrier 1 to N perhaps present large gain variation in the same band. In order to overcome these problems, $H_k^{f_a}$ is taken as the average channel matrix for all sub-carriers.

$$H_k^{f_a} = \frac{1}{N} \sum_{i=1}^{N} H_k^{f_a}[i] \quad (1)$$

Let's $v_g^{f_a} M_f \mathrm{x} 1$ is beamforming weight vector applied to the transmitter. Assuming that the information signal s_g, directed to receivers in set g, is zero mean, temporally white with unit variance and the waveforms $\{s_g\}_{g=1}^{G}$ are mutually uncorrelated. The total radiated power is equal to

$$P_{tx}^{f_a} = \sum_{g=1}^{G} \|v_g^{f_a}\|_2^2 \quad (2)$$

If $U_k^{f_a} M_r \mathrm{x} M_r$ is the matrix applied at user k then the Rx power at the receiver k is

$$P_k^{f_a} = |(U_k^{f_a})^H H_k^{f_a} v_g^{f_a}|^2 \quad (3)$$

Suppose that the noise at receiver k is zero mean with variance $(\sigma_k^{f_a})^2$ then the noise power is

$$N_k^{f_a} = (\sigma_k^{f_a})^2 \|U_k^{f_a}\|^2 \quad (4)$$

The APs and users exploit Channel State Information (CSI) to form beamorming weights. In short-range scenario like WLAN, CSI is feasible because of low mobility. WLANs operating in the 5GHz spectrum implement dynamic frequency selection (DFS) in order to protect radars, satellite and other systems. For every channel, each user measures the interference level in its vicinity by scanning the wireless medium. Then, RSSI (Received Signal Strength Indication) values are reported to AP via feedback. We introduce the notion of

Interference Factor $I(f_a, f_b)$ or I-factor, where $f_a, f_b \in \mathcal{C}$ are the frequencies at the center of the band of AP $a, b \in \mathcal{A}$. I-factor translates into the normalized fraction of power which is transmitted at frequency f_b and is captured from receiver that works at frequency f_a. In [6], one can see how we calculate the I-factor. Given $P_k^{f_b}$ the average over all sub-carriers power measured from receiver k at frequency f_b, when AP a is silent, the total interference power correspond to user k is

$$\mathcal{I}_k^{f_a} = \sum_{f_b} P_k^{f_b} I(f_a, f_b) \quad \forall f_b \in \mathcal{C} \quad (5)$$

III. DOWNLINK BEAMFORMING DESIGN

A. Optimum Receiver Antenna Arrays

The receiver antenna arrays have a properly determined beam pattern. They steer the beams to enhance the total power in all reflected paths at a scattering environment. Array gain is achieved via coherent combining of the signal paths. The proposed strategy is based on ES or E-SDM. H_k^n can be diagonalized as

$$H_k^n = U_k^n D_k^n (V_k^n)^H = \sum_{i=1}^{q} \sqrt{\lambda_{ki}^n} u_{ki}^n v_{ki}^n \quad (6)$$

D_k^n is a $M_r \times M_t$ matrix where only non zero elements are given by

$$D_k^n[i, i] = \sqrt{\lambda_{ki}^n} \quad (7)$$

with $i = 1, \ldots q$. The scalar $q = \min(M_t, M_r)$ denotes the rank of H_k^n and represents the number of spatial degrees of freedom. The SVD is an appropriate way of diagonalizing the matrix H_k^n which leads to a number of parallel channels (eigen modes). The power gain of i channel (ith eigen mode) is λ_{ki}^n. The columns $u_{ki}^n (v_{ki}^n)$ of $U_k^n (V_k^n)$ are orthonormal so that

$$(U_k^n)^H U_k^n = I_{M_t} \quad (8)$$
$$(V_k^n)^H V_k^n = I_{M_t} \quad (9)$$

The columns $u_{ki}^n (v_{ki}^n)$ are the optimum weights of Rx antenna arrays (Tx antenna arrays) for ith eigen mode [10]. E-SDM forms beams using eigen-vectors and can configure a spatially orthogonal MIMO channel that is a channel without crosstalk. Therefore, receiver antenna arrays form beams using eigen-vectors and expect to capture all possible orthogonal spatial streams derived from scatters which are found to the neighborhood of transmitter and receiver. SVD must be evaluate at the receiver. The calculation load increases proportionally according to the number of sub-carriers. But the channel in frequency domain is smooth. The adjacent sub-carriers are highly correlated because we multiply all sub-carriers by the same complex weights. This correlation reduces the calculation load. One can estimates U_k^n matrix in one specific sub-carrier n by interpolation and smoothing over adjacent sub-carriers. In E-SMD technique, the beamformer applied at the transmitter is the matrix V_k^n at each sub-carrier. The equivalent channel after beamforming is not still remaining smooth leading to higher computation load and high power consumption.

B. Beamforming optimization for AP

The general power minimization problem (subject to SINR constraints) of simultaneously designing beamformers for several co-channels multicast sets of users and frequency flat channel was studied in [11]. This problem can be formulated as a convex optimization problem. However, the optimum solution is considered for a single antenna receiver. We extended this design problem taking account interference from neighboring co-working APs and that the remote users have multiple antennas (MIMO system). Given received vector $U_k^{f_a}$ for all users of set g, calculating from SVD of the channel matrix, the posed problem is to generate an optimal downlink beamforming at AP a, minimizing at the same time the total transmit power and guaranteeing a prescribed SINR constraints γ_k at each user of set g.

$$\mathcal{Q} \quad \min_{\{v_g^{f_a} \in C^{M_t}\}_{g=1}^{G}} \sum_{g=1}^{G} \left\| v_g^{f_a} \right\|_2^2$$

$$\frac{\left| (U_k^{f_a})^H H_k^{f_a} v_g^{f_a} \right|^2}{\sum_{l \neq g} \left| U_k^{f_a} H_k^{f_a} v_l^{f_a} \right|^2 + (\sigma_k^{f_a})^2 \left\| U_k^{f_a} \right\|^2 + \sum_{f_b} P_k^{f_b} I(f_a, f_b)} \geq \gamma_k$$

$$\| U_k \|^2 = 1, \qquad \forall k \in \{1, 2, \ldots K\},$$

$$\forall g \in \{1, 2, \ldots G\}, \ \forall f_b \in \{1, 2, \ldots F\}$$

$\| U_k \|^2 = 1$ because U, derived from SVD, is a unitary matrix. This problem was found NP-hard for general channel vector [11,12]. Let's introduce

$$r_k^{f_a} = (U_k^{f_a})^H H_k^{f_a} \quad (10)$$

size $M_r \times M_r$ complex matrix, define

$$V_g^{f_a} = v_g^{f_a} (v_g^{f_a})^H \quad (11),$$
$$R_k^{f_a} = (r_k^{f_a})^H r_k^{f_a} \quad (12)$$

and use

$$\left| r_k^{f_a} v_g^{f_a} \right|^2 = (v_g^{f_a})^H (r_k^{f_a})^H r_k^{f_a} v_g^{f_a} = tr(V_g^{f_a} R_k^{f_a}) (13)$$

For reason of simplicity, we have the shorthand notation R_k for $R_k^{f_a}$, V_g for $V_g^{f_a}$, v_g for $v_g^{f_a}$ and σ_k for $\sigma_k^{f_a}$. The problem $\mathcal{Q}$ is transformed as

$$\mathcal{Q}' \quad \min_{\{V_g \in C^{M_t \times M_t}\}_{g=1}^{G}} \sum_{g=1}^{G} tr(V_g)$$

$$\text{s.t.} \quad \frac{tr(R_k V_g)}{\sum_{l \neq g} tr(R_k V_l) + \sigma_k^2 + \sum_{f_b} P_k^{f_b} I(f_a, f_b)} \geq \gamma_k$$

$$V_g \geq 0 \quad V_g = V_g^H \quad rank(V_g) = 1$$

$$\forall k \in \{1, 2, \ldots K\} \quad \forall g \in \{1, 2, \ldots G\}$$

$$\forall f_b \in \{1, 2, \ldots F\}$$

The constraint $rank(V_g) = 1$ is applied from the fact that $V_g = v_g v_g^H$. Constrains $V_g \geq 0$ and $V_g = V_g^H$ mean that V_g is symmetric, positive, semidefinite matrix. In general case, the constraint $\{rank(V_g)\}_{g=1}^{G}$ is not convex [12]. By dropping the associated non

convex constraints, the original non-convex Quadratically Constrained Quadratic Programming (QCQP) problem $\mathcal{Q}$ relaxed to a suitable Semi Definite Programming problem (SDP). As shown by Bengtsson and Ottersten, the above relaxation is guaranteed to have at least one optimal solution which is rank one [13]. We introduce K real non-negative "slack" variables $\left\{s_k\right\}_{k=1}^K$ and we underline the fact that the terms in denominator of linear inequalities are all non-negative; we take the relaxation problem $\mathcal{R}$.

$$\mathcal{R} \quad \min_{\{V_g \in C^{M_t \times M_t}\}_{g=1}^G} \sum_{g=1}^G tr(V_g)$$

$$tr(R_k V_g) - \gamma_k \sum_{l \neq g} tr(R_k V_l) - s_k =$$
$$\gamma_k(\sigma_k^2 + \sum_{f_b} P_k^{f_b} I(f_a, f_b))$$

$$V_g \geq 0, V_g = V_g^H, s_k \geq 0, \forall k \in \{1, 2, \ldots K\}$$

$$\forall g \in \{1, 2, \ldots G\}, \forall f_b \in \{1, 2, \ldots F\}$$

The relaxation technique can be interpreted as the Lagrangian dual of the dual of the original problem because it gives a lower bound for the original problem. The first advantage of using SDP is that problem $\mathcal{R}$ is a convex optimization problem and hence it has not local minima. The second one is that problem can be efficiently solved by any SDP solver, such as SeDuMi [14], based on interior point methods. Problem $\mathcal{R}$ can be expressed in the standard prima form used in SeDuMi. The relaxed problem $\mathcal{R}$ provides only lower bounds on the optimal solution $\left\{v_g^{\text{opt}}\right\}_{g=1}^G$ due to the fact that V_g^{opt} will not be rank – one in general. In [15] randomization is proposed for computing feasible points in a QCQP problem. If x is the variable matrix of the original problem and $X = x\,x^T \geq 0$ the variable of the relaxed problem then x is selected as a Gaussian variable with $x \backsim N(x, X)$. Afterwards, x will solve the QCQP "on average". A good feasible point can be obtained by trying enough x. Inspired by the above method, a randomization procedure is employed in [11] to generate candidate beamforming vectors v_g. This procedure is mentioned as $rand\mathcal{C}$. At the beginning, SVD is used in $V_g^{\text{opt}} = U \Sigma^{\frac{1}{2}} U^H$ and $v_g = U \Sigma^{\frac{1}{2}} w_g$ is put, where w_g is a Gaussian variable with $w_g \backsim N(0,1)$ to insure that $E\left[v_g\, v_g^H\right] = V_g^{\text{opt}}$. However, the candidate beamforming vectors must satisfy the constraints of original problem $\mathcal{Q}$. In this way, for each candidate set of beamforming vectors, a multi-group power control ($\mathcal{MGPC}$) problem is solved.

$$\mathcal{MGPC} \quad \min_{\{P_g \in \mathcal{R}\}_{g=1}^G} \sum_{q=1}^G \beta_g P_g$$

$$\text{s.t.} \quad \frac{P_g \alpha_{g,k}}{\sum_{l \neq g} P_l \alpha_{l,k} + \sigma_k^2 + \sum_{f_b} P_k^{f_b} I(f_a, f_b)} \geq \gamma_k$$

$$\forall g \in \{1 \ldots G\} \quad P_g \geq 0 \,\forall f_b \in \{1, 2, \ldots F\}$$

where

$$\beta_g = \|v_g\|_2^2 \quad (14)$$

$$\alpha_{g,k} = \left|v_g^H R_k v_g\right| \quad (15)$$

and P_g denotes the power boost factor for multicast set of users g. This is a Linear Program (LP) and can be solved by SeDuMi with the computational cost being negligible.

Finally, after calculating beamforming weight vectors $v_g^{f_a}$ applied at the transmitter for all possible operating channels $f_a \in \mathcal{C}$, we select channel $f_c \in \mathcal{C}$ that minimize total transmit power of AP a for all channels. Transmit power $P_{TX}^{f_a}$ is computed from equation (2). Therefore,

$$f_c = arg \min_{\{f_a \in \mathcal{C}\}} P_{TX}^{f_a} \quad (16)$$

IV. SUB-CARRIER ASSIGNMENTS

The transmission of optimized power at the center frequency follows beamforming; the problem which has to be solved is how to assign N=48 OFDM overlapping data sub-channels to each co-channel set of users. In [16], the posed problem is the allocation of sub-carriers and time slots to sub-carriers so that rate requirements for each user are satisfied. Our application doesn't require continuous transmission to consider slot allocation. Carrier-Sense Multiple Access (CSMA) is used. Transmitters sense the channel and delay transmission if they detect that another transmitter is currently emitting. A sub-carrier is only allocated to one user. The solution is developed as in [17] in two steps. *a)* Resource Allocation: Find the number of sub-carriers that each user will be assigned to, *b)* Sub-carrier Allocation: Allocate the sub-channels according to resource allocation and the state of the channel. Compared to [17], our approach is different due to the fact that the goal is not the minimization of the total transmitted power but fairness with considerable throughput. MAC protocol must support users that demand a mixture of services. The support of these services require a cross-layer design between MAC and PHY with QoS (Bit Error Rate-BER, minimum rate required, etc) that depend on applications.

Let's m_k the number of sub-carriers allocated to user k. If set g has K_g users, then

$$\sum_{k=1}^{K_g} m_k = N \quad \forall g \in \{1 \ldots G\} \quad (17)$$

In this section, we determine the number of sub-carriers taking into account:

a) $SINR_k$ calculated in section III

b) Minimum rate required R_k^{min} in bits per symbol

c) Maximum BER required.

R_k^{min} and maximum BER are related to different classes of services. At each user k, a maximum modulation level with b_k bits per symbol is selected from a set $\mathcal{M}$ of available QAM. For $M - QAM$ modulation, $M = 2^{b_k}$ with $b_k \in \mathcal{M}$. The throughput

of user k for each sub-channel $n \in \{1 \ldots N\}$ can be calculated as

$$T_k = W_{subchannel} \log (1 + a\, SINR_k^n) \quad (18)$$

where $a = \frac{1.5}{-\ln(5\,BER)}$ for additive White Gaussian noise environment and $a = \frac{1.5}{\frac{0.2}{BER} - 1}$ for Rayleigh fading[18]. In our case, $W_{subchannel} = \frac{312.5}{2}\, KHz$. When $a = 1$, the relationship is similar to Shannon Capacity of user k. Suppose that $SINR_k^n$ is constant and equal to $SINR_k$ for all sub-carriers, the number m_k is

$$m_k = \lceil \frac{R_k^{\min}}{T_k} \rceil \quad (19)$$

$\lceil x \rceil$ denotes the smallest integer that exceeds x. For a feasible solution, the minimum value which takes m_k is $\lceil \frac{R_k^{\min}}{T_k} \rceil$ and the maximum is N. We distinguish between two cases:

a) $\sum_{k=1}^{K_g} m_k > N$: The user with maximum calculated m_k is the user who required high bit rate but has small T_k i.e. bad $SINR$. Therefore, fair allocation imposes the removal of one subcarrier.

b) $\sum_{k=1}^{K_g} m_k < N$: in order to achieve maximum throughput, we add one sub carrier to the user with minimum m_k and high $R_k^{\min}$. Under the assumption that the channel is flat for the entire band, we propose the algorithm below:

$\mathcal{R}.\mathcal{A}$ $T_k \leftarrow \log_2 ((1 + a\, SINR_k))$

$m_k \leftarrow \lceil \frac{R_k^{\min}}{T_k} \rceil$

$R_{th} = \text{threshold}$

while $\sum_{k=1}^{K_g} m_k > N$ do

$l \leftarrow \arg \max_{1 \le k \le K_g} m_k$

$m_l \leftarrow m_l - 1$

end while

while $\sum_{k=1}^{K_g} m_k < N$ do

$l \leftarrow \arg \min_{\substack{1 \le k \le K_g \\ R_k^{min} > R_{th}}} m_k$

$m_l \leftarrow m_l + 1$

end while

The hypothesis in that the channel held constant over the whole band is acceptable only for resource allocation. We calculate a list $S_k^{\max}$ with all acceptable sub-carriers for each user k.

for all users

$S_k^{\max} \leftarrow \{\ \}$

end for

for $n = 1$ to N do

calculate $SINR_k^n$

if $SNR_k^n \ge \gamma_k$

then $S_k^{\max} \leftarrow S_k^{\max} \cup \{n\}$

end if ,end for

We normalize $SINR_K^n$ $\forall k \in \{1 \ldots K\}$ and $\forall n \in \{1 \ldots N\}$ relatively to maximum value $SINR^{\max} = \max SINR_k^n$,

$$w_k^n = \frac{SINR_k^n}{SINR^{\max}} \quad (20)$$

If we consider two disjoint sets of vertices, one which represents the K_g users and the other the N sub-carriers then the problem of sub-carriers allocation is transformed into a weighted bi-partite matching. In [19], the authors propose the method of maximum augmenting path to obtain maximal weighted matching. Neverhless, this approach is a modification of alternating path method [20] which is difficult to apply in weighted matching. We propose a heuristic algorithm with fast computation and performance close to the optimal matching. The algorithm is divided in two sub-algorithms. The first, which is referred as Channel Gain Grade $(\mathcal{CGG})$ algorithm, assigns the sub-carriers to users according to highest w_k^n. Let S_k the set of allocated sub-carriers for user k and F the set of available sub-carriers for assignment. Initially, S_k is empty and F contains all sub-carriers with index from 1 to N.

$S_k \leftarrow \{\ \}$,

$F_1 \leftarrow \{1 \ldots N\}$.

The sub-algorithm terminates when the number of elements for set F doesn't change in two consecutive repetitions.

$\mathcal{CGG}$ $i \leftarrow 0$

do

$i \leftarrow i + 1$

$\forall k \in K$ and $n \in F_i$

$(k^*, n^*) \leftarrow \arg \max w_k^n$

$S_{k^*} \leftarrow S_{k^*} \bigcup \{n\}$

$F_{i+1} \leftarrow F_i / \{n^*\}$

$w_k^{n^*} \leftarrow 0 \quad \forall k \in K$

if $(\#S_{k^*} = m_{k^*})$

$(k^*, n) \leftarrow 0 \quad \forall n \in F_{i+1}$

end if

while $\#F_{i+1} < \#F_i$

This sub-algorithm is very efficient when the number of users is small compare to the number of sub-channels as in our case. If there are sub-carriers which are not

allocated then we run the below sub-algorithm named InterChange Sub-carriers $(\mathcal{ICS})$ algorithm.

1. The users whose the number of allocated sub-carriers is satisfied $(\#S_k = m_k)$ will be included in set $\mathcal{A}$, otherwise in set $\mathcal{A}'$.

2. Find subset $\mathcal{I}$ of users $k \in \mathcal{A}$ $(\mathcal{I} \subseteq \mathcal{A})$ whose one at least sub-carrier $n \in S_k^{\max}$ could be interchanged with the set of not allocated sub-carriers $F (F \cap S_k^{\max} \neq \{\})$.

3. $(k^*, n^*) \leftarrow \arg\max w_k^n$, $\forall k \in \mathcal{I}$ and $n \in F \cap S_k^{\max}$.

4. $l \leftarrow \arg\min w_{k*}^n, \forall n \in S_{k*}$

5. Swap $n^* \in F$ with $l \in S_{k*}$

6. Allocate $l \in F$ to one of users $k' \in \mathcal{A}'$ running $\mathcal{CGG}, (F_1 \leftarrow F)$

7. Go to step 1 until $F = \{\}$

V. SIMULATION RESULTS

The example of simulation scenario is illustrated in figure 1. The network consists of 5 cells partially overlapping with $F = 4$ channel reuse in 5GHz spectrum. The cell with an AP at the center is represented by a circle radius $R = 100m$. AP 1 is $D = \sqrt{3}R$ distance from neighboring APs. A possible optimum channel assignment is the following: AP 2 to channel 1, AP 4 to channel 2, AP 3 to channel 3 and AP 5 to channel 4. Our proposed technique enables self-configuration to AP 1, based on the measurement of channel conditions in the wireless environment. Physical layer (PHY) modes compliant to IEEE 802.11n are given in [4]. The received SINR constraints are set $\gamma_k = 15dB$ and the additive noise power at the receiver k is set $\sigma_k^2 = -95dBm$. According to the system description of IEEE 802.11n WG [4], $I(f_a, f_b)$ is equal to

$$I(f_a, f_b) = \begin{cases} 0\text{dB} & \text{for co-channel} \\ -16\text{dB} & \text{for adjacent channel} \\ -32\text{dB} & \text{in other cases} \end{cases}$$

Maximum transmit power for each AP is $P_t = 250$mW or 24 dBm. The simulation is done with MATLAB environment. Uniform Linear Arrays (ULA) with $M_t = 4$ and $M_r = 4$ antenna elements is considered. The position of users at each cluster follows a Uniform Distribution. 1000 Gaussian randomization samples to solve $randC$ problem are generated. Due to Doppler effect, we have a time varying channel and we collect 104 samples at each user's position. If we take the speed of moving scattering environment to be equal to $v_o = 1.2\frac{Km}{h}$, maximum Doppler shift is $f_m = \frac{v_o f}{c} = 208Hz$. Coherence time due to Doppler spread is $T_c \approx \frac{1}{f_m} = 40808\mu s$, i.e. 10000 times slower that the transmitted OFDM symbol (~ 4μs). We model the wireless channel as a sum of two components, a LOS component and a NLOS component
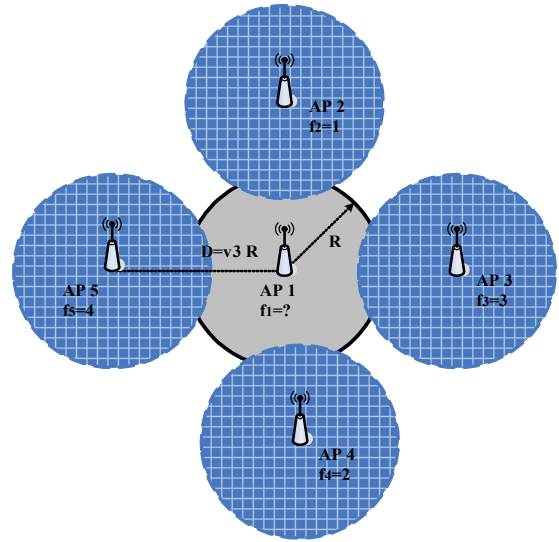

Figure 1. Deployment of a configuration with 5 cells partially overlapping

$$H = \sqrt{\frac{K_f}{K_f+1}}H_{LOS} + \sqrt{\frac{1}{K_f+1}}H_{NLOS} \quad (21)$$

where K_f is the Ricien K-factor and is defined as the ratio between the power of the LOS component and the mean power of the NLOS component. Channel matrix H_{LOS} is computing with a break point 5m, a path loss exponent 3, a shadowing deviation 4dB and $K_f = 3$. Channel matrix H_{NLOS} is simulated as model B proposed by the IEEE 802.11n channel model [21]. MATLAB implementation of IEEE 802.11n channel model is available from L. Schumacher [22]. Figure 5 shows the average physical layer data rate of a) our scheme, b) eigen beamforming on every sub-carrier (based on SVD and proposed in the on going IEEE 802.11n standardization) and c) IEEE 802.11a $1x1$ standard. The beams of neighboring APs are presented in Figure 2. Radiation of interference cells is constant for all runs and it's computing for 4 users placed in 4 sets (each cluster of Figure 8 contains one user). At the first five runs, the range of 4 sets is 350-10 degrees, 80-100 degrees, 170-190 degrees and 260-280 degrees. At the next five runs the range of sets is 340-20 degrees, 70-110 degrees, 160-200 degrees and 250-290 degrees. The final five runs correspond to range 330-30 degrees, 60-120 degrees, 150-210 degrees and 240-300 degrees. Improvement of our beamforming technique is noticeable. Throughput from 80Mbits/s to 200Mbits/s in a strong interference environment is achieved for our proposed technique while SVD technique gives data rate not bigger than 50 Mbits/s. We remark that throughput diminish as set of users cover bigger area. In continuously, two different simulation scenarios A and B are examined. For simulation scenario A, we make a list of operation frequencies with random order $\mathcal{F} = \{1, 2, 4, 3\}$. Our results are examined for 10 users located at AP 1. The first cluster consists of 4 users, the second of 3 users, the third of 2 users and the fourth contains 1 user as in figure 8. Figure 2 depicts beams of neighboring APs for scenario A. Figure 6 presents radiate power of AP 1 according the list $\mathcal{F}$.

Each run corresponds to different locations of users, randomly placed as figure 8. The first calculation of each run is for operating frequency 1, the second for 2, the third for 4 and the fourth for 3. The profit of finding optimum frequency is remarkable. In run 1 the difference between maximum power corresponds to frequency 4 and minimum power correspond to frequency 2 is 0.235W.Operating frequencies 1 and 3 which correspond to powers greater than the maximum value of 250 mW are rejected. In run 3 only frequency 2 is acceptable. Finally, a setting in strong interference environment (scenario B) by four users located in four sets (one user at each set) is studied. Five channels are possible for assignment according frequency list $\mathcal{F} = \{5, 1, 4, 2, 3\}$. Figure 3 shows beamforming of AP 3 and 5 while figure 4 of AP 2 and 4. Figure 7 gives the calculated power of scenario B for 15 different runs. We remark that the optimum solution is obtained when channel 5 is assigned to AP 1. The proposed algorithm doesn't give acceptable values of transmit power for run 5,9,10 and 12 in the case where channel 1 to 4 is allowed. If that happens, CSMA mechanism is enable to avoid co-channel interference from neighboring cells and transmitted power is set equal to 250mW.

For reasons of validating the proposed algorithms in section IV, a set of 16 users is used with $SINR$ resulting from section III. Minimum rate required for each user k is equal to $R_k^{min} = 2048\,Kbits/s$. We calculate theoretical throughput T_k considering additive White Gaussian noise with $BER = 10^{-5}$. Normalized elements w_k^n follow a normally distribution with mean value the $SINR_k$ given from section III and deviation $\sigma = 3dB$ as in [16]. We simulate $\mathcal{CGG}$ sub-algorithm for 100 Monte Carlo runs. The results are showed in Figure 9. This figure gives the number of no allocated users and frequencies as function of number of active users. It's clear that $\mathcal{CGG}$ sub-algorithm is efficient under our experiment conditions. $\mathcal{ICS}$ sub-algorithm always converges in our network configuration. According to figure 10, the number of users $k \in \mathcal{I}$ which are available to swap their frequencies is large compare to the number of no allocated users $k' \in \mathcal{A}'$. This explain why $\mathcal{ICS}$ algorithm is efficient and always converges.

VI. CONCLUSIONS

In this paper, we studied and developed strategies compliant with IEEE 802.11n standard. Our distributed algorithms suppress interference among vicinities WLANs and allow APs to choose a channel band that will experience minimal interference by enforcing common transmission weight vectors for all sub-carriers allocated to the same set of users. We can efficiently share the wireless resources in an environment with fast and unmanaged deployment of WLANs. We adopt a frequency allocation scheme, which allows channel state driven link adaptation by estimating the state of the channel. Finally, our proposed strategy is a cost-saving and less complex implementation approach.

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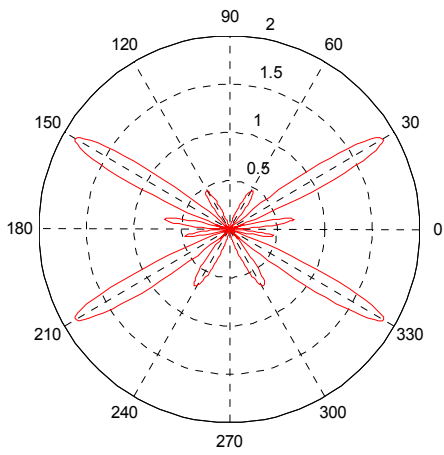
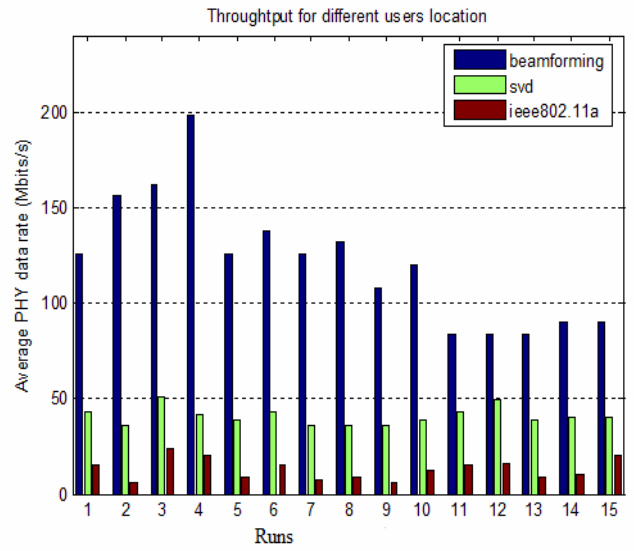Figure 2.   Beamforming of neighboring APs - scenario A

Figure 3 Beamforming of AP 3 and 5 scenario B

Figure 4 Beamforming of AP 2 and 4 scenario B

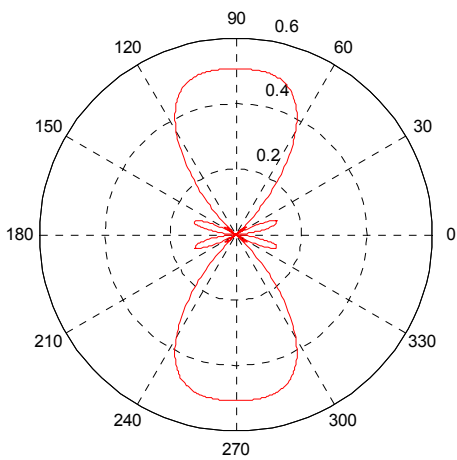Figure 5 Average PHY data rate for different users locations

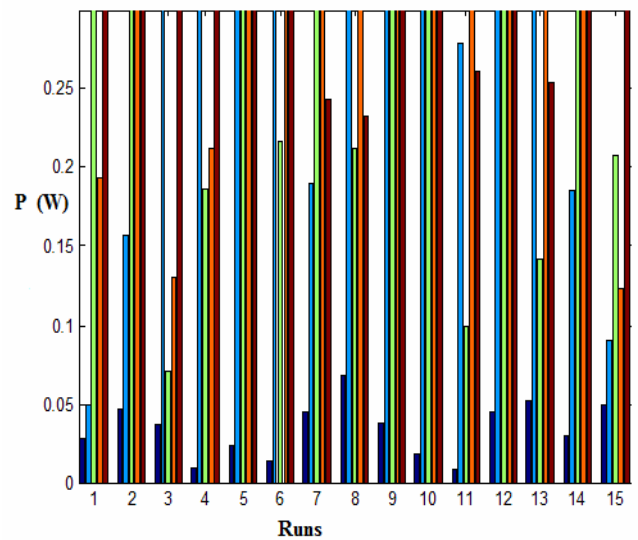Figure 6 Calculated power for 4 operating frequencies-scenario A
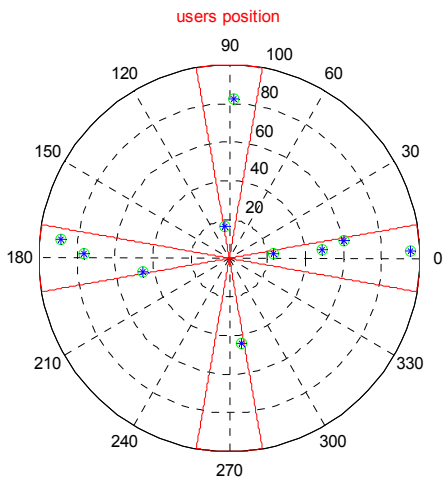

Figure 7 Calculated power for 5 operating frequencies-scenario B
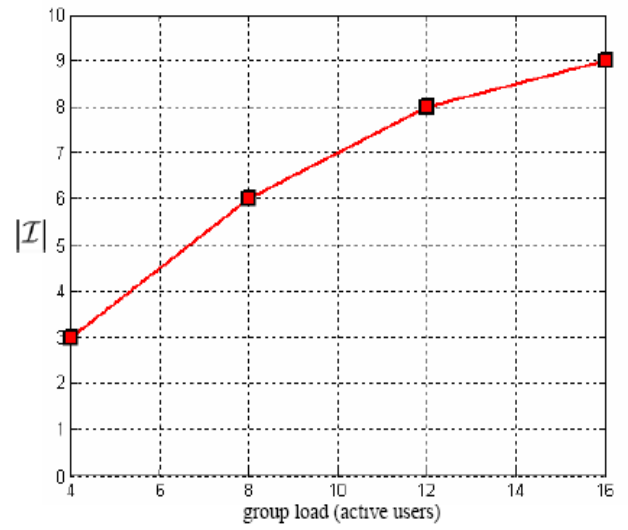
Figure 8 Location of 10 users in 4 groups

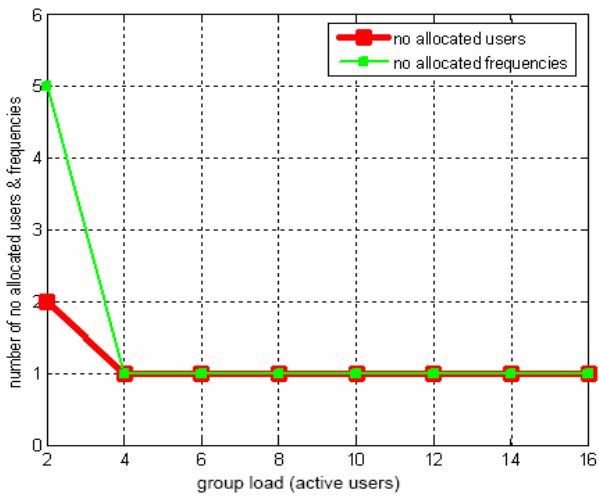Figure 10 Number of allocated users available to swap their frequency vs active users at step 2 of $\mathcal{ICS}$ sub-algorithm.

Figure 9 No allocated users and frequencies vs active users after running of $\mathcal{CGG}$ sub-algorithm.