Bernoulli Distribution Effects on ABS Pattern in Heterogeneous Networks

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***Abstract*— Almost Blank Subframe (ABS) is a technique which allows an interfering cell to mute some of its transmissions in selected subframes to reduce interference in these resources to other cells. The set of ABS is called ABS pattern. This way, ABS pattern properly configured can increase the system capacity, while ABS pattern unsuitable can generate significant interference and loss of capacity. In this work, we investigated the effects of the Bernoulli distribution in ABS pattern to Heterogeneous Network (HetNet). The Bernoulli distribution was chosen due to its simplicity of implementation, which allows an intuitive analysis of scenarios with and without ABS pattern. Also, it can be used as baseline for complex algorithms. Results indicate that the ABS pattern through Bernoulli distribution has different performances, depending on the parameterization of the distribution, which can provide capacity gains between $3.7\,\%$ and $10.4\,\%$ to the system.**

***Keywords*— ABS pattern, Bernoulli Distribution, e-ICIC, Heterogeneous Networks, Power Efficiency.**

I. Introduction

The growth of mobile devices with high processing power, coupled with the user expectation to be fully connected, that is to have access to all services anywhere and anytime has resulted in an exponential increase in cellular capacity demand. Hetnet, in other words, the set of cells with different access technologies and different types, such as size, air interface and communication protocols can be used for the purpose described above.

Several challenges need to be overcome in the HetNet due to their complexity and diversity of operation. One of the main challenges of HetNet refers to interference, since certain area is occupied by macro-, micro-, pico- and femto-cells each with its transmit power and size [1].

There are general and specific techniques for interference control in HetNet, such as Inter-Cell Interference Coordination (ICIC) and Enhanced Inter-Cell Interference Coordination (e-ICIC), respectively [2].

Initially the ICIC was shown in 3rd Generation Partnership Project (3GPP) release 8-Long Term Evolution (LTE) and defined three schemes:

- Scheme 1: Resource blocks are allocated among neighboring cells so that no two cells use the blocks at the same time;
- Scheme 2: Exhibits different behavior for User Equipment (UE) that are near to the cell antenna versus those near the edge. Centrally located UE use all resource blocks, while those near the edge use scheme 1;
- Scheme 3: All neighbor cells use different power schemes for their UE. Low power is used for near UE and power boost is used for edge UE, while sharing resource blocks.

The techniques used in ICIC were improved seeking modern alternatives to control interference, e-ICIC was defined in 3GPP release 10-LTE and describes the following:

- Scheme 1: It is used the concept of the ABS, which can be configured by a macro cell to carry control channel frames with very low power. Small cells can then use the ABS to transmit data that will not interfere with macro cells transmissions;
- Scheme 2: Cell Range Expansion (CRE) is a technique to expand a picocell range virtually by adding a bias value to the pico received power, instead of increasing transmit power of pico base station (PBS), so that coverage, cell-edge throughput, and overall network throughput are improved.

The main focus of this paper is to use ABS concept for efficient spectrum reuse, because it provides time-domain coordination and cancellation of inter-cell interference in HetNet that orthogonalize the small cell and macro cell transmissions.

The form of coordination in the time domain, that is, the choice of the ABS pattern in this paper was through the Bernoulli Distribution, due to its simplicity of implementation that provides an intuitive analysis of scenarios with and without the use of ABS. In addition to serving as a baseline for complex algorithms.

This paper is organized as follows. Section II introduces a background on e-ICIC emphasizing ABS concept. Section III presents the system modeling and describes the ABS pattern considered in this work. Section IV provides the simulation results; and finally, in Section V some conclusions are addressed.

II. Related Works

In [3], the authors discussed the problem of ABS-slot access in the HetNet to optimize network performance under the ABS scheme. The problem was solved from an interference minimization perspective, so that only local information was needed and was feasible in large scale or dense networks.

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The paper [5] proposes a dynamic ABS assignment method with power control subframe to improve sum rate and user fairness together. The results show that the proposed method improves the sum rate and user fairness compared with the conventional dynamic ABS assignment method.

The paper [4] addressed a dynamic ABS assignment method to improve the convergence time of subframe assignment and the resource utilization of Base Station (BS) . The results show that the proposed method improves the resource utilization of BS and the convergence time of subframe assignment compared with the conventional dynamic ABS assignment one, while achieving a similar user outage ratio.

The authors of [6] determined the amount of radio resources that macro cells should offer to picocells and the association rules that decide which UE should associate with picos in a real Radio Frequency (RF) scenario. The main contributions were to develop a framework for network dependent e-ICIC and provide an efficient algorithm to compute ABS and UE-associations.

The paper [2] used concepts shown above to control interference in a HetNet scenario, the CRE was adjusted by means of load balancing algorithm and ABS parameter was optimized by maximizing a proportional fair utility of user throughputs. It was used two Self Organizing Networks (SON) algorithms (distributed) for optimizing ABS using Proportional Fair (PF) utilities.

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The paper [7] address some weak points of ABS scenarios and propose our approach to improve them. The first point is the latency of Real Time (RT) traffic, such as voice, would get longer if the proportion of ABS is getting higher. Second is about ABS scenarios sacrifice some subframes to protect small cell, and the behavior decrease the spectrum utilization. The author proposed Multi-tone ABS to solver these problems, this way was possible to increase the capacity and energy efficiency and decrease delay.

The paper [8] proposes a Genetic Algorithm (GA) to find optimal ABS pattern that maximizes the network capacity and provides better fairness in resource allocation between all users. The results indicate that the ABS pattern provided by GA achieve a Fairness Jain Index 59,63 % better compared with use of random pattern.

This way, the main contributions of this paper are:

- Present a simple method to set ABS pattern;
- Show the performance of HetNet with and without ABS;
- Examine the effects of the Bernoulli Distribution;
- Provide a baseline for complex algorithms.

III. System Model

The scenario of this paper consists of two hexagonal small cells on the inside of macro cell, where UEs within the macro and small cell are uniformly distributed over the cell area. All UEs and BSs are equipped with a single omni directional antenna and each small cell is located near the edge of the macro cell. Herein, the system has 6 users, where 2 users are located in macro cell and each small cell have 2 users, 1 user is located in central region and another in edge, see Fig. 1.

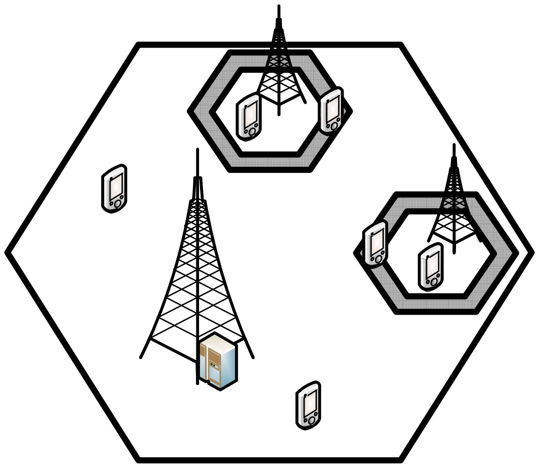


Fig. 1. Scenario using ABS in Downlink (DL).

In order that the LTE system can maintain synchronization and management of the different types of information that need to be carried between the BS and the UE. The LTE system has a defined LTE frame and subframe structure for the air interface. The frame has an overall length of $10\,\mathrm{ms}$ and it is divided into a total of 20 individual slots. The LTE subframes $(1\,\mathrm{ms})$ then consist of two slots - in other words there are ten LTE subframes within a frame [9].

The modeling of the complex channel coefficients includes propagation effects on the wireless channel, namely, pathloss, shadowing and fast fading. It was used in our scenario the Method of Exact Doppler Spread (MEDS), this model was first introduced in [10]. Despite its simplicity, the MEDS has high peformance and quasi-optimal approximation of the autocorrelation function corresponding to the Jakes power spectral density [11].

We use Round Robin (RR) scheduling policy to provide a fair and neutral scenario for sharing resources and it is used Shannon-Hartley theorem to measure the channel capacity in our system. The basic system parameters are presented in Table I.

The Signal to Interference-plus-Noise Ratio (SINR) in DL communication for each receiver in order to determinate capacity for macro and small cell are describe bellow.

The SINR γ_u^{Macro} for macro cell during ABS subframes is:

$$\gamma_u^{Macro} = \frac{|h_u|^2 p_u}{\sum_t^T \sum_c^C |h_c^{(t)}|^2 p_c^{(t)} + \sum_t^T \sum_b^B |h_b^{(t)}|^2 p_b^{(t)} + \eta} \quad (1)$$

while for non-ABS subframes,

$$\gamma_u^{Macro} = \frac{|h_u|^2 p_u}{\sum_t^T \sum_c^C |h_c^{(t)}|^2 p_c^{(t)} + \eta} \quad (2)$$

The SINR $\gamma_i^{(t)Small}$ for user i in small cell during ABS subframes is:

$$\gamma_i^{(t)Small} = \frac{|h_i^{(t)}|^2 p_i^{(t)}}{\sum_{t'\neq t}^{T}\sum_{c}^{C}|h_c^{(t')}|^2 p_c^{(t')} + \sum_{t'\neq t}^{T}\sum_{b}^{B}|h_b^{(t')}|^2 p_b^{(t')} + \eta} \tag{3}$$

while for non-ABS subframes,

$$\gamma_i^{(t)Small} = \frac{|h_i^{(t)}|^2 p_i^{(t)}}{\sum_{u}^{U}|h_u|^2 p_u + \sum_{t'\neq t}^{T}\sum_{c}^{C}|h_c^{(t')}|^2 p_c^{(t')} + \eta} \tag{4}$$

where,

- u is the receiver in macro cell $u \in \{1, 2, \cdots, U\}$;
- h is the channel that models the link between the transmitter and receiver;
- p is the transmit power allocated to transmitter to link between the receiver;
- t is the index of small cell $t \in \{1, 2, \cdots, T\}$;
- c is the receiver located in center of small cell $c \in \{1, 2, \cdots, C\}$;
- b is the receiver located in edge of small cell $b \in \{1, 2, \cdots, B\}$;
- η is the noise power.

TABLE I

PARAMETERS OF PROPAGATION FOR THE CHANNEL MODEL

Parameter	Value	Ref.
Macro cell radius	1500 m	[12]
Micro cell radius	250 m	[12]
UE height	1.5 m	
Macro transmit power	48 dBm	[13]
Micro transmit power	38 dBm	[13]
Macro cell pathloss model	$34.5 + 38\log_{10}(d)$ dB	[13]
Small cell pathloss model	$35.7 + 38\log_{10}(d)$ dB	[14]
Shadowing std. dev. (Macro)	8 dB	[13]
Shadowing std. dev. (Small)	10 dB	[13]
Fast fading model	MEDS	[12]
Thermal noise power	-112 dBm	[13]
Monte Carlo	1000	

d is the distance between communicating devices in meters

A. ABS pattern

HetNet is a set of small cells deployed within a macro cell coverage, this scenario is common in a metropolitan cities, where the amount of small cells are high. It is possible to use this scenario to increase network capacity, however, the cell interference is high due to proximity and variety of cells [15].

The ABS pattern provides a way to solve inter-cell interference in a HetNet scenario, because it prevent cell-edge UE in a small cell to be interfered by macro cell and vice versa [16].

We can see in the Fig. 2 an example, where the macro cell decides which subframes will be used (denoted by 1) or not (denoted by 0, i.e. ABS), after defining the ABS pattern the macro cell sends the information to small cell.

In our system the ABS pattern is defined through the Bernoulli Distribution, which is the discrete distribution of sample space $\{0, 1\}$, which takes the value 1 with the probability p (i.e. success probability) and value 0 with the probability $q = 1 - p$ (i.e. failure probability) [17].

This way, if Y is a random variable with this distribution, we have:

$$P(Y = 1) = 1 - P(Y = 0) = 1 - q = p \tag{5}$$

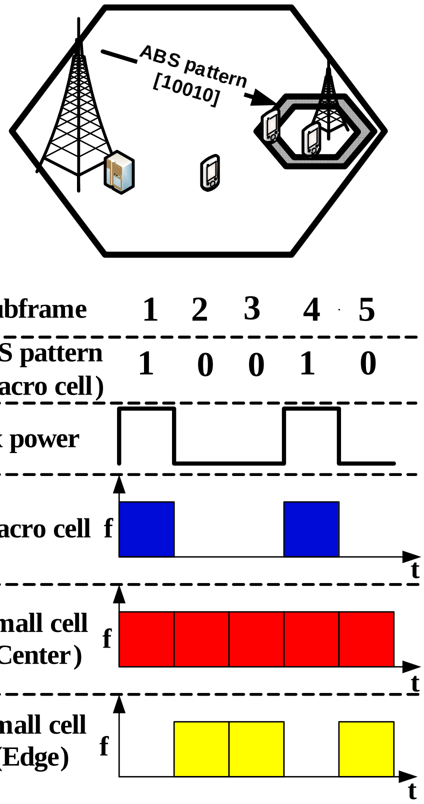
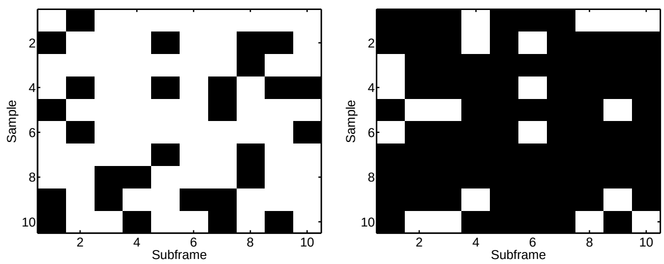


Fig. 2. Basic idea of ABS in a generic scenario.

Another interesting behavior is to note ABS pattern displayed graphically. We see in Fig. 3 the pattern up to 10 subframes and 10 samples. Each black and white square represents 1 (i.e. subframe used by macro cell) and 0 (ABS), respectively. As we can see Fig.s 3(a) and 3(b), it is usual ABS to low p values and rarely in the opposite case.



(a) $p = 0.2$. (b) $p = 0.8$.

Fig. 3. ABS pattern using different values of p.

IV. RESULTS

This section provides the performance assessment of the pattern ABS for HetNet in DL using Bernoulli Distribution with different probabilities. In the following, the range of probability p is between 0.1 up to 0.9, this way is possible to analyze the effects on ABS.

Before examining the effect of the Bernoulli Distribution on macro cell, it is necessary to emphasize the ABS case. In this case, the macro cell transmits only control signals for network management, that is, there is not total link mitigation of the macro cell.

Thus, the SINR of the macro cell becomes sensitive to p values, which is the parameter responsible for generating the ABS pattern. When low values of p are assigned to the system, the macro cell uses subframes every so often, for example, the scenario of low number UEs in macro cell. In this situation, edge users in the small cell have a chance to establish a communication link, thus from a macro cell's viewpoint, this scenario presents low SINR level. The main reason for low SINR level is due to interference from edge users in the small cell that harm the macro cell link, as shown in Fig. 4.

If the system is changed to high p values, it is created a scenario in which the macro cell often uses subframes, for instance, high number UEs in macro cell. When high values of p are assigned to the system, the macro cell uses subframes constantly, making it impossible the communication link of the edge users at small cell. Thus, the macro cell SINR level increase due to the interference level from the small cell to decline.

In small cell's viewpoint, as illustrated in Fig. 5, SINR level improves when p decreases, because the interference from macro cell is reduced (e.g. scenario in which macro cell has low load). An interesting result is obtained by comparing the scenario using ABS and no ABS. It should be noted that in all scenarios analyzed, the small cell SINR using ABS exceeds the case no ABS. However, this behavior is not noticed in the macro cell, since it is harmed to p values below 0.5.

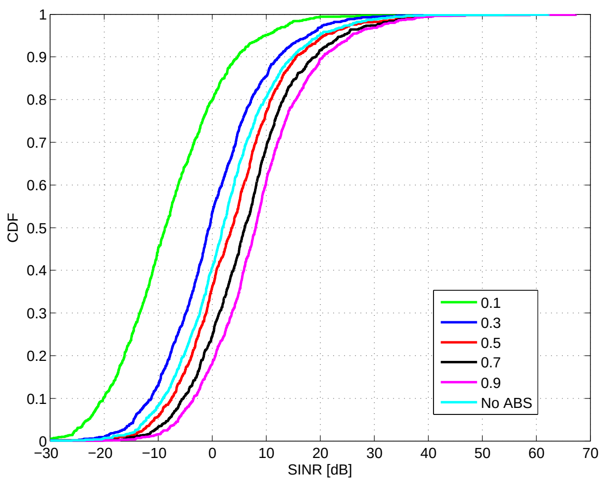


Fig. 4. SINR of macro cell applying different values of p to ABS pattern.

The Fig. 6 shows total system capacity, that is, the sum of macro cell and small cell capacity. The total system capacity using ABS overcomes the scenario no ABS for all p values. However, this result needs to be observed with caution, since the ABS technique must not only ensure the quality of the macro cell users but also improve the total system capacity.

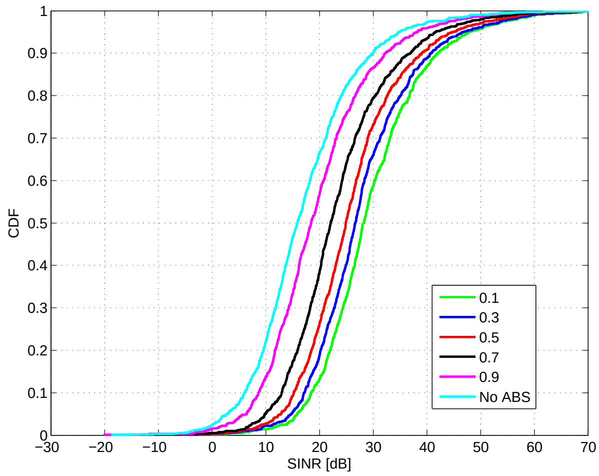


Fig. 5. SINR of small cell applying different values of p to ABS pattern.

By analyzing the results in detail, as shown in Table II, the relative gain of the total system capacity in all scenarios with ABS has higher values when compared to scenario no ABS. However, the p values below 0.4 should be avoided because the macro cell has negative gain, in other words, the technique ABS harms macro cell by up to $32\,\%$ loss. In order to provide macro cell capacity gain, the system must be parameterized with p values between 0.5 and 0.9, which provides relative gain between $10\,\%$ and $4\,\%$ for the system.

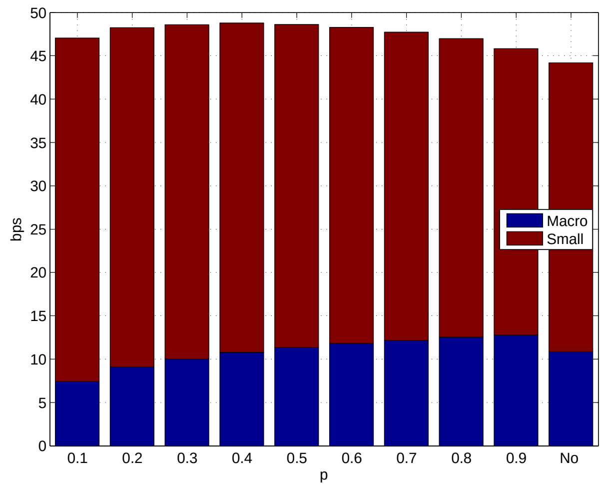


Fig. 6. Total channel capacity achieved by system.

Furthermore, benefits of ABS can be verified in terms of power efficiency, as illustrated in the Fig.s 7 and 8. Both the macro cell and small cell become more efficient when they use ABS technique from the fact that ABS provides increased system capacity without changing the transmission power of the BS, unlike Power Control (PC) techniques.

TABLE II

RELATIVE GAINS APPLYING ABS COMPARED WITHOUT ABS (%).

p	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Macro	-31.7186	-15.9298	-7.5815	-0.7862	4.2746	8.7889	12.0091	15.5888	17.9639
Small	18.8741	17.2747	15.5752	13.9780	11.8318	9.4011	6.6799	3.2515	0.9908
Total	6.4567	9.1250	9.8917	10.3543	9.9769	9.2508	7.9879	6.2796	3.6614

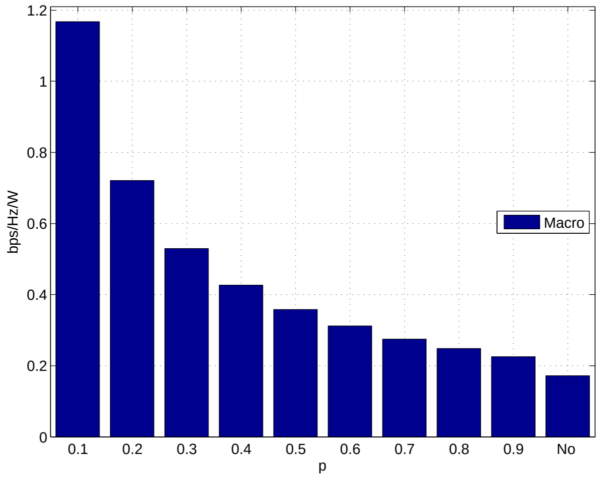


Fig. 7. Power efficiency achieved by macro cell.

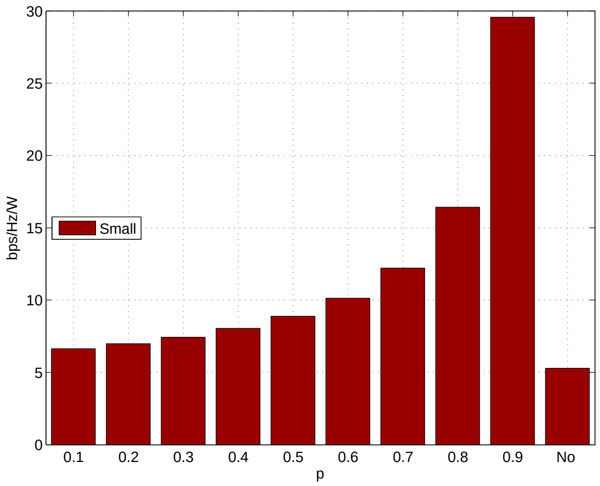


Fig. 8. Power efficiency achieved by small cell.

V. CONCLUSIONS

In conclusion, ABS technique provides benefits in terms of capacity and power efficiency to HetNet when parameterized correctly. The total system capacity achieves up to 10 % gain, while keeping good results of power efficiency. In this paper, the ABS concept was based on the Bernoulli Distribution, since it is simple to implement and can be used as baseline for complex algorithms. Therefore, the results presented in this paper are valid only for Bernoulli Distribution, however other distributions and heuristics not analyzed in the literature could be employed to ABS pattern, such as Poisson Distribution, Hypergeometric Distribution, Tabu Search or Simulated Annealing.

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