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Performance Evaluation of Joint Transmission Coordinated Multipoint approach in Dense Very High Throughput WLANs scenario

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Abstract—In this paper, we propose to use the Joint Transmission approach of Coordination Multipoint (JT-CoMP) of cellular networks, in order to reduce the interference impact in dense Very High Throughput (VHT) WLANs. 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 to fully reaping the capacity improvement of such networks. We consider the stadium dense scenario, where the AP locations are carefully planned to optimize coverage and minimize cell overlap. To study the performance in such deployments, we develop a geometric stochastic model and investigate the benefit of JT-CoMP. Using simulation, we characterize the performance in terms of coverage and throughput for different sizes of coordinated set and carrier sensing domain of access points. Our results show that JT-CoMP is an interesting technique for dense networks.

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 LANs networks (WLANs). The aim is to fulfill the increasing demand of users and the exponential growth of wireless data traffic. As a consequence, critical applications like high definition video streaming (HDTV) and networked gaming can fully benefit from this new generation of WLANs. New standards like 802.11ac also called Gigabit Wi-Fi, are expected to provide up to 7 Gbps in 5GHz band [13], [14], [5]. These improvements are based on three factors: wider channel bandwidth, efficient modulation techniques and support for spatial streams using MIMO scheme and its variations: Single User (SU-MIMO) in 802.11n, Multiple User (MU-MIMO) in 802.11ac [13], [14], [5]. However, even using these new generation of wireless access points (APs), the interference problem cannot be totally avoided in very dense networks.

High-density wireless networks are typically considered to be environments where the wireless devices like access points are placed in a very closed proximity and the number of client devices and required application throughput exceed the available capacity of a traditional "coverage-oriented"

Wi-Fi network design. Dense networks scenarios were first considered in multi-apartment buildings where a lot of home APs are deployed in each flat in a chaotic manner [2]. [2] gives the examples of cities like Boston and San Diego, where a particular wireless AP has about 80 other APs deployed in close proximity. A second example of dense WLAN is the stadium or arena deployment to offer high capacity Internet access and to enhance spectators experience by providing new services such as real-time concessions, ticket-ordering and online gambling. In this scenario, a lot of APs are deployed to offer the maximum capacity and the AP locations are carefully planned to optimize coverage and minimize cell overlap. In both scenarios, high density of APs causes a high interference level inducing collision in MAC transmission and reducing the overall customer throughput.

This interference also called inter-BSS (Base Service Set) interference is inevitable in such situations even using 802.11ac/n technologies. Obviously, 802.11ac or n (with beamforming option) access point which provides CSI (Channel State Information) can reduce interference by selecting accurately beams to serve clients. However, in dense configuration where frequency reuse or planning is difficult to control, this objective is seldom easy. The inter-BSS is mainly due to three factors : 1) the lack of non-overlapping channels when large channels are used (40MHz for 802.11n, 40MHz, 80MHz, and 160MHz in 802.11ac), for example only one non-overlapping 40MHz exists for 802.11n in the 2.4GHz band [1]. 2) The use of heterogeneous channel widths causing overlapping between primary and secondary channels like in 802.11ac [22]. 3) The unplanned deployment where APs are deployed in chaotic manner with factory default parameters. The latter is common with legacy 802.11a/b/g dense WLANs.

Recent work [22] shows by experiments that interference in 802.11ac WLAN is one of the major throughput degradation problem to face, due to unplanned selection of primary channels and channel widths when for example 20/40MHz channel is used in secondary channels of another 80MHz link. It suggests to design an appropriate interference mitigation

scheme for the success of 802.11ac. Furthermore, in [1], the authors state that the capacity improvements of 802.11n can be fully utilized only when clients distribution is properly planned. However in dense networks, it is very difficult to know a priori the client location or their load distribution for both indoor and outdoor APs deployment.

Recently, for cellular networks, new revolutionary approaches have been developed and are expected to improve the throughput at the cell edge besides reducing interference in 5G cellular networks of the Public Private Partnership in Horizon 2020. These approaches called Coordinated Multipoint (CoMP) induce cooperation between base stations (BSs) and ensure both spatial and spectral efficiency of MIMO schemes [8], [7], [16]. Coordinated MultiPoint approaches are based on a constructive exploitation of interference, where the interferers BSs in the neighborhood cooperate together to serve the same device. The coordinated BSs form a coordinated set and use either Channel State Information (CSI) or user data to cooperate. Mainly three coordination multipoint techniques have been proposed: Joint Transmission (JT), Coordinated Beamforming/Scheduling (CB/CS) or Dynamic Point Selection (DPS) [21].

In this paper, we propose to use the Joint Transmission of Coordination Multipoint approach (we use the term JT-CoMP throughout the paper) to reduce the interference problem in dense VHT WLANs. We provide a framework to investigate JT-CoMP in dense WLANs and use simulation to show the gain of using such solution. The mathematical model takes into account both the interference and the contention domain of CSMA/CA when defining the set of coordinated APs. As stated earlier, in stadium scenario, a large number of APs close together within a large but highly concentrated area are placed in such a way to ensure performance requirements like coverage and capacity in RF environment where APs are LOS to each other with huge interference problem. In fact, in such environments, classical Poisson point process model of stochastic geometry is not appropriate at all. To develop our mathematical model we use the $r-l$ square point process of [4] which seems to be more appropriate to model such a dense WLANs, where the positions of WLAN APs are correlated in order to ensure a minimum coverage. We derive the coverage probability and the throughput formulas when JT-CoMP is used and evaluate by simulation these two performance parameters depending on the size of the coordinated set, i.e. the number of cooperating APs among the neighboring APs of a typical user equipment UE, and the SINR ratio. Two strategies are considered. In the first one, only APs beyond the contention domain of the serving AP but in vicinity of the UE are used to send the same signal as the serving AP. The second strategy, bolder than the first one, consists in coordinating the APs in the contention domain of the serving AP. In standard 802.11b/g, these APs remain silent thanks to the DCF (Distributed Coordination Function) access control. In this case, coordinated APs are closer to the typical UE and guarantee a best transmission gain. Moreover, we give a few hints on how to integrate JT-CoMP in a CSMA/CA

network where only one AP transmits at each time, but the synchronization problem between coordinated APs is beyond the scope of the present work.

This paper is structured as follows. We first introduce in section II some background materials and some related work on coordinated multipoint (CoMP) techniques. In section III, we recall the definition of $r-l$ Square p.p. and derive the underlying analytical model of JT-CoMP. The simulation results are discussed in IV. In V, we propose some insight on how to integrate the coordination in the network. We conclude the paper in section VI and give some perspectives to this work.

II. BACKGROUND MATERIALS

A. VHT dense WLANs problems and limitations

By integrating a Wi-Fi access point into the Internet box provided by ISP (Internet Service Provider), individuals can easily deployed a private network to connect all the devices (computers, tablets, smartphones or printers) together and to give all them a shared gateway to the Internet. As every household has access to the Internet at home, and its private WLAN, it has led to the emergence of high density 802.11 networks in urban areas and enterprises. High density wireless networks, by design, face significant challenges due to increased interference resulting from the close proximity of co-channel cells. Two types of dense WLAN have been identified: 1) multi-apartment buildings where a lot of home APs are deployed in each flat in a chaotic manner [2], like cities of Boston and San Diego, where a particular wireless AP has about 80 other APs deployed in close proximity. 2) stadiums, amusement parks or arenas deployment to offer high capacity Internet access and to enhance spectators experience. In the last scenario, a lot of APs are deployed to offer the maximum capacity and the AP locations are carefully planned to optimize coverage and minimize cell overlap. In both scenarios, high density of APs causes a high interference level inducing collision in MAC transmission and reducing the overall customer throughput. For the first case of dense WLANs, i.e. Wi-Fi networks for offices, public buildings, schools, hospitals, are typically designed to optimize the capacity with a fairly large coverage area for each AP. In second case, stadiums for example, have different requirements such as to cover a very large number of people and devices within a large but highly concentrated area where users equipment and APs are LOS to each other [15]. As a consequence, the main challenge to be considered is an increased RF interference due several factors : 1) very high number of APs in closed proximity, 2) the reduced number of non-overlapping channels mainly when large channel widths are used to increase the capacity in order to guarantee the QoS requirements for applications, 3) an unplanned selection of primary channels and channel widths when for example 20/40MHz channel is used by an AP in secondary channels of 80MHz channel of another AP.

In [1], the authors explain that the network planning should be considered from "the three C's" perspective (context, coverage, and capacity). They point out the need to consider the

interference when using 40MHz channels in 802.11n and the complex site-specific dependencies of MIMO in the planning phase and APs placement.

Dense WLANs were addressed in previous works using both experiments [2], [6], [20] and modeling [11], [9] to investigate the impact of interference in 802.11a/b/g. In such networks, the interference is related to several factors: 1) lack of coordination between neighbors 2) restrictions of many ISP contracts which lead to over-deployment of APs, 3) handoff time reduction to meet multimedia QoS. 4) reduced number of non-overlapping channels [6]. The authors of [6] show that the cumulative throughput is characterized by the number of interfering access points rather than the number of clients. In [2], [6], some power control, rate regulation algorithms are designed to reduce interference among neighboring APs. In [20] other control strategies are evaluated like channel and power allocation algorithms, load-balancing algorithms, client-driven association versus infrastructure-selected association, and 5GHz band-steering.

The author of the paper [11] propose a modified version of Matèrn point process of stochastic geometry to consider the spatial distribution of nodes: APs and mobile stations (MSs), by representing the impact of CSMA/CA. The proposed model is used to address some planning problem to provide QoS with a reduced deployment cost, relying on the effect of interferences and MAC constraints. The QoS parameters are defined by the coverage and the average bandwidth of each client. Another work [9] is interested in comparing the deployment of different wireless technologies: dense Wi-Fi, pico-cellular network with frequency planning and multi-cell joint processing transmission system from the techno-economic point of view to meet a critical level of demand [9]. Using random sequential packing process, they estimate the required AP density to meet an average traffic demand and use it as the performance parameter for such comparison.

B. Coordinated Multipoint in cellular networks

CoMP is a cooperation technique used to reduce interference and hence to increase the cellular network throughput. In a cellular network, this cooperation is performed between BSs by exchanging data in joint transmission mode (JT-CoMP) or the channel information in the Coordinated Beamforming/Coordinated Scheduling (CB/CS-CoMP) mode. In JT, users receive multiple copies of the same data from different BSs in the coordinated set, and the signal received from BSs outside the coordinated set is seen as interference. Several works investigate the modeling and evaluation of CoMP approaches using stochastic geometry in order to derive the closed form of coverage probability and throughput. In [17], authors characterize the SINR distribution and discusses some practical design problems. It concludes that increasing the BS density while fixing the cooperation radius improves the SINR. Also, the benefit of cooperation, in terms of coverage, increases with the path loss exponent. The work of [12] considers a Poisson Point Process to evaluate the coverage probability of a heterogeneous network under different connec-

tivity models. It concludes that the n -strongest BS connectivity model (the n BSs with strongest received signal) is better than the n -nearest BSs one (the nearest BS from each tier). In other words, defining a coordination set based on the strongest received power is more efficient than a coordinated set based on the short distance. In CB/CS, only beamforming vectors are shared between coordinated BSs. The effect of non ideal backhaul network is studied in [18]. Limited feedback issues are discussed in [3]. It is proved in [21], that the CoMP-JT strategy offers better performance than the CB/CS thanks to the improvement of the received signal power. All these works consider Poisson Point Process to model the BSs location.

C. Related work

As for cellular networks, coordination CoMP between Wi-Fi APs requires an ideal backhaul network with high-speed capacity and low delay, as well as a strict synchronisation in order to ensure simultaneous/coherent transmissions improving the signal quality at the device side. Few works have considered coordinated multipoint transmission in WLANs networks until now. The proposition of IEEE 802.11HEW (High Efficiency WLAN) [10] deals with the feasibility of CoMP in HEW networks and gives directives on how to integrate coordination in such networks. It proposes a centralized architecture where one AP is designed as controller (AC) to coordinate transmission between adjacent APs. Five schemes are defined: 1) the time is divided into two categories: Coordinated TX/RX Intervals (CTRI) and Non-Coordinated TX/RX Intervals (NCTRI), the AC schedules these intervals according to the amount of stations (STAs) and their distribution. 2) Coordinated power allocation by the AC 3) Coordinated frequency band allocation as in fractional frequency reuse in LTE. 4) Joint dynamic allocation of frequency and power which is the combination of coordinated power allocation and coordinated frequency band allocation. 5) Joint Transmission based on joint precoding as SU-MIMO/MU-MIMO of 802.11ac.

To address the strict synchronization requirement of CoMP, the authors of [10] suggest to use CPRI/IEEE 1588 for time and frequency synchronization among neighbor coordinated APs. A testbed is deployed to measure the benefit of joint transmission with joint precoding. The AC selects one AP from a coordinated set for transmission on the downlink, depending on the channel condition and load balance. The throughput gain is considerable compared to that using CoMP in LTE, thanks to the collision decrease and transmission opportunity increase.

[23] argues that the CSI of feedback scheme in MIMO network leads to a serious overhead problem mainly in outdoor deployment with mobility. So, it considers an indoor 802.11ac network and investigates, by simulation and measurement on a testbed, the CB/CS approach of CoMP and compares its performance to MIMO Interference Alignment (IA). The paper also studies the impact of the time varying channel and the overhead using the 802.11ac feedback scheme. The obtained results show that CB/CS-CoMP provides better results than

IA approach in terms of throughput i.e. 27% for IA against 47% using CoMP with overhead about 2,5%. The throughput is reduced in case of time varying channel to 16% and 45% respectively. At the other side, the author of [19] show that a robust synchronization is guaranteed in between APs in a multi-hop WLAN thanks to the information acquired by nodes through a standard carrier sensing mechanism. So that, they do not need explicit synchronization messages to maintain a synchronized slotted execution of transmission.

In this paper, we first consider the $r-l$ square point process to describe the position of the APs and derive the model of JT-CoMP mechanism. Next, we use simulations to evaluate the gain. In the next section, we introduce the $r-l$ square p.p and explain the modeling steps of the coverage probability and throughput of the JT-CoMP.

III. SYSTEM MODEL : INTER-CELL INTERFERENCE COORDINATION

In the past, dense deployments of wireless networks consisted of campus-like environments, where interference was mitigated by carefully planning cell layout. To characterize the increase of interference resulting from the close proximity of co-channel APs in high-density WLANs, we model this problem with stochastic geometry where the APs and devices are distributed using a 2D point process.

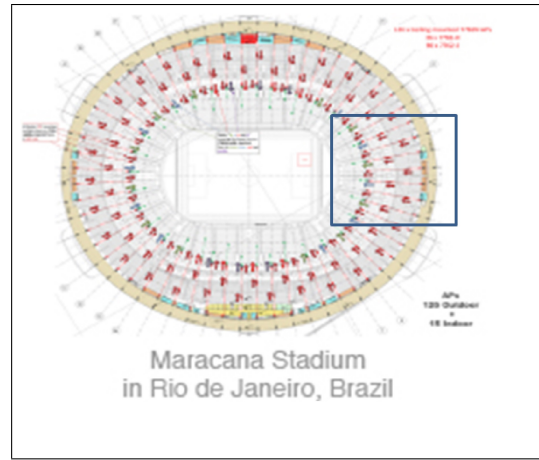
A. APs locations model in stadium

We consider a typical dense scenario as the one deployed in stadium.

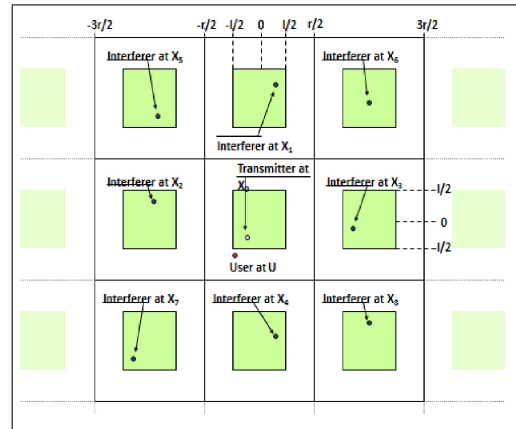
We approximate this network by a grid model as represented in figure 1(a), where the APs positions are distributed over the plan according to $r-l$ square point process (figure1(b)). Here, we briefly describe the $r-l$ square point process and give the modeling steps of JT-CoMP based on this process.

As we said, Poisson point process generates nodes independently in the plane, which leads to many problems such as uncovered regions or nodes very close to each other causing strong interference. To overcome those problems, a new point process, called $r-l$ Square point process has been proposed as a planning tool to extend the cellular coverage in rural or poorly-covered regions using multimode femtocells. It models the position of these femtocells to meet requirements like coverage, throughput and energy efficiency [4]. $r-l$ Square point process is built as follows: the plane (\mathbb{R}^2) is divided into squares of the sizes $r \times r$. 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 is uniformly distributed in each sub-square. Those points represent the APs. When $l < r$, this process is a Hard Core point process, as the points can not lie at a distance less than $r-l$. Hence, this model imposes that two points in adjacent squares can not be too close to each other, which reflects the real deployment of nodes and overcomes problems of the Poisson point process. Mobile stations are set according to a Poisson p.p. in the plane. Illustration of this point process is given in figure 1(b).

In the following, we focus on the downlink and we evaluate the performance in terms of coverage probability, under



(a) Example of stadium dense WLANs deployment



(b) $r-l$ square model approximation

Fig. 1. Stadium dense WLANs: approximation using $r-l$ square Point Process

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 relying APs to transmit all duplicated signals or to share data used for cooperation without collision and retransmission.

B. Joint Transmission coordination model

CoMP-JT is a cooperation technique used to reduce interference. In the classical CoMP-JT 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:

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

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.

Remark 1: As stated in cellular heterogeneous network [12], connecting to the n -strongest base stations enhance the performance better than the n -nearest base stations. In this

work, since we suppose that all APs transmit at the same power level, the two strategies are equivalent.

The received signal at a typical user station u is:

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

where p_t is the transmission power of nodes (APs), it is assumed to be the same for all APs, $(\xi_i)_i$ are i.i.d $\sim \mathcal{CN}(0, 1)$ Gaussian random variables with mean 1 modeling fading, $l(\cdot)$ 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 protocol which uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). It allows to reduce collisions and enhance the network data rate.

Remark 2: In this paper, we are interested in one typical user, which represents all the remaining users in the network. 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*:

$$\mathbb{E}_\xi [\xi_i \|X_i\|^{-\alpha} p_t] \leq CS_{th} \quad (3)$$

Hence, an AP located at distance $\|X_i\|$ is allowed to transmit if and only if $\|X_i\| \geq \left(\frac{p_t}{CS_{th}}\right)^{1/\alpha}$. 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 the 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:

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

Where X^* is the serving AP and \bar{A} represents $\Phi \setminus A$.

- \mathcal{B} : represents the set of interferers,

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

Figure 2 illustrates the carrier sensing (CS) domain and the coordinated set \mathcal{C} .

Remark 3: Some of the silent APs which belong to the contention domain of CSMA/CA can also be used to coordinate the transmission to further enhance the network performance. The implementation of this strategy is more complicated than the used strategy in this paper as it requires to use another MAC access technique and a different channel should be used to avoid interference when coordinating APs outside the carrier sensing range.

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

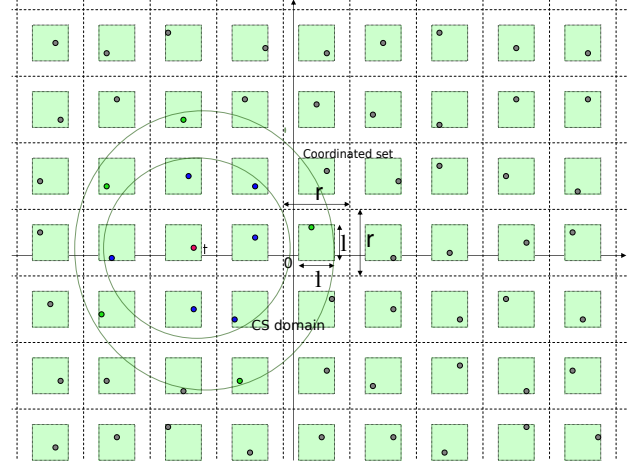


Fig. 2. The r - l square p.p., the serving AP is the nearest one to the typical user, APs inside the CS domain are silenced by the CSMA/CA procedure and APs in (\mathcal{A}) are APs inside the coordinated set and outside the carrier sensing domain

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

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

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

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

Proof:

$$p_c(T) = \Pr(\text{SINR} > T) \quad (8)$$

$$= \Pr \left\{ \frac{|\sum_{X_i \in \mathcal{A}} \sqrt{p_t} \xi_i \sqrt{l(\|X_i - u\|)}|^2}{\sum_{X_j \in \mathcal{B}} p_t |\xi_j|^2 l(\|X_j - u\|) + \sigma^2} > T \right\} \quad (9)$$

$$= \Pr \left\{ \left| \sum_{X_i \in \mathcal{A}} \sqrt{p_t} \xi_i \sqrt{l(\|X_i - u\|)} \right|^2 \right. \quad (10)$$

$$\left. > T \left(\sum_{X_j \in \mathcal{B}} p_t |\xi_j|^2 l(\|X_j - u\|) + \sigma^2 \right) \right\} \quad (11)$$

$$\stackrel{(a)}{=} \mathbb{E} \left[\exp \left(-T \frac{\sum_{X_j \in \mathcal{B}} p_t |\xi_j|^2 l(\|X_j - u\|) + \sigma^2}{\sum_{X_i \in \mathcal{A}} p_t l(\|X_i - u\|)} \right) \right] \quad (12)$$

$$= \mathbb{E} \left[\exp \left(-T \frac{\sum_{X_j \in \mathcal{B}} p_t |\xi_j|^2 l(\|X_j - u\|)}{\sum_{X_i \in \mathcal{A}} p_t l(\|X_i - u\|)} \right) \right] \quad (13)$$

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

where (a) follows the hyper exponential property. The first term is as follows:

$$\mathbb{E} \left[\exp \left(-T \frac{\sum_{X_j \in \mathcal{B}} P_t |\xi_j|^2 l(\|X_j - u\|)}{\sum_{X_i \in \mathcal{A}} P_t l(\|X_i - u\|)} \right) \right] \quad (14)$$

$$= \mathbb{E} \left[\exp \left(-T \frac{\sum_j |\xi_j|^2 l(\|X_j - u\|) \mathbb{1}_{\{X_j \in \bar{B}_u(d) \cap \bar{B}_{X^*}(d_{CS})\}}}{\sum_{X_i \in \mathcal{A}} l(\|X_i - u\|)} \right) \right] \quad (15)$$

$$= \mathbb{E} \left[\prod_j \exp \left(-T \frac{|\xi_j|^2 l(\|X_j - u\|) \mathbb{1}_{\{X_j \in \bar{B}_u(d) \cap \bar{B}_{X^*}(d_{CS})\}}}{\sum_{X_i \in \mathcal{A}} l(\|X_i - u\|)} \right) \right] \quad (16)$$

$$\stackrel{(b)}{=} \mathbb{E} \left[\prod_j \left(\frac{1}{1 + T \frac{l(\|X_j - u\|) \mathbb{1}_{\{X_j \in \bar{B}_u(d) \cap \bar{B}_{X^*}(d_{CS})\}}}{\sum_{X_i \in \mathcal{A}} l(\|X_i - u\|)}} \right) \right] \quad (17)$$

$$= \mathbb{E} \left[\prod_j \left(\frac{1}{1 + T \frac{l(\|X_j - u\|) \mathbb{1}_{\{X_j \in \bar{B}_u(d) \cap \bar{B}_{X^*}(d_{CS})\}}}{\sum_i l(\|X_i - u\|) \mathbb{1}_{\{X_i \in \bar{B}_u(d) \cap \bar{B}_{X^*}(d_{CS})\}}}} \right) \right] \quad (18)$$

$$= \prod_j \mathbb{E} \left[\left(\frac{1}{1 + T \frac{l(\|X_j - u\|) \mathbb{1}_{\{X_j \in \bar{B}_u(d) \cap \bar{B}_{X^*}(d_{CS})\}}}{\sum_i l(\|X_i - u\|) \mathbb{1}_{\{X_i \in \bar{B}_u(d) \cap \bar{B}_{X^*}(d_{CS})\}}}} \right) \right] \quad (19)$$

where (b) from the fact that $(|\xi_i|^2)_i$ are exponentially distributed. ■

Remark 4: In the Interference limited (free noise) regime, the coverage probability is independent from the transmit power of the LPNs.

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

$$R = \mathbb{E}(\log_2(1 + \text{SINR})) \quad (20)$$

$$= \int_0^\infty \Pr\{\log_2(1 + \text{SINR}) > t\} dt \quad (21)$$

$$= \int_0^\infty \frac{\Pr\{\text{SINR} > e^t - 1\}}{\log(2)} dt \quad (22)$$

$$\stackrel{(a)}{=} \frac{1}{\log(2)} \int_0^\infty \frac{\Pr\{\text{SINR} > x\}}{(x+1)} dx \quad (23)$$

$$= \frac{1}{\log(2)} \int_0^\infty \frac{p_c(x)}{(x+1)} dx \quad (24)$$

Where (a) follows from a variable change ($x = e^t - 1$).

Hence, the throughput is derived by replacing $p_c(T)$ (Eq. 7) in equation 22.

Remark 5: The expectation in eq. 7 is over the p.p. and it is difficult to compute because the probability density function (pdf) of the r - l square p.p. is unknown. Hence, Monte Carlo simulation is used to validate results.

IV. 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 the other users, so

Parameters	Values
r	50 m
l	30 m
Path-loss function	$l(d) = d^{-\alpha}$
α	3.0
p_t	100 mW
Bandwidth	10 MHz
Noise	Normal ($1.0e^{-11}$, $3.76e^{-11}$)

TABLE I
PARAMETERS FOR THE NUMERICAL EVALUATION.

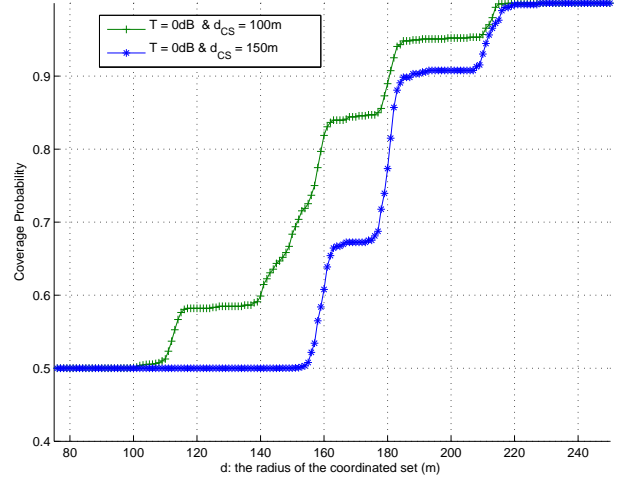


Fig. 3. The coverage probability vs d , the radius of the coordinated set for different values of the SINR threshold and for two values of d_{CS} the carrier sensing radius

we do not derive results for all users. We consider one typical user placed uniformly at random in the grid. According to [9] which gives guidelines of APs characteristics, we set the transmission power to $p_t = 100mW(20dBm)$, $r = 50m$, the sides of squares, and $l = 30m$, the sides of sub-squares. By this configuration, the distance between two nodes can not be less than $r - l = 20m$. 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 10 MHz. We take, for analysis, the mean over 1000 realizations of the spatial process. Simulation parameters are summarized in table I.

Remark 6: 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 comment 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.

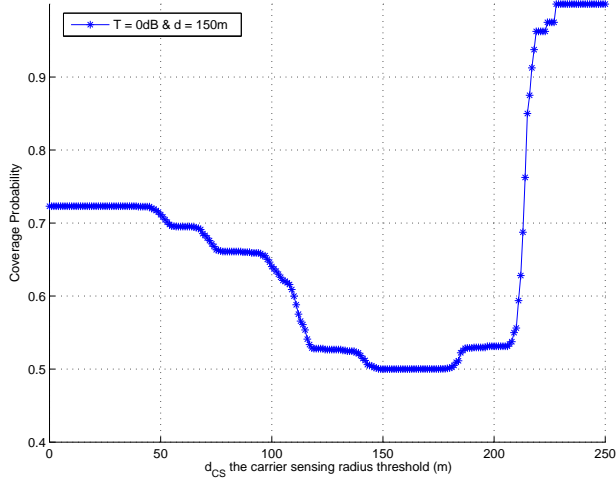


Fig. 4. The coverage probability vs d_{CS} , the radius of carrier sensing domain for $d = 150\text{m}$, radius of the coordinated set and for different values of the SINR threshold

In figure 3, we plot the coverage probability versus the coordinated set radius for two values of the radius of the carrier sensing domain, $d_{CS} = 100\text{m}$ 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 for values of $d \geq d_{CS}$. This can be explained by the fact that by increasing d more APs will join the coordinated set. However, since the serving AP performs the CSMA/CA procedure, the APs inside the ball of radius d_{CS} are silent. Namely that 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.

In contrast, we keep the carrier sensing radius threshold fixed and we vary d . Figure 4 shows the coverage probability in function of 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 the values greater than d . This is because the number of potential coordinated APs muted (silent) grows when increasing d_{CS} until it reaches d . Then, the coverage probability starts to increase, because interfering APs outside the coordination set and in the carrier sensing domain are silent.

Figure 5 shows the impact of the cooperation on the user rate. The radius of the carrier sensing domain is fixed to $d_{CS} = 150\text{m}$. 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 gets improved. The reason is that the APs joining \mathcal{C} are outside the carrier sensing domain. Hence, they send an effective signal which improves

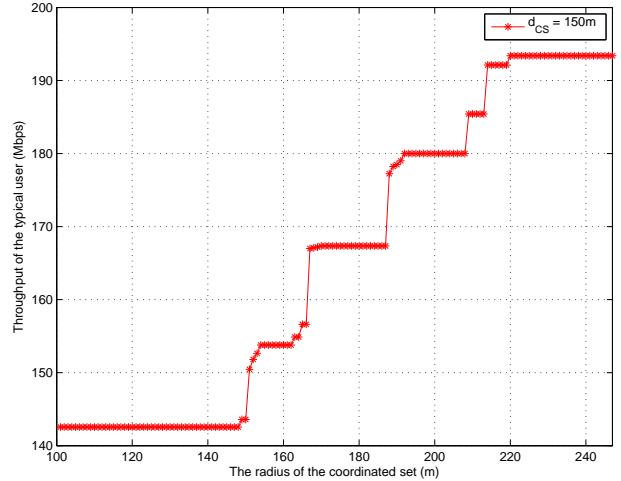


Fig. 5. The coverage probability vs d_{CS} , the radius of carrier sensing domain for $d = 150\text{m}$, radius of the coordinated set and for different values of the SINR threshold

this performance metric.

V. HOW TO IMPLEMENT JT-CoMP IN CSMA/CA NETWORKS

The main challenges to use CoMP approaches in WLAN are related to: 1) the use of CSMA/CA access control where only one AP transmits at each time; and 2) the lack of synchronization between WLAN APs when serving their user equipments [10]. The context is completely different from the cellular one where the BSs are synchronized in symbol and slot as in LTE network. Moreover, the position of BSs are planned unlike dense WLANs where the nodes location is mainly in ad hoc manner (in case of cities deployment). The paper [10] shows how to integrate coordinated transmission in Wi-Fi networks and show the throughput gain (by experience) using CoMP in 802.11HEW (High Efficiency WLAN).

To include JT-CoMP between APs of a WLAN, we propose to modify the control plan of 802.11, mainly the association and re-association phase. When a node receives beacons from the neighboring APs, it first estimates the distance or the signal strength and next sends a request to ask for association with coordination. Also, during the transmission, APs in the coordinated set can use the Point Coordination Function (PCF) option and use the Contention Free Period (CFP) of the superframe to transmit without contention.

VI. CONCLUSION

In this paper, we propose to use Joint Transmission approach of cellular networks to mitigate the interference problem in dense VHT WLANs. We provide a framework to model this approach using stochastic geometry and evaluate the performance by simulations, in terms of coverage and throughput.

Very High Throughput wireless LANs which use the latest IEEE 802.11ac or 802.11n standards, suffer from interference

in dense configuration like stadium. Consequently, the mobile stations are prevented from fully reaping the capacity improvement of such networks. Usually, APs location deployed in a stadium are carefully planned to optimize coverage and minimize cell overlap. We use the $r - l$ square point process to model APs positions and derive the coverage probability and throughput when JT-CoMP is used.

By simulation, we evaluate the gain of JT-CoMP 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 to use in dense wireless networks.

However, these results have to be confronted with operational implementation. Moreover, the proposed model can be used as a planning tool for coordination between APs by an operator considering real parameters of commercial APs in order to optimize the performance.

The main challenges to use JT-CoMP approaches in WLAN are related to the CSMA/CA medium access protocol which does not provide yet any synchronization between APs. In a future work, we will be interested in how to integrate the JT-CoMP coordination in WLANs according to [10], mainly by modifying the control plan of Wi-Fi networks, using ns-3 simulator. Moreover, considering CoMP in dense WLANs with another access protocol like TDMA is an interesting perspective. Another extension of this work on improving the $r - l$ Square p.p. based on parameters related to the access protocol like Clear Channel Assessment (CCA) threshold.

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