Performance Evaluation of Joint Transmission Coordinated-MultiPoint in Dense Very High Throughput WLANs Scenario

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***Abstract*—In this paper, we propose to use the Joint Transmission approach of Coordinated Multipoint (JT-COMP) of cellular networks to reduce the interference in dense Very High Throughput (VHT) wireless LANs. VHT WLANs are based on wider channel bandwidth, efficient modulation techniques and support for spatial streams using MIMO schemes. However, the interference problem persists despite these approaches, and thereby prevents mobile stations from fully reaping the capacity improvement of such networks. In order to optimize the coverage and minimize the cell overlap in dense stadium scenario, AP locations must be planned carefully. To this end, we model positions of nodes using a spatial stochastic model called the $r-l$ square point process. Then, we derive the coverage probability and throughput expressions and investigate the benefit of Joint Transmission coordination technique. Using simulation, we characterize the performance metrics for different sizes of coordinated set and carrier sensing domain of access points. Our results show that JT-CoMP is a promising scheme for dense WLANs.**

***Index Terms*—WLANs, JT-CoMP, $r-l$ square point process.**

I. Introduction

In the last Wi-Fi standards and amendments, Task Groups of IEEE 802.11 are seeking to provide very high throughput (VHT) and low latency services over wireless local area networks (WLANs). The aim is to fulfill the increasing demand of end users and the exponential growth of wireless data traffic. New standards like 802.11ac, also called Gigabit Wi-Fi, are expected to provide up to 7 Gbps in 5GHz band [3]. These improvements are based on three factors: wider channel bandwidth, efficient modulation techniques and support for spatial streams using MIMO scheme and its variations. However, even using these new generation of wireless access points (APs), the interference problem cannot be totally avoided in dense networks. As a consequence, critical applications such as high definition video streaming (HDTV) cannot fully benefit from this new generation of WLANs.

High density WLANs, like multi-apartment building [1] and stadiums [9], face significant challenges due to the very high number of APs in closed proximity. It results in a significant increase of interference level for co-channel APs due to the limited number of non-overlapping channels, the unplanned selection of primary channels and channel widths, and the unplanned deployment of APs with factory default parameters. Authors of [1], [4] show that the number of interfering access points highly affect the throughput and they propose power control and rate regulation algorithms to reduce the interference among neighboring APs. From a systems modelling approach, authors of [8] use a modified Matèrn point process (p.p.) to consider the impact of CSMA/CA and address planning problems to provide a certain QoS with a reduced deployment cost. In [5], the required APs density to meet an average traffic demand is estimated.

Coordinated Multipoint in cellular networks (CoMP): Taking advantage of multiple antenna in MIMO systems, CoMP is a cooperation technique with the objective of reducing the interference and hence increasing the cellular network throughput. In a cellular network, Base Stations (BSs) communicate with each other over a backhaul network and exchange data in Joint Transmission mode (JT-CoMP). Users receive multiple copies of the same data from different BSs in the coordinated set, and the signal received from BSs outside of the coordinated set is seen as interference. Several works investigate the modeling and evaluation of CoMP approaches using stochastic geometry. In [10], authors characterize the SINR distribution, discuss some practical design problems and conclude that increasing the BSs density while fixing the cooperation radius improves the SINR. Moreover, the benefit of cooperation, in terms of coverage, increases with the path loss exponent.

However, only a few works have considered the CoMP approach in WLANs. For example, [7] deals with the feasibility of CoMP in IEEE 802.11 High Efficiency WLAN (HEW) and gives directives to integrate coordination in such networks. It proposes a centralized architecture where an AP is chosen as a controller to coordinate transmissions.

In this paper, we aim at analysing the interference in dense Wi-Fi networks. Three main contributions are presented in this

paper:

- Utilization of Joint Transmission Coordination Multipoint approach, usually used in cellular networks, to manage the interference and hence improve the received signal quality.
- Providing a mathematical framework to model the coordination in Wi-Fi networks using a realistic p.p.. We use a spatial stochastic model, the $r-l$ square p.p., which is more appropriate to model dense WLANs, where positions of APs are correlated like in stadium deployment in order to ensure high capacity. We derive the coverage probability and the throughput expressions when CoMP-JT is performed.
- Evaluation of the analytical model is performed using Monte Carlo simulation in MATLAB.

The paper is structured as follows. In section II, we recall the $r-l$ square p.p. and derive the analytical model of JT-CoMP. Simulation results are discussed in section III. We conclude the paper in section IV and give some perspectives to this work.

II. System Model

To represent the APs locations we use a two dimensional point process model. It allows us to characterize the interference resulting from the close proximity of co-channel APs in high-density WLANs.

A. Nodes locations: $r-l$ square point process

Poisson p.p. (PPP) is the most used spatial model for BSs position. However, it has some drawbacks as it generates nodes independently in the plane, which leads to uncovered regions or nodes very close to each other causing strong interference. To better represent the controlled deployment of APs in a stadium, we choose to use the $r-l$ square p.p.. It has been proposed to model positions of femtocells in a multimode femtocells (both Wi-Fi and cellular) deployment to extend the cellular coverage in poorly-covered regions [2], [6]. In [2], the coverage and the throughput have been characterized. $r-l$ square p.p. is built as follows: the plane ($\mathbb{R}^2$) is divided into squares of size $r \times r$. In each $r \times r$ square, a new sub-square of size $l \times l$ (with $0 \leq l \leq r$) is placed. A point, representing an AP, is uniformly distributed in each sub-square. When $l < r$, this process is a Hard Core p.p., as points cannot lie at a distance less than $r-l$. Hence, this model imposes that two points in adjacent squares cannot be too close to each other, which reflects the real deployment of nodes and overcomes drawbacks of PPP. Mobile stations are then set according to the Poisson p.p. in the plane.

In the following, we focus on the downlink and we evaluate the performance in terms of coverage probability and throughput, under the $r-l$ square model described above when coordination in particular JT-CoMP is applied between APs to mitigate the interference. We assume an ideal backhaul network connecting APs to transmit duplicated data or to share data used for cooperation without collisions and retransmissions.

B. Joint Transmission Coordination Model

JT-CoMP is a cooperation technique used to reduce the interference. In the classical JT-CoMP a mobile user receives data not only from the serving AP, but also from APs in its coordinated set. Signals received from APs outside the coordinated set are seen as interference. This is illustrated by equation (2). First, we define the coordinated set as follows:

$$\mathcal{C} = \{X_i \in \Phi \text{ s.t.} X_i \in B_u(d)\} \tag{1}$$

where Φ is the $r-l$ square p.p., X_i is the AP i and $B_u(d)$ is the ball of radius d centered at u, the typical user. Here d is the radius of the coordinated set.

The received signal at a typical user station u is:

$$y = \underbrace{\sum_{X_i \in \mathcal{A}} \sqrt{p_t}\xi_i \sqrt{l(||X_i - u||)}}_{\text{Useful signal}} + \underbrace{\sum_{X_j \in \mathcal{B}} \sqrt{p_t}\xi_j \sqrt{l(||X_j - u||)}}_{\text{Interference}} + \underbrace{N}_{\text{Noise}} \tag{2}$$

where p_t is the transmission power of nodes (APs), which is assumed to be the same for all APs, $(\xi_i)_i$ are i.i.d $\sim \mathcal{CN}(0,1)$ Gaussian random variables modeling fading, $l(.)$ is the path loss function and $N \sim \mathcal{CN}(0,\sigma^2)$ is an additive white Gaussian noise (AWGN). $\mathcal{A}$ and $\mathcal{B}$ represent the set of APs sending useful signals and the set of interferers, respectively.

The Distributed Contention Function (DCF) is a contention-based decentralized approach which uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). It allows to reduce collisions and enhance the network data rate.

Remark 1: In this paper, we are interested in one typical user located at the edge of the cell, which represents all the remaining users in the same case. Therefore, we derive the analytical expressions considering that only the serving AP (nearest to the mobile user) will perform the CSMA/CA procedure.

Let CS_{thr} be the carrier sensing threshold.

An AP can transmit if it satisfies the following carrier sensing condition:

$$\mathbb{E}_\xi \left[\xi_i \mid\mid X_i \mid\mid^{-\alpha} p_t\right] \leq CS_{th} \tag{3}$$

Hence, an AP located at distance $\mid\mid X_i \mid\mid$ is allowed to transmit if and only if $\mid\mid X_i \mid\mid \geq \left(\frac{p_t}{CS_{th}}\right)^{1/\alpha}$. Let define the radius of carrier sensing domain as: $d_{CS} = \left(\frac{p_t}{CS_{th}}\right)^{1/\alpha}$.

We define the useful APs and interferers sets as follows:

- $\mathcal{A}$: is the set of APs in the coordination set $\mathcal{C}$ *and* outside the contention domain of the serving AP. It can be expressed as:

$$\mathcal{A} = \left\{X_i \in \phi \text{ s.t. } X_i \in B_u(d) \cap \bar{B}_{X^*}(d_{CS})\right\} \tag{4}$$

  Where X^* is the serving AP and $\bar{A}$ represents $\Phi \backslash A$.
- $\mathcal{B}$: represents the set of interferers,

$$\mathcal{B} = \left\{X_i \in \phi \text{ s.t. } X_i \in \bar{B}_u(d) \cap \bar{B}_{X^*}(d_{CS})\right\} \tag{5}$$

Figure 1 illustrates the carrier sensing (CS) domain and the coordinated set $\mathcal{C}$.

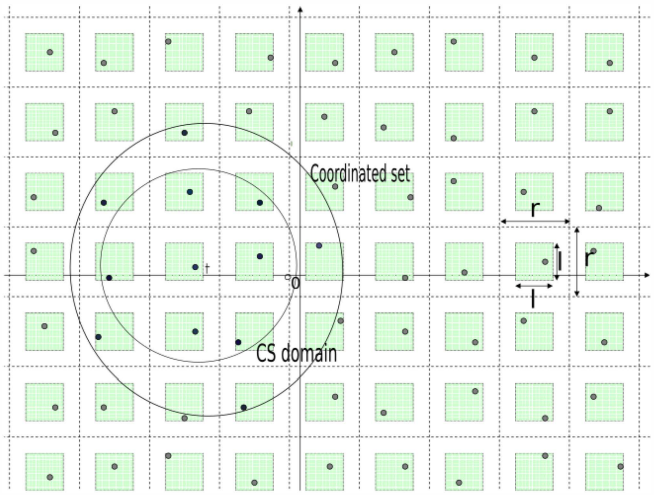

Fig. 1. The $r-l$ square p.p., the serving AP is the nearest one to the typical user

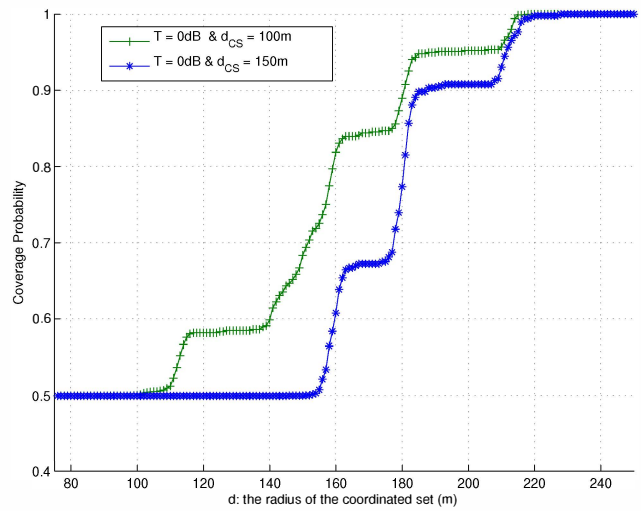

Fig. 2. p_c vs d for two values of d_{CS} (the carrier sensing radius)

In the following, we derive the analytical expression of the coverage probability of a typical user.

Proposition 1: The coverage probability under CoMP-JT is given by:

$$p_c(T) = \Pr(\text{SINR} > T) \tag{6}$$

$$= \prod_j \mathbb{E}\left[\left(\frac{1}{1+T\frac{l(||X_j-u||)\mathbb{1}_{\{X_j\in \bar{B}_u(d)\cap \bar{B}_{X^*}(d_{CS})\}}}{\sum_i l(||X_i-u||)\mathbb{1}_{\{X_i\in B_u(d)\cap \bar{B}_{X^*}(d_{CS})\}}}}\right)\right]$$

$$\times \mathbb{E}\left[\exp\left(-T\frac{\sigma^2}{\sum_{X_i\in\mathcal{A}} p_t l(||X_i-u||)}\right)\right] \tag{7}$$

The proof is omitted due to space constraints, and it can be found online on: https://hal.inria.fr/hal-01176030.

Remark 2: In the Interference limited (free noise) regime, the coverage probability is independent from transmit powers of APs.

The rate can be derived from the coverage probability by the following formula:

$$R = \mathbb{E}(\log_2(1+\text{SINR})) \tag{8}$$

$$= \frac{1}{\log(2)}\int_0^\infty \frac{p_c(x)}{(x+1)}dx \tag{9}$$

Hence, the throughput is derived by replacing $p_c(T)$ (Eq. 7) in Eq. (9).

Remark 3: The expectation in Eq. (7) is over the p.p. and it is difficult to compute it because the probability density function (pdf) of the $r-l$ square p.p. is unknown. Hence, Monte Carlo simulation is used in order to validate results.

III. Performance evaluation: simulation and results

We consider a network composed of 7 × 7 (49) APs distributed in the plan according to the $r-l$ square p.p., all transmitting with the same power p_t. As we said, a typical user will have the same performance as other users, so we do not derive results for all users. We consider one typical user placed uniformly at the edge of a big square ($r \times r$) in the grid. According to [5] which gives guidelines of APs characteristics, we set the transmission power to $p_t = 100$mW (20dBm), $r = 50m$ (sides of squares) and $l = 30$m (sides of sub-squares). By this configuration, the distance between two nodes can not be less than $r - l = 20$m. The path loss model considered is given by: $l(r) = r^{-\alpha}$, where α is the path-loss exponent. Furthermore, we use a bandwidth of 10MHz. We take the mean over 1000 realizations of the spatial process.

Remark 4: As explained before, the carrier sensing domain and the cooperation domain are illustrated by balls of radius d centered at u, and d_{CS} centered at X^*, respectively. To make the analysis of the result more clear and easier, and since the distance $\|u - X^*\|$ is not significant, we use the following nomenclature:

- d $\leq d_{CS}$: the coordinated set $\mathcal{C}$ is inside the carrier sensing domain, $B_{X^*}(d_{CS})$.
- d $\geq d_{CS}$: the coordinated set includes the carrier sensing domain.

In Figure 2, we plot the coverage probability versus the coordinated set radius for two values of the radius of the carrier sensing domain, d_{CS} = 100m and 150m. It can be seen that the coverage probability remains constant (p_c = 0.5) for values of d less than d_{CS} (d $\leq d_{CS}$) *and* increases when $d \geq d_{CS}$. This can be explained by the fact that when increasing d, more APs will join the coordinated set. However, since the serving AP performs the CSMA/CA procedure, APs inside the ball of radius d_{CS} are silent. Namely, an AP sends a useful signal if it is in the coordinated set, and not in the coordination carrier sensing domain. The step function form of the increasing part of the coverage probability is explained as: p_c remains constant until a new AP joins $\mathcal{A}$, then it moves to the next step.

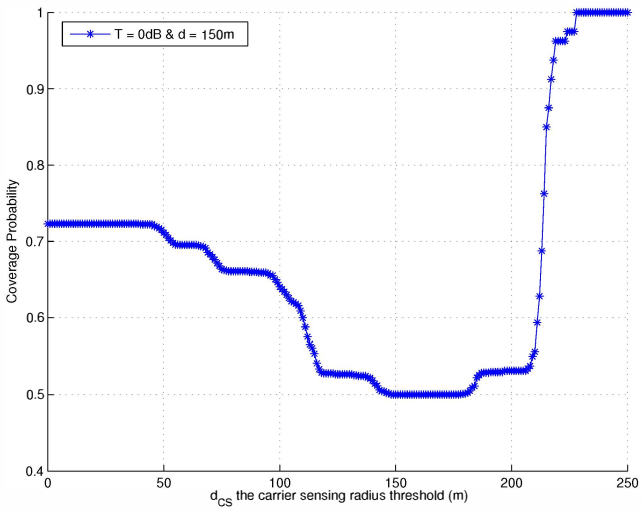

Fig. 3. p_c vs d_{CS}, for d = 150m, radius of the coordinated set

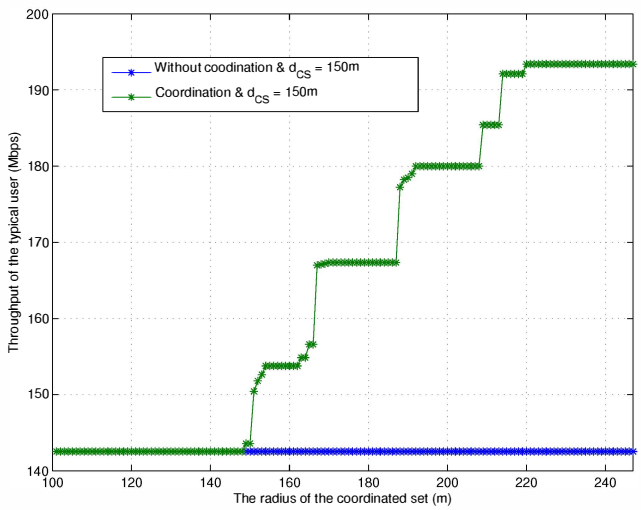

Fig. 4. Throughput vs d_{CS}, for d = 150m, radius of the coordinated set

In contrast, we keep the carrier sensing radius threshold fixed and we vary d. Figure 3 shows the coverage probability depending on the radius of the carrier sensing domain. It can be seen that the coverage probability decreases for values of d_{CS} less than d, the coordinated set $\mathcal{C}$ threshold, and increases for values greater that d. Actually, the number of potential coordinated APs which are muted (silent) grows when increasing d_{CS} until it reaches d. Therefore, the coverage probability starts to increase, because interfering APs outside the coordination set and inside the carrier sensing domain, are silent.

Figure 4 shows the impact of the cooperation on the user rate. The radius of the carrier sensing domain is fixed to d_{CS}= 150m. Remember that the maximal rate is about 195 Mbps. The rate remains constant for values of d less than d_{CS}. In fact, when increasing the radius of the coordination set, the APs in $\mathcal{C}$ become silent due to the CSMA/CA procedure. Starting from values of d around d_{CS}, the rate is improved because the APs joining $\mathcal{C}$ are outside the carrier sensing domain. Hence, they send an effective signal which improves this performance metric.

IV. Conclusion

In this paper, we use Coordinated Multipoint Joint Transmission to mitigate the interference problem in dense VHT WLANs. We use the $r-l$ square p.p. to model APs positions and derive the coverage probability and the throughput. Using simulation experiments, we evaluate the gain of this technique considering different values of SINR, the carrier sensing threshold of CSMA/CA access control and different sizes of the coordinated set. Our results show that JT-CoMP is a promising approach in dense mesh networks.

The main challenges of using JT-CoMP approaches in WLAN are related to the CSMA/CA protocol which does not provide any synchronization between APs. In a future work, we will interest in integrating the coordination in WLANs [7], mainly by modifying the control plan of Wi-Fi networks. Moreover, considering CoMP in dense WLANs with another access protocol like TDMA is an interesting perspective.

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