International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 24 (2016) pp. 11925-11934
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Interference Mitigation of Heterogeneous Networks by Proposed Combined Optimal Frequency and Power Allocations Scheme

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Abstract

In wireless networks, like LTE, the attractive features of the small cells, such as easy deployment, low cost, and low power consumption, have led to development of Heterogeneous Network (HetNet) approach. In HetNet, the limited resources are to be shared by the small cells, which in turns results in an interference problem challenges. The latter can be considered as the major barrier for acceptable HetNet performance. In this paper a new scheme that optimally controls the allocations of the HetNet limited resources is proposed, to mitigate its interference, it is a Combined Optimal Frequency and Power Allocation (COFPA) scheme. In this scheme the decision is to be made for selecting the best set of Physical Resource Blocks (PRBs) that dedicated to each cell (i.e. frequency allocation) with an optimum power, rather than random selection of PRBs with equal power allocations. These procedures are performed using central control unit at each sector that, firstly gathers sector information like; small cells utility, power and users channel states, then implementing the proposed COFPA scheme. A comprehensive analyses, comparisons and evaluation tests are done on the proposed scheme at both low and high Traffic Load (TL) conditions. The obtained results showed the powerful of the proposed model in mitigating interference of the designed LTE HetNet to large extents, where about (47%) and (40%) interference mitigation gains are achieved at low and heavy TL conditions respectively.

Keywords: Frequency allocation, Power allocation, PSO, HetNet.

INTRODUCTION

Recently HetNets have been introduced in major wireless communication standards like Long Term Evolution (LTE) and LTE-advanced (LTE-A). HetNet is a number of small cells (e.g. Pico cell, femto cell….etc) with low power, low cost and easy deployment overlaid the macro cell that adopted to solve the problem of coverage holes [1]. HetNet increases the spectral efficiency per unit area by offloading users from the macro cell through reusing macro cell spectrum due to the scarcity of the resources. However, special care should be given to the resulted interference. Many interference management techniques were proposed to reduce the interference effects and to increase the spectral efficiency during the HetNet operation. The LTE technique is based on Orthogonal Frequency Division Multiplexing Access (OFDMA) in the downlink (DL), where the entire spectrum is divided into blocks called PRB. Each PRB is composed of twelve subcarriers corresponding to 180 kHz in frequency domain and six/seven symbols in time domain for normal/extended cyclic prefix. In LTE Rel-8, the Inter-cell Interference Coordination (ICIC) is proposed to manage the PRBs such that inter-cell interference is kept under control by exchanging information via the LTE X2 Interface between Base Stations (BSs) [2]. In LTE Rel-9, the enhanced Inter Cell Interference Coordination (eICIC) was done through the resources coordination in time domain, where blanked subframes, referred to as Almost Blank Subframes (ABSs) were dedicated. This is done in order to serve the small cells' UEs without any data transmission from the macro cell except that for some necessary control signals [3]. LTE-Advance in introduces Further eICIC (FeICIC), which has a proposal scheme to reduce the power of the macro cell during the ABS rather than muting it, to enhance the performance of the macro cell [4].

The resources coordination between cells assists in enhancing the HetNet performance and has attracted much attention within the telecommunication industry [5]. Controlling time, power and frequency allocation between small cells represent a great challenge. This challenge opened wide area for the researches to candidate how to manage the HetNet operation by optimally allocating these resources.

The most related researches are worked on one or two of these resources only. For example, [6] presented a self-organization procedure performed in time and frequency domains, while [7] discussed interference minimization by optimally controlling the power of femto cells. Also, [8] introduced optimized joint time and power resources allocations. However, [9] proposed a dynamic spectrum allocation scheme. On the other hand, a fuzzy q-learning approach is introduced [10] to manage the interference. Hence, the novelty of this work is to optimally control the network resources by introducing a new Combined Optimal Frequency and Power Allocations (COFPA) scheme to mitigate the interference throughout the operation of HetNet during the ABS. COFPA scheme is composed of two procedures; in the first procedure PRBs are allocated to different cells (i.e. frequency allocation) based on Binary

Particle Swarm Optimization algorithm (BPSO).The second procedure is based on controlling the power, where a PSO algorithm is used to reallocating the power to the selected PRBs. The two procedures aim to enhance the overall site performance by mitigating the interference, based on the cell utility (related to the variations of TL in time) and the channel characteristics (shadowing and fading) without the need for users scheduling.

This paper is organized as follows; section (2) introduces the network model. The theoretical model of the proposed COFPA scheme is introduced in section (3). Analyses and evaluation tests are presented in section (4) and finally the conclusions are introduced in section (5).

NETWORK MODEL

The network model that adopted in this work has been built in two phases [11], where a new interference aware framework is developed for an optimum E-government network planning and operation. In phase one, the LTE network is planned for a target region at the center of Baghdad city, where the Users Equipment (UEs) of the network represent 228 governmental buildings. BPSO is used for selecting the best eight sites (3 sectors each) from a set of candidate sites (represent the existing nodes of the national Iraqi optical fiber network). Through the BPSO iterations a set of macro BSs are activated and deactivated till the dominate interferer site is cancelled and minimum cost function is reached under acceptable percentage of covered UEs. In the second phase, HetNet is implemented to solve the problem of limited resources in the congested sectors. A Multi-Stage PSO (MS-PSO) scheme is performed such that each macro cell can optimize the number and the power of its pico cells according to the TL profile. This scheme optimizes pico cells zooming by controlling their power, in such a way that some or all these small cells will be switched off and going into sleeping mode at low traffic to reduce the interference to prevent extra consumption expenditure.

This paper presents the third phase of the above mentioned framework development. In this phase the proposed COFPA scheme is performed at each sector of the network independently to achieve optimized and self-organized radio resources for both frequency and power allocations related to the TL variations with time.

PROPOSED COFPA SCHEME

In order to optimally frequency allocating PRBs to different cells, first BPSO algorithm is performed to distribute PRBs between the cells. PRBs are switching on and off through the iterative optimization procedure till finding the best set of these PRBs that minimizing the overall interference. Later and for further enhancement, the power of each selected set are being optimized using PSO in order to reduce the interference resulted from highly gained PRB which may affects their neighbors or increase the power of the weak PRB to overcome the predefined threshold. Both proposed frequency and power allocation schemes procedures are based on the same cost function that given in eqn. (1).

$$INT_{HetNet} = \sum_j \sum_{j'} INT_{jj'} \quad \ldots\ldots (1)$$

Subjected to C1: $\sum_i Pt_{i,j}^{PRB} = Pt_j^{BS}$ ……………… (1.1)

C2: $UT_j^{BS} \leq N_j^{PRB}$ …..……..…… (1.2)

where, INT_{HetNet} represents the intracell interference characterization all over the HetNet, which is the summation of the interference between each two cell denoted by j and j'. The condition in (1.1) ensures that the power summation of the used PRBs by the *jth* BS will never exceed its power.

The condition in (1.2) ensures that the number of PRBs dedicated to the *jth* BS and denoted by (N_j^{PRB}) will be no less than its demand denoted by the *jth* BS utility (UT_j^{BS}). The cell utility is defined by the percentage of PRBs used to serve the UEs associated to that cell to the total available PRBs as in eqn. (2). Since the UEs of the network are fixed in locations, then the only factor that affects the utility is the variation of the TL during the day business, hence the cell utility may vary from 100% for heavy TL at the busy hours to 20% for low TL as the users demands are decreased.

$$UT_j^{BS} = \frac{\sum_k NPRB_{k,j}^{UE}}{PRB_{total}} \quad \ldots\ldots (2)$$

where $NPRB_{k,j}^{UE}$ is the total DL PRBs dedicated to the *kth* UE from the *jth* BS.

A central control unit implements the proposed scheme to characterize the interference not quantify it, which means that the proposed scheme will only senses and distinguishes the PRBs that cause high interference rather than measuring the interference. The successive steps to characterize the interference are illustrated through the implementation steps (1-5) [12] under the following assumptions:

1) Assuming that the channel characteristics are static per each 12 consecutive subcarriers, hence 25 PRBs is adopted rather than 300 subcarriers for 5MHz Band Width (B.W).

2) Assuming that the channel characteristics are semi-static in time, so the proposed COFPA scheme can be implemented for long time period.

3) Assuming that the information about the UEs channel states are fed backed and gathered in a central control unit that may be located at the macro cell.

A. Implementation Steps:

Step 1- For each interferer cell denoted as *j'th* BS and each interfered cell denoted as *jth* BS, steps 2-5 are implemented.

Step 2- Each PRB is assigned to each UE associated to that cell, and the ratio between the PRB received power from that cell and other interfering one is determined as in eqn. (3).

$$\frac{C}{I}_{i,k}(dB) = \frac{Pr_{i,k,j}^{PRB}}{Pr_{i,k,j'}^{PRB}} \quad \ldots\ldots (3)$$

where $Pr_{i,k,j}^{PRB}$ and $Pr_{i,k,j'}^{PRB}$ are the power received of the *ith* PRB from the *jth* and *j'th* BS respectively to the *kth* UE and can be determined as in eqn. (4) [2].

$$Pr_{i,j,k}^{PRB} = Pt_{i,j,k}^{PRB} . A_{j,k}^{PL} . A_{j,k}^{sh} . A_{i,j,k}^{ff} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where $Pr_{i,j}^{PRB}$ and $Pt_{i,j}^{PRB}$ is the received and the transmitted power respectively of *ith* PRB used by the *jth* BS and dedicated to the *kth* UE. $A_{j,k}^{PL}$, $A_{j,k}^{sh}$ *and* $A_{i,j,k}^{ff}$ represent the channel characteristics between the *jth* BS and the *kth* UE in terms of path loss, the shadowing and the fast fading respectively.

Step 3- Each time C/I exceeds a predefined threshold (C/I_{thr}), an Interference Event is registered denoted as (*EI*). The interference event is accumulated for each PRB over all the UEs, as below:

$$EI_i = \begin{cases} EI_i + w1 & if\ C/I_{i,k} \le C/I_{thr},\ and \quad C/I_{i,k} > 0 \\ EI_i + w2 & if\ C/I_{i,k} \le C/I_{thr},\ and \quad C/I_{i,k} = 0 \\ EI_i + w3 & if\ \frac{C}{I_{i,k}} \le \frac{C}{I_{thr}},\ and \quad 0 < \frac{C}{I_{i,k}} > -\delta \\ EI_i + w4 & if\ \frac{C}{I_{i,k}} \le \frac{C}{I_{thr}},\ and \quad \frac{C}{I_{i,k}} < -\delta \\ EI_i & else \end{cases} \quad \ldots.. (5)$$

Assuming that (C/I_{thr}) is a positive value, eqn. (5) gives different potential to the PRBs as their values go far from the threshold and bounded by($-\delta$). This will dedicate more flexibility to the network operator to configure ($w1 \ldots. w4$) according to the network rudiments. As an example, if $w4 \gg w1$, the highest priority will be offered to the weak PRBs, so if the interference cannot be eliminated, at least it can be mitigated.

Step 4- At the same time the C/I values are accumulated over all the UEs denoted as (DI_i) as in eqn. (6):-

$$DI_i = \sum_k DI_{i,k} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Step 5- Each PRB interference can now be characterized as in eqn. (7), denoted as (Iev_i). The total interference occurrence between *jth* and *j'th* BS can be characterized as in eqn. (8) denoted as ($Iev_{jj'}$), where the summation of all PRBs used by the *jth* BS and interfered by the *j'th* BS is divided by the number of PRBs used in both cells (N_j^{PRB} *and* $N_{j'}^{PRB}$) to identify the percentage in which both cells are transmitting the same PRBs and results in interference occurrence. [12].

$$INT_i = \frac{EI_i}{DI_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$INT_{jj'} = \frac{1}{N_j^{PRB} N_{j'}^{PRB}} \sum_i INT_i \ .x_j \ .x_{j'} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

$$s.t. \quad x_j \ or\ x_{j'} \in \{0,1\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8.1)$$

$$x_j = \begin{cases} 1 & if\ PRB_i\ \ is\ used\ by\ the\ BS_j \\ 0 & else \end{cases} \quad \ldots\ldots\ldots (8.2)$$

The conditions in (8.1) and (8.2) ensure that the interference will only be determined to those PRBs which are common in use.

Accordingly, implementing the proposed COFPA mitigates the interference either by replacing the weak PRB by stronger one through the first procedure, or by equilibrates the power distribution between the PRBs in the second procedure. Both procedures aim to reduce the EI and increase the PRB DI values.

As a result INT_{HetNet} in eqn. (1) is the outcome of the above mentioned steps which characterizes the interference as the percentage in which the HetNet cells are transmitting the same PRBs and results in interference occurrence. INT_{HetNet} will be used later for interference mitigation gain calculation.

ANALYSES AND EVALUATION TESTS

A target sector (M3) is being chosen for testing COFPA scheme. M3 is the third macro cell in a set of twenty four macro cells represent the LTE e-government network. The simulation of this network is done by ICS Telecom software which is used for network planning and simulation. Five pico cells (indexed P5-P9) are deployed at the hot spot of M3 as depicted in figure (1). The adopted frequency reuse pattern between macro cells is 1×3×3, while the pattern inside each sector is 1×1×1.

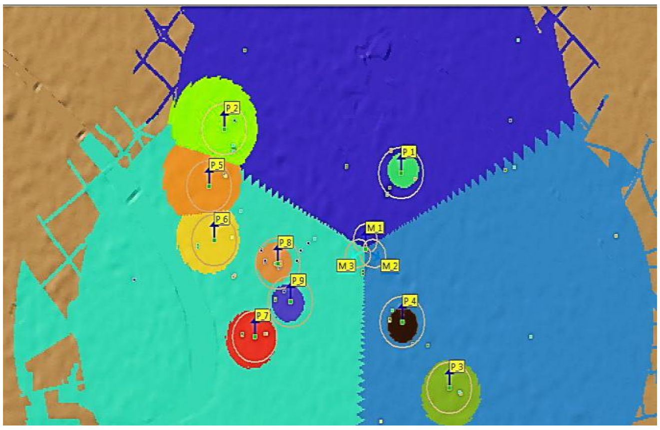
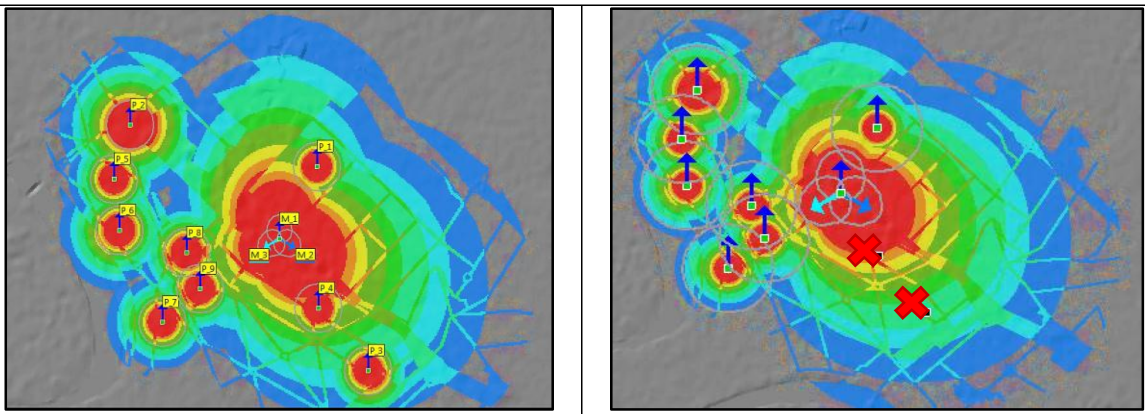


Figure 1: HetNet implementation at sites M1, M2 and M3

The power and the status of pico cells are optimized in phase (1) and phase (2) of the work (described in section 2) according to the TL. Figure (2) represents the coverage sites of M1, M2 and M3 at heavy and low TL, where the red crosses indicate cells in sleeping mode.



Heavy traffic load	Low traffic load

Figure 2: M1,M2 and M3 HetNet coverage

According to the M3 nominal parameters given in table (I) which were obtained by the previous phases, and in order to investigate the effectiveness of the proposed COFPA scheme, first PRB frequency allocation and power allocation optimizations are evaluated and tested separately, then effect of the proposed COFPA scheme in enhancing the frequency mitigation is analyzed and evaluated.

Table I: Power and utility of HetNet cells

Site M1, M2, M3						
TL=100%						
Cell no.	**M3**	**P5**	**P6**	**P7**	**P8**	**P9**
Power (watt)	1.999	.399	.5036	.3999	.5267	.429
Utility%	.98	.99	.99	.97	.942	.99
TL=20%						
Cell no.	**M3**	**P5**	**P6**	**P7**	**P8**	**P9**
Power (watt)	2.338	.399	.399	.399	.399	.399
Utility%	.388	.321	.1208	.073	.4938	.1987

A. PRBs Frequency Allocation Optimization Tests

PRBs frequency allocation optimization procedure was evaluated under both low and heavy TL conditions. Figure (3) depicts the simulation results in terms of interference events before and after optimization.

It is obvious that the PRBs frequency allocation optimization procedure has a major effect in reducing the interference at low TL, measured by the number of interference events occurrence before and after optimization. At the contrary to low TL, the frequency allocation optimization lost its contribution at heavy TL condition. This is due to the high cell utility, given in table (1), which results in using large number of PRBs by each cell that is close to the maximum. Accordingly, the proposed frequency allocation scheme will lost the flexibility in allocating PRBs, hence the interference mitigation gain will be senseless. This result can be concluded also from the comparison between the interference events occurrences before and after PRBs allocation optimization that depicted in figure (3.b).

Figure (4) depicts the PRBs utilization in all cells before and after implementing the frequency allocation optimization procedure at low TL condition. It is obvious show, how the above mentioned procedure reallocates the PRBs in such a way that reduce their usage by the cells. As an example (PRB no. 25) was randomly utilized by M3, P5, P8 and P9, while after optimization it is utilized by M3, P7 and P8 only. As a result, the frequency allocation optimization procedure reallocate PRB no. 25 in order to contribute in mitigation interference not only by reducing its utilization from 66% to 50% but also by allocating it to the appropriate cells.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 24 (2016) pp. 11925-11934
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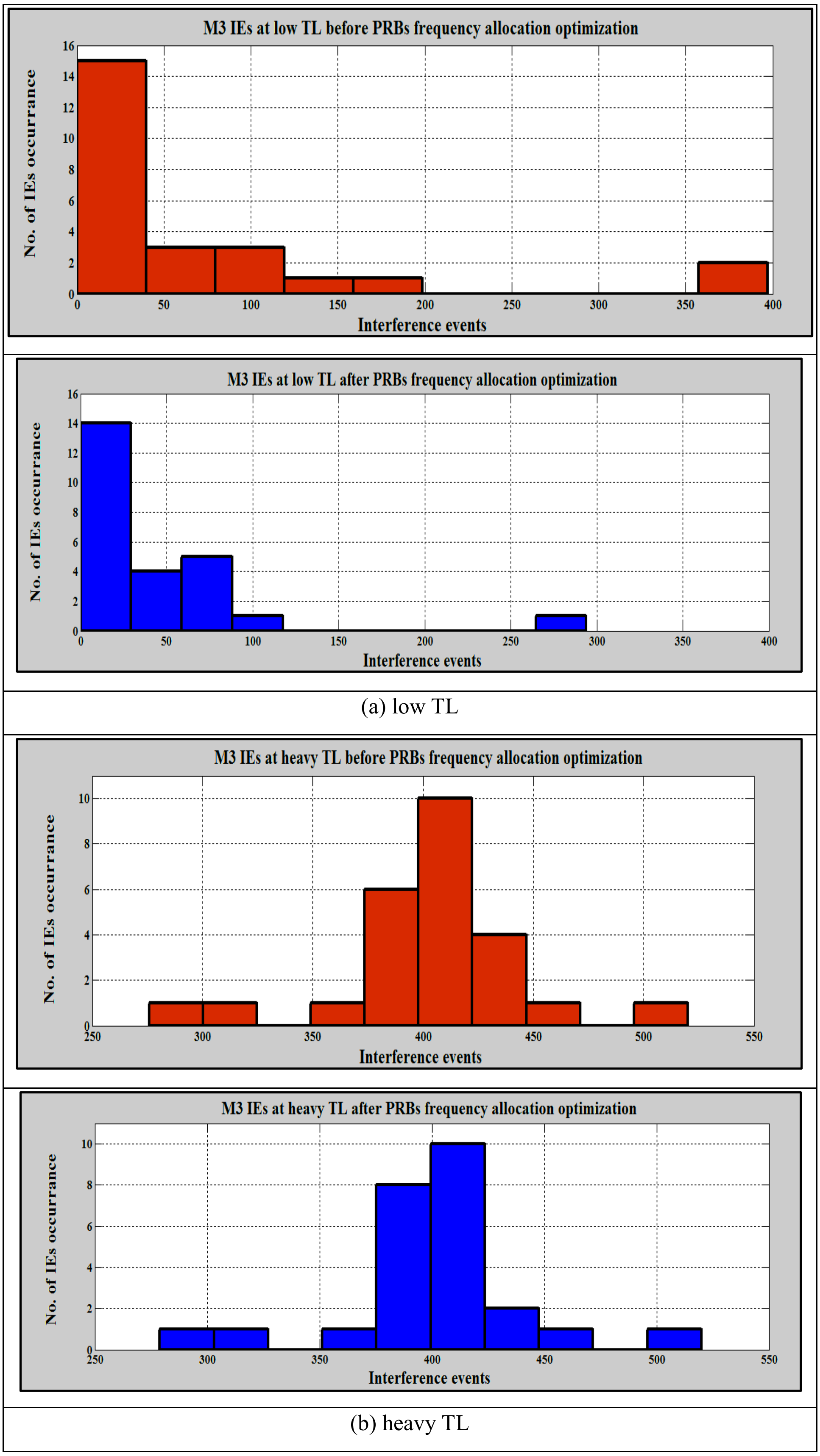


(a) low TL

(b) heavy TL

Figure 3: PRBs frequency allocation optimization tests

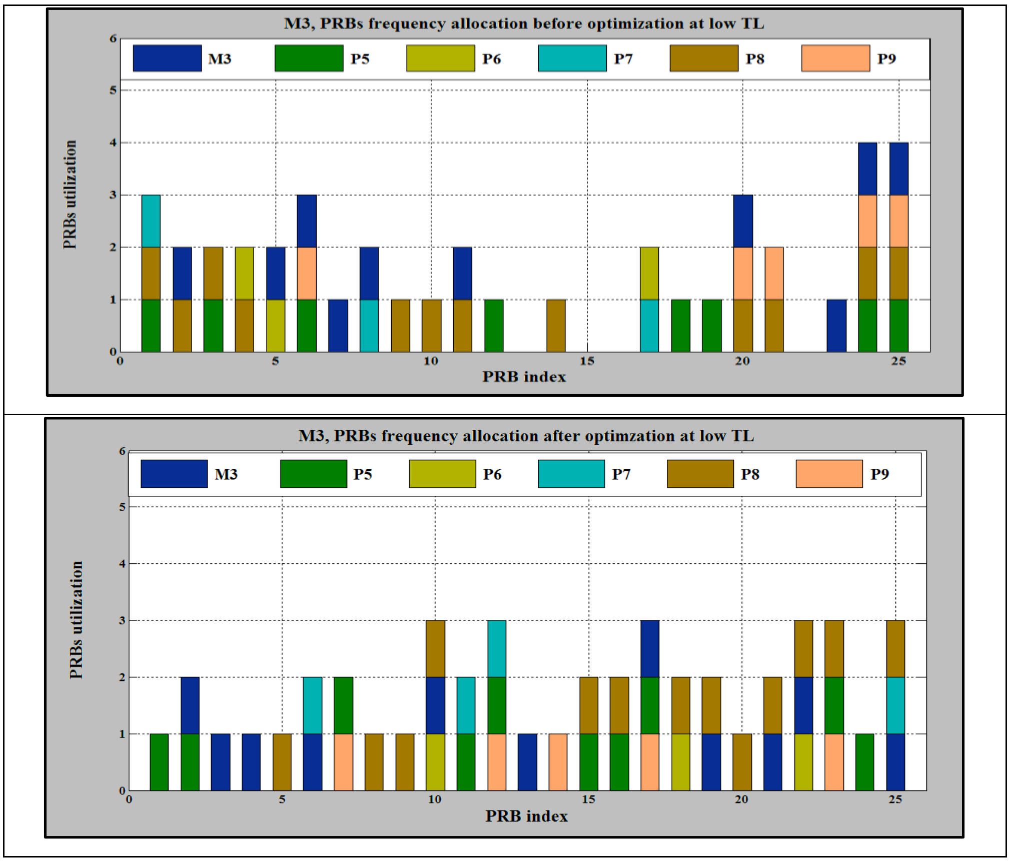
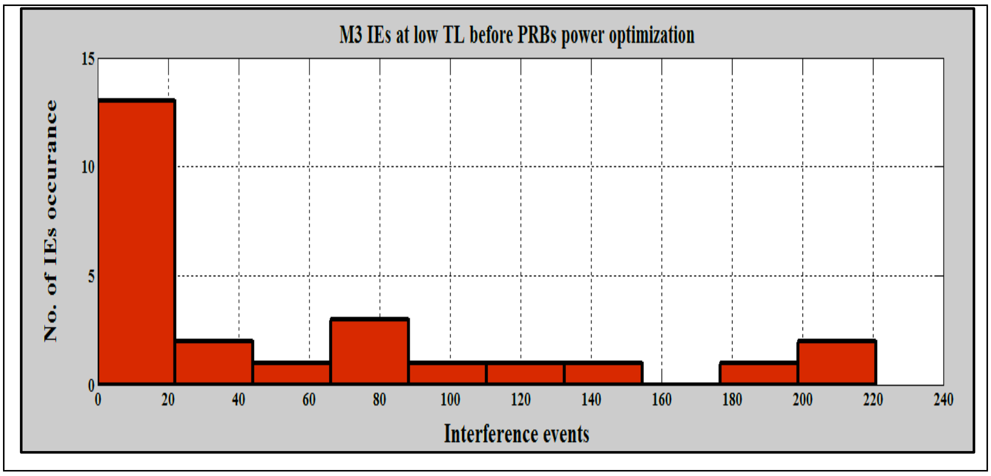
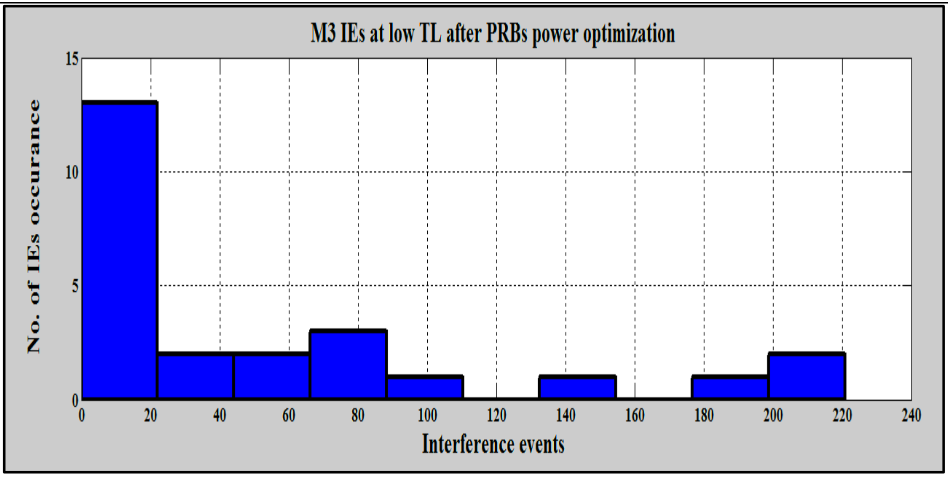


Figure 4: PRBs utilization by different M3 HetNet cells at low TL

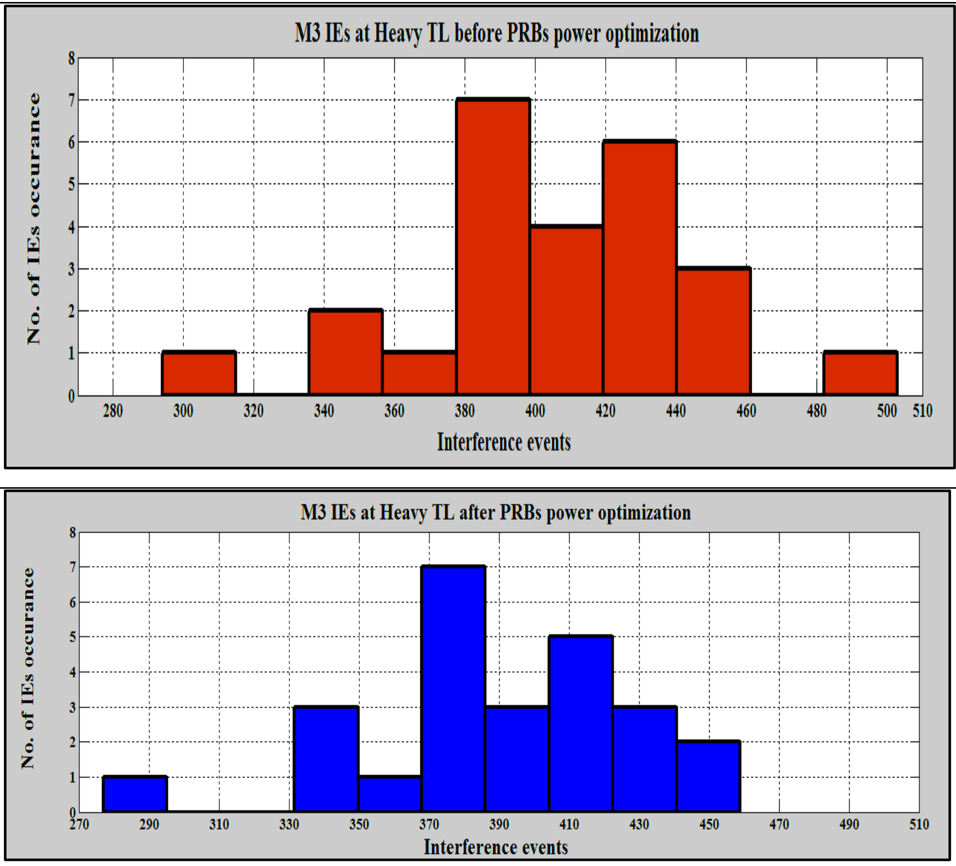
B. PRBs Power Allocation Optimization Tests

The PRBs' power optimization procedure simulation results in terms of interference events are depicted in figure (5).





(a) low TL



(b) heavy TL

Figure 5: PRBs power optimization procedure

At the contrary of PRBs assignment optimization procedure, the PRBs' power optimization procedure registers less interference mitigation gain at low TL. This result can be noticed from the number of interference events before and after the optimization, as depicted in figure (5.a). This is due to the limited cell transmitting power which offers less search space bounded by the condition (C1) in eqn. (1.1).

At heavy TL, the second procedure for PRBs power optimization registers a little bit higher interference mitigation gain as depicted in figure (5.b) despite that the power allocation between PRBs after optimization was also limited due to the higher utilization percentage. Figures (6) and (7) represent the PRBs' power optimization for each HetNet cells after optimization

at low and heavy TL respectively.

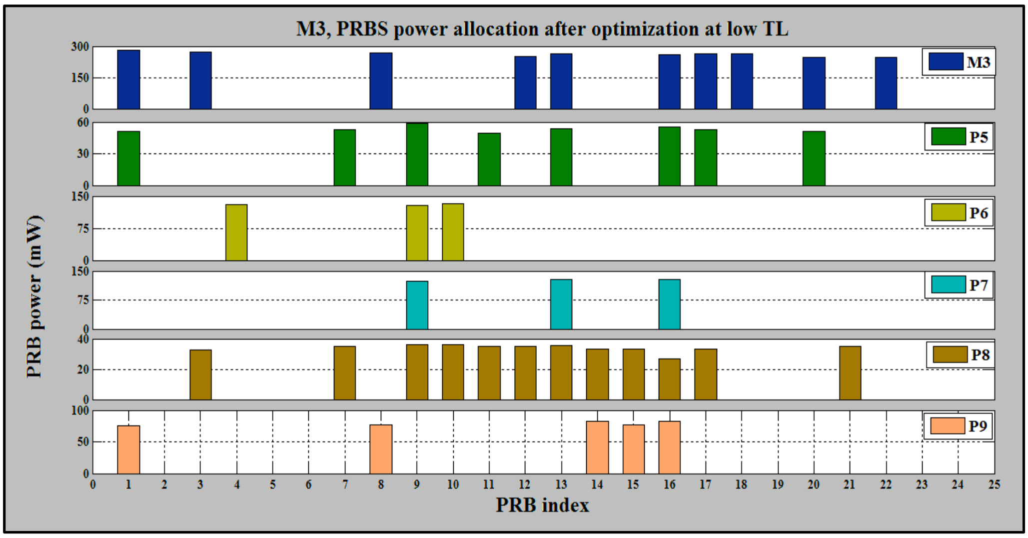


Figure 6: PRBs' power for each HetNet cells after optimization at low TL.

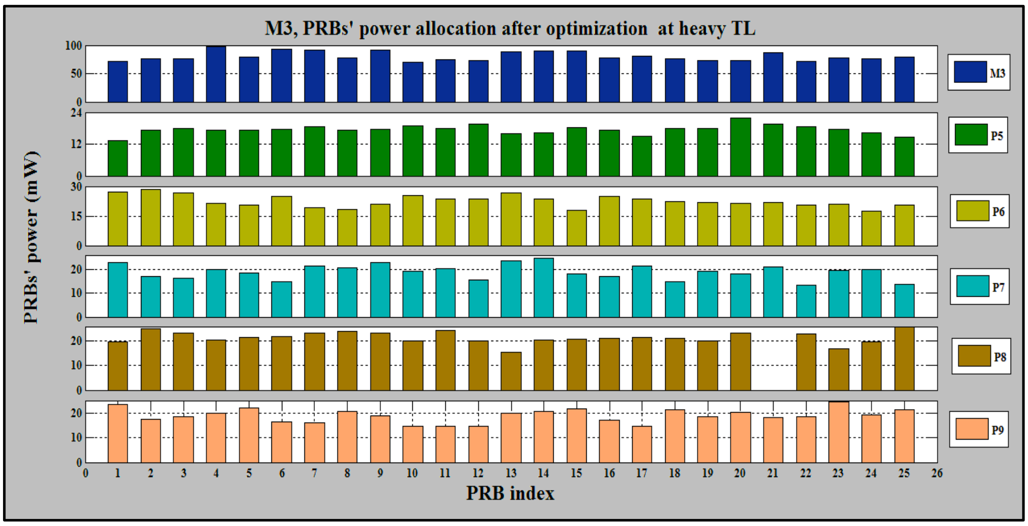


Figure 7: PRBs' power for each HetNet cells after optimization at heavy TL

C. COFPA Scheme Evaluation Test

The designed LTE network is simulated throughout performing the proposed COFPA scheme for both heavy and low TL. C/I_{thr} is assumed to be (15 dB), δ is set to (-5dB) and $(w1, w2, w3, w4)$ are set to (1,5,10,20) respectively. Comparing the proposed COFPA scheme compared to randomly PRBs frequency allocation and equally PRBs' power allocations, an average interference mitigation gain for N trails can be calculated by eqn. (9)

$$AV\ Interference\ mitigation\ gain = \frac{1}{N}\sum_{n=1}^{N}\frac{(INT_{HetNet})_{randomly}-(INT_{HetNet})_{COFPA}}{(INT_{HetNet})_{randomly}} \times 100\% \quad \text{..........} (9)$$

Figure (8) shows increasing in the average interference mitigation gain as the TL decreased, where the proposed COFPA scheme achieves 40% and 47% at heavy and low TL conditions respectively. This due to lower utilization percentage which offers more flexibility to the optimization process. On the other hand, frequency optimization procedure achieves higher mitigation gain when implementing at low traffic which equals 30%. That's at the contrary to the heavy traffic condition, where the mitigation gain equals 1% which is due to the same above mentioned reason. Due to the limited transmitting power at low traffic, the power optimization procedure achieves 7% interference mitigation gain only at this TL condition, while at heavy TL the interference mitigation gain is increased to 22%.

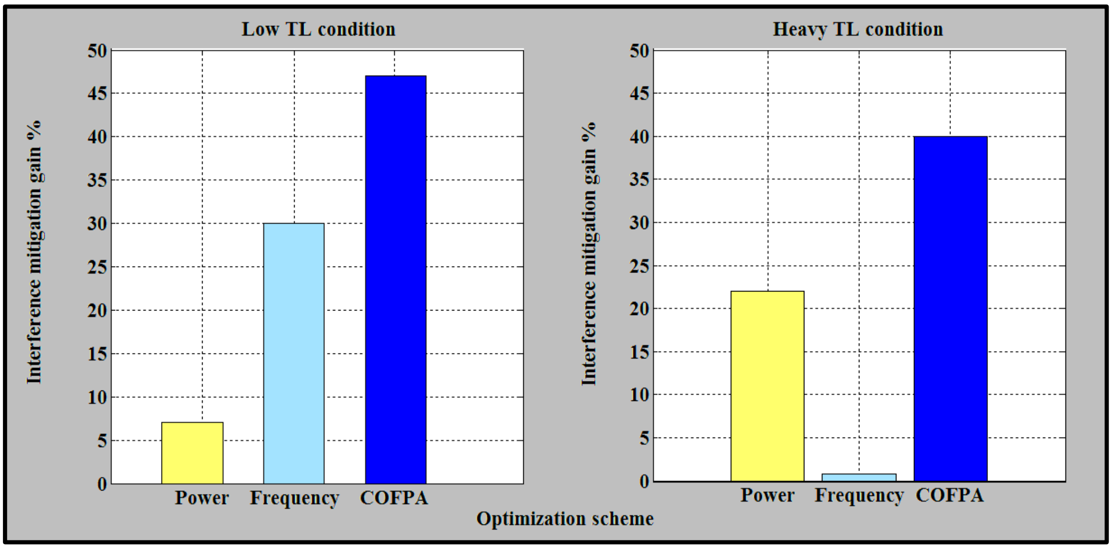
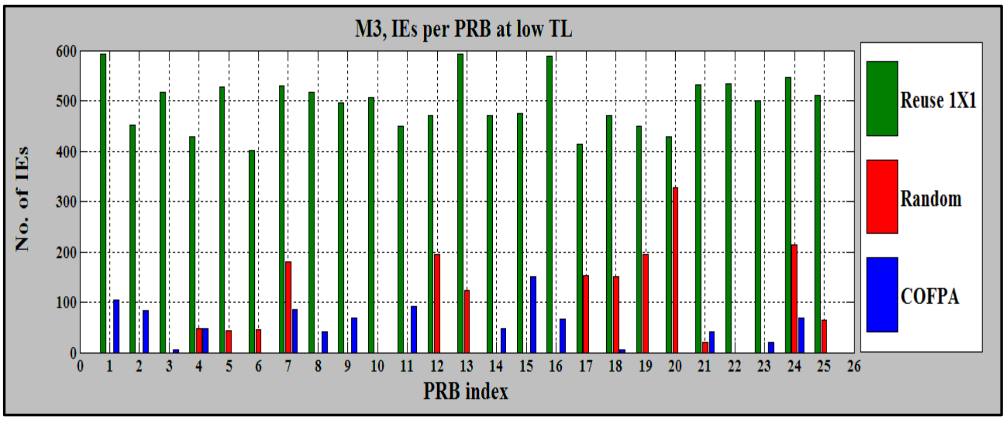
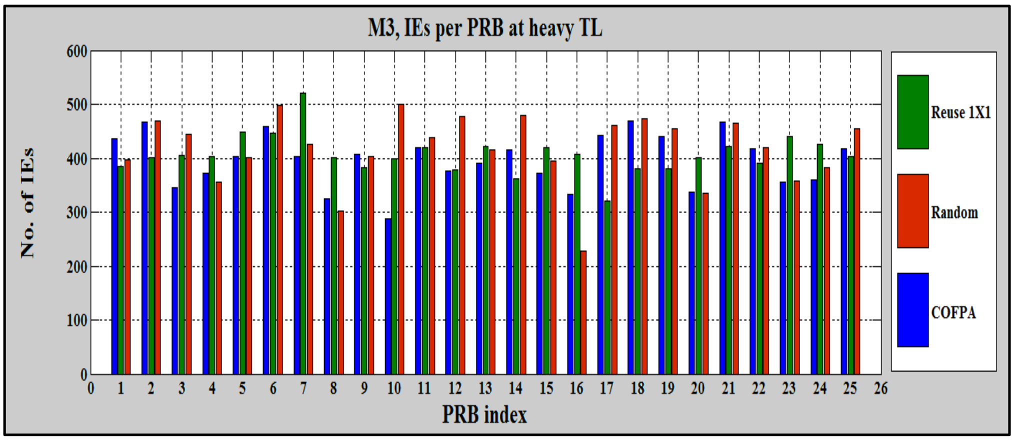


Figure 8: Comparison of interference mitigation gain

Figure (9) depicts the summation of interference events registered by each PRB whenever it is used all over the HetNet. Besides comparing COFPA scheme to randomly allocating frequency and power, a reference model that adopts frequency reuse pattern of 1×1×1, is compared also. The results showed again the powerful of proposed COFPA scheme in mitigation interference especially at low TL condition.



a- Low TL



b- Heavy TL

Figure 9: Comparison of proposed COFPA scheme to other procedures.

CONCLUSIONS

In this paper, a new COFPA scheme is proposed to mitigate the HetNet interference at each sector. The proposed scheme is composed of two optimization procedures; the first procedure based on BPSO for optimally frequency allocating PRBs to different cells rather than the usual randomly allocation. BPSO reallocates PRBs using one of two ways; either by benefiting from the unused PRBs, or by optimally selecting the repeated ones based on their interference event. The simulation results show that the proposed optimization for PRBs frequency allocation has major effects by reducing the PRBs utilization from different cells especially at low TL. The interference mitigation gain obtained by PRBs frequency allocation optimization procedure comparing to random allocations equals (30%) and (1%) at low and heavy TL respectively. The second procedure that based on PSO is introduced for optimally allocating power to the selected PRBs, taken into consideration the channel characteristics. The interference mitigation gain obtained by PRBs optimal power allocating procedure comparing to equally power allocations equals (7%) and (22%) at low and heavy TL respectively. As the procedure effectiveness is governed by the cell transmitting power, hence low interference gain is achieved at low TL condition. Generally combining the two procedures resulted in further enhancement, where the proposed COFPA achieves (47%) and (40%) interferences gain at low and heavy TL respectively.

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