Enhancing Performance of Victim Macro Users via Joint ABSF and Dynamic Power Control in LTE HetNets

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***Abstract*—The rise in mobile data traffic demands from indoor users (UEs) coupled with poor cellular coverage in indoor environments, triggering the growth of Femto cell deployments. However, due to densification of Femtos, frequency reuse one, and lack of coordination among Femtos in LTE HetNets, cell-edge users of Macro cells, who are in the vicinity of Femtos, get affected by cross-tier interference of the Femtos. In this work, we investigate how to improve performance of Victim Macro UEs (VMUEs). In order to provide better coordination between interfering Macro and Femtos, a centralized algorithm is proposed which performs Femto muting via joint Almost Blank Subframe (ABSF) and power control. During ABSF, Femto automatically adjusts its transmission power depending on the level of interference suffered by VMUEs. Our proposed scheme, called as RrMute, is compared with baseline schemes and the simulation results show that RrMute enhances the performance of VMUEs without jeopardizing the performance of Femto UEs in LTE HetNets.**

I. Introduction

In the last decade, cellular networks have witnessed a phenomenal growth in mobile data traffic from indoor user equipments (UEs). A recent survey by Cisco [1] shows that 80% of the mobile data traffic consumption is because of indoor UEs, which is expected to grow even more in future. In an indoor scenario, electromagnetic signals from outdoor base station have to penetrate through walls and floor of the buildings, which makes electromagnetic signals more vulnerable and therefore indoor UEs will receive weak signal quality. Heterogeneous Networks (HetNets) can play a significant role in addressing this issue. In HetNets, as shown in Fig. 1, a variety of base stations exist such as Macros, low power small cells *i.e.,* Femtos, Picos, Relays, and Remote Radio Heads. These nodes vary in terms of their transmission power, coverage range, and access control. Macro base station offloads some of its mobile traffic load to small cells deployed in its coverage region. The inclusion of small cells in cellular networks brings transmitter (BS) closer to UEs, which in turn enhances spectral efficiency and system capacity. Despite of several advantages with dense Femto deployment, there are still some challenges to resolve like co-tier and cross-tier interference.

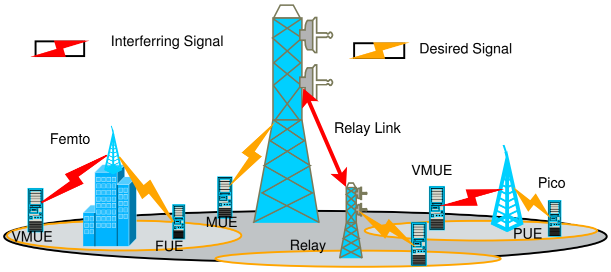

Figure 1: An example of LTE HetNet.

Typically, Femtos are deployed in three distinct operating modes *i.e.,* Open Access (OA), Closed Access (CA), and Hybrid Access (HA). In OA mode, any user in the cell range of Femto can get attached to it, but in CA mode, only a registered set of UEs (Closed Subscriber Group (CSG)) in Femto coverage range get attached to it. HA mode is a combination of OA and CA in which, a limited set of radio resources are reserved for non-CSG UEs. Residential Femtos are configured in CA mode and operate on the channel as that of Macro(s) (*i.e.,* reuse one) which leads to cross-tier interference from the Macros and co-tier interference from other conflicting small cells. The cell-edge users of Macro cells, who are in the vicinity of Femtos, also get affected by cross-tier interference of the Femtos. We call such cell-edge users as Victim Macro UEs (VMUEs) in the rest of this paper.

3GPP introduced Almost Blank Subframe (ABSF) in rel. 10 as a time domain enhanced Inter-Cell Interference Coordination (eICIC) mechanism for interference mitigation in LTE HetNets. In ABSF scheme, one interfering tier will mute some of its subframes also known as ABSFs (*i.e.,* subframes contain only control and cell reference symbols) while another interfering tier will schedule its interfering UEs during ABSFs so that the interfering UEs of the non-muting tier will suffer less interference and receive better SINR. The ABSF scheme enhances the channel quality of VMUEs at the cost of degradation in the performance of Femtos. As a Femto does not send any user data during ABSF, it is the prime cause of throughput degradation for Femtos. In this paper, we propose a centralized scheme RrMute (*i.e.,* Round robin Femto Muting) which identifies VMUEs and provides a strong coordination between Femto and Macro for mitigating cross-tier interference. The two main issues discussed in this paper are: **a)** Adjusting the transmission power at Femto during ABSF and then calculating the number of ABSF required, and **b)** Determining appropriate subframes for muting at a Femto.

978-1-5090-5356-8/17/ $31.00

II. RELATED WORK

In [2], the authors proposed ABSF solution for enhancing the throughput of VMUEs and activated the ABSF mode at an interfering Femto through X2 interface. This work significantly improved the throughput of VMUEs but at the cost of severe degradation in Femto UEs performance. Furthermore, the ABSF patterns chosen are static. In [3], the authors addressed the problem of VMUEs poor channel quality by combining the frequency allocation and power control techniques. They proposed an interference map, which used by a central entity for identifying the level of interference between Femtos and UEs. They claimed that by limiting resource sharing among far away neighbors, better throughput can be achieved for VMUEs. In another work [4], the authors proposed a method for enhancing the performance of VMUEs by placement of Femtos and dynamic power control at Femtos. In the literature, there are some works which address the issue of performance degradation at the Macro when employing ABSF. In [5], the authors proposed the multitone muting for Macro, which states that instead of completely muting Macro during ABSF, just reduce the transmission power level in those subframes. But, the transmission power level chosen during ABSF does not consider the degree of interference suffered by interfering UEs. In [6], a solution is proposed in which Macro reserves some resource blocks (RBs) for interfering UEs during ABSF for minimizing the throughput degradation at the Macro during ABSF.

III. SYSTEM MODEL AND PROPOSED METHOD

In this paper, we consider an LTE HetNet system with Femtos configured in CA mode. Macro UEs are categorized into VMUEs and non-VMUEs based on their received SINR. It is assumed that VMUEs are distributed over the entire Femto coverage region and interference suffered by VMUEs is proportional to the proximity of VMUE from its conflicting Femto. In RrMute scheme, based on the Channel State Information (CSI) received from VMUEs, we introduce the notion of sectorization by segregating the Femto coverage region into four different cell areas as shown in Fig. 2. Moreover, by sectorization of Femto transmission region, a precise transmission power level can be chosen during ABSF *i.e.,* if interference suffered by VMUEs is higher, then more reduction in transmission power level of Femto is needed during ABSF and vice-versa.

(a) Global Information Center (GIC): RrMute proposes coordination among Femtos and Macro for providing global information about all channels and interference scenarios. GIC (refer Fig. 3) has a matrix ζ (Channel State Matrix). ζ is a 2D matrix, between UEs $\mathcal{U}$ and base stations $(\mathcal{F} \cup \mathcal{M})$ and used for tracking the channel conditions of MUEs to identify VMUEs. ζ_x^i denotes Reference Signal Received Quality (RSRQ) received by MUE x from an interfering Femto i, same applies for ζ_x^j as well. In our case, we are considering the indoor scenario and our algorithm uses the existing LTE CSI for constructing ζ. Some major challenges that come with the centralized approach is the delay, signaling overhead during communication with the base stations, and strict time synchronization required by ABSF. As the core component of our algorithm is GIC, it is placed in each Macro. Thus, delay and overhead can be reduced significantly.

Table I: Notations

Notation	Interpretation
$\mathcal{M}$, $\mathcal{F}$	Set of Macros, Femtos and $i \in \mathcal{F}$, $j \in \mathcal{M}$
$\mathcal{U}$, x	Set of UEs, $x \in \mathcal{U}$, and $b \in (\mathcal{M} \cup \mathcal{F})$
x_i, x_j	An arbitrary UE x connected to Femto i and Macro j, respectively
$\mathcal{I}_{x_i}, \mathcal{I}_{x_j}$	Interference received by UEs x_i, x_j
f, $f^{'}$	Number of Femtos interfering with UE x_i and x_j, respectively
$\mathcal{G}_{i,x_i}, \mathcal{G}_{j,x_j}$	Channel gain between Femto i and UE x_i, Macro j and UE x_j, respectively
Phi_i, Phi_j	Maximum transmit power for Femto i and Macro j, respectively
$\mathcal{N}$, $\mathcal{R}_A$	Number of subframes and RBs per TTI
$\mathcal{FR}_d$, $\mathcal{SB}_d$	Frame duration, subframe duration
c_{x_b}	1 if UE x is connected to base station b, 0 otherwise
v	Number of VMUE in territory of an arbitrary Femto i
ϕ	Minimum interference bound denoting poor channel condition
ψ	Maximum interference tolerance bound
N_0, $\mathcal{C}_0$	Background noise and constant of 126
β	If β value is 4, then $4x4$ MIMO antenna
$\mathcal{N}_{AB,i}$	Number of ABSF calculated per periodic run of algorithm w.r.t. Femto i
$\mathcal{N}_{MAX_i}$	Maximum number of subframes allocated by Femto i
$\mathcal{M}_{ix}$	Throughput of VMUE x in the territory of Femto i
$\mathcal{D}_{min_f}$, $\mathcal{D}_{min_m}$	Minimum bit rate required for Femto UE (FUE) and MUE, respectively
$\mathcal{RB}_{x_j}$	RBs required by VMUE x connected to Macro j
$\mathcal{R}_{av,i}$	Average RB requirement per Femto i
$\mathcal{R}_{MAX,i}$	Maximum RBs given per TTI by Femto i
$\mathcal{D}_{ar_i}$	Bit rate per Femto i after employing ABSF

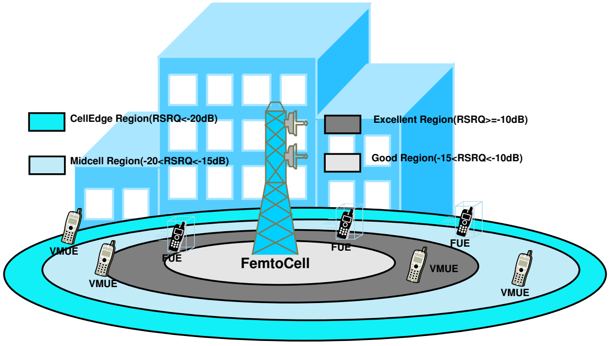

Figure 2: Categorization of UEs into four Femto cell regions based on CSI.

(b) Transmission Power: For each Femto, categories of its VMUEs are determined using ζ. According to the category of VMUEs, a unique transmission power level will be chosen. In RrMute algorithm, Femtos keep transmitting throughout frame durations (*i.e.,* 10 ms) without muting. But, Femto transmission power level during ABSF is set proportional to interference experienced by its VMUEs. Transmission power level for the Femto i is $\rho(i)$, where $\rho(i) \in \mathcal{P}$ and $\mathcal{P} = \rho_1, \ldots, \rho_k$, where k is the number of interference categories available and $\psi \in \psi_1, \ldots, \psi_{k-1}$ represent interference bounds. If $k = 4$

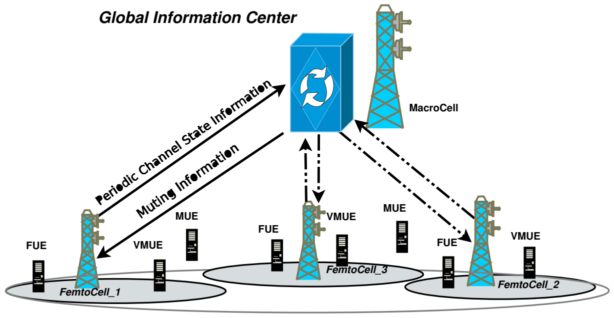

Figure 3: Interaction between Femto/Macro and Global Information Center.

and $\psi_1, \ldots, \psi_{4-1}$ are interference bounds, then transmission power level set for the Femto i, $\rho(i)$, is given by:

$$\rho(i) = \begin{cases} \rho_1 & \zeta_x^i \leq \psi_1 \\ \rho_2 & \psi_1 \leq \zeta_x^i \leq \psi_2 \\ \rho_3 & \psi_2 \leq \zeta_x^i \leq \psi_3 \\ \rho_4 & \psi_3 \leq \zeta_x^i \end{cases} \tag{1}$$

$$\mathcal{I}_{x_i} = \begin{cases} \Phi_j \times \mathcal{G}_{j,x_i} + \sum_{f'=1}^{f'} p(f') \times \mathcal{G}_{f',x_i}, & \textit{ABSF} \\ \Phi_j \times \mathcal{G}_{j,x_i} + \sum_{f'=1}^{f'} \Phi_{f'} \times \mathcal{G}_{f',x_i}, & \textit{non-ABSF} \end{cases} \tag{2}$$

$$\mathcal{I}_{x_j} = \begin{cases} \sum_{f=1}^{f} p(f) \times \mathcal{G}_{f,x_j}, & \textit{ABSF} \\ \sum_{f=1}^{f} \Phi_f \times \mathcal{G}_{f,x_j}, & \textit{non-ABSF} \end{cases} \tag{3}$$

SINR calculation for FUEs:

$$SINR(x_i) = \begin{cases} \frac{p(i) \times \mathcal{G}_{i,x_i}}{\mathcal{I}_{x_i} + N_0}, & \textit{During ABSF} \\ \frac{\Phi_i \times \mathcal{G}_{i,x_i}}{\mathcal{I}_{x_i} + N_0}, & \textit{During non-ABSF} \end{cases} \tag{4}$$

SINR calculation for MUEs:

$$SINR(x_j) = \begin{cases} \frac{\Phi_j \times \mathcal{G}_{j,x_j}}{\mathcal{I}_{x_j} + N_0}, & \textit{During ABSF} \\ \frac{\Phi_j \times \mathcal{G}_{j,x_j}}{\mathcal{I}_{x_j} + N_0}, & \textit{During non-ABSF} \end{cases} \tag{5}$$

In CA system, each UE (FUE or MUE) is allowed to associate with only one base station.

$$\sum_{b \in \mathcal{F} \cup \mathcal{M}} c_{x_b} = 1 \qquad \forall x \in \mathcal{U} \tag{6}$$

IV. PROBLEM FORMULATION

The objective is to maximize the aggregate throughput of VMUEs, while maintaining the minimum bit rate requirement of FUEs as well as non-VMUEs.

$$\text{Maximize} \sum_{i=1}^{f} \sum_{x=1}^{v} \mathcal{M}_{ix} \tag{7}$$

$$\text{Subject to } \mathcal{D}_{ar_i} \geq \mathcal{D}_{min_f}, \quad i = 1, \ldots, f. \tag{8}$$

$$\mathcal{D}_{ar_x} \geq \mathcal{D}_{min_m}, \quad i = 1, \ldots, v. \tag{9}$$

Above constraints help in improving throughput of VMUEs without degrading the performance of FUEs. However, according to [7], maximization of aggregate throughput of VMUEs is an NP-Hard problem. Our proposed algorithm 1 considers the density of VMUEs inside the Femto coverage region and then applies power control on subframe level to achieve fair results dynamically. The below constraints formulate RB requirement based on the subframe slot, minimum bit rate required for FUE & MUE, and Modulation Coding Scheme (MCS) based on SINR.

$$\mathcal{RB}_{x_j} = \frac{\mathcal{D}_{min_m} * \mathcal{SB}_d}{\mathcal{C}_0 * MCS(SINR_{x_j}) * \beta} \tag{10}$$

$$\mathcal{RB}_{av,i} = \frac{\sum_{x=1}^{v} \mathcal{RB}_{x_j}}{v} \qquad \forall i \in \mathcal{F} \tag{11}$$

Femto bit rate requirement is split into two different bit rates, during ABSF $\mathcal{D}_{AB,i}$ and during normal subframes $\mathcal{D}_{N,i}$ as an outcome of varying SINR.

$$\mathcal{D}_i = \begin{cases} \mathcal{D}_{AB,i}, & \textit{During ABSF} \\ \mathcal{D}_{N,i}, & \textit{During non-ABSF} \end{cases} \tag{12}$$

$$\mathcal{R}_{MAX,i} = \frac{\mathcal{D}_{min_f} \times \mathcal{SB}_d}{\mathcal{C}_0 \times MCS(SINR_{x_i}) \times \beta} \tag{13}$$

$$\mathcal{N}_{AB,i} \leftarrow [min(\mathcal{RB}_{av,i} \times v, (\mathcal{R}_A - \mathcal{R}_{MAX,i}))/\mathcal{R}_A] \tag{14}$$

$$\mathcal{D}_{ar_i} = \frac{\mathcal{D}_{AB,i} \times (\mathcal{N}_{AB,i} \times \mathcal{SB}_d) + \mathcal{D}_{N,i} \times (\mathcal{N} - \mathcal{N}_{AB,i}) \times \mathcal{SB}_d}{\mathcal{FR}_D} \tag{15}$$

A. Comparative eICIC schemes

NoeICIC: In this naive scheme, VMUEs experience poor SINR as no eICIC mechanism is applied.

OpTPowSub: It begins by calculating the number of ABSFs initially and then reduces transmission power (refer Algorithm 1) for an interfering Femto. Further, it implements uniform Femto muting. In other words, all interfering Femtos in the entire system do not follow any specific pattern while muting. By muting all interfering Femtos at the same time or without following any specific Femto muting pattern, the number of VMUEs to be scheduled at the Macro scheduler during ABSF will increase. Although the scheduler will give preference to VMUEs over regular UEs, as it will assign resources to some of the VMUEs than those VMUEs, which does not get resources during ABSF, it will unnecessarily degrade the performance of an interfering Femto. Therefore, Macro do not perform efficiently.

RrMute: Non-uniform Femto muting is of paramount significance to ensure that VMUEs exploit the ABSF thoroughly. VMUEs need to get scheduled during ABSF by its serving Macro. Unlike OpTPowSub, where muting its interfering Femtos does not follow any pattern, RrMute mutes Femtos in a round-robin fashion. VMUEs in the territory of muted Femto will get scheduled by its serving Macro, which eradicates the unnecessarily Femto muting. RrMute performs a two-tier approach. In first tier, OpTPowSub scheme will be responsible for assigning appropriate transmission power level and number of ABSFs and in second tier it carries out a round-robin based Femto muting which ensures a guaranteed bit rate to all UEs (refer Algorithm 2). Therefore, RrMute overcomes shortcomings of OpTPowSub.

ABSF: In this scheme, Femtos transmit control and reference signals in some subframes unlike in OpTPowSub and RrMute schemes.

Algorithm 1 Algorithm for Finding Λ Map

```
Inputs : $\zeta_x^i$, $x \in \mathcal{U}$, and $i \in \mathcal{F}$
Outputs : $\Lambda$, $\kappa$
Initialization : Clear $\Lambda$, $\kappa$, $\Gamma$
for each $x \in \mathcal{U}$ for $j$ do
    if $\zeta_x^j \leq \phi$ then
        $flag \leftarrow false$
        for each $i \in \mathcal{F}$ do
            if $\zeta_x^i \neq \Upsilon$ and $\zeta_x^i \geq \psi$ then
                $\kappa_x.push(i)$
                $flag \leftarrow true$
                if $i \notin \Gamma$ then
                    $\Gamma.insert(i, \zeta_x^i)$
                else
                    if $\Gamma.find(i) < \zeta_x^i$ then
                        $\Gamma.insert(i, \zeta_x^i)$
                    end if
                end if
            else
                UE $x$ is not getting interference from Femto $i$
            end if
        end for
        if $flag \neq flase$ then
            UE $x$ is experiencing cross-tier interference
        else
            UE $x$ is at cell-edge and getting low signal
        end if
    else
        UE $x$ is receiving desired SINR
    end if
end for
for $i \in \Gamma$ do
    Create a tuple for $\Lambda_i$
    $\Lambda_i.Power \leftarrow \rho(i)$          $\longrightarrow$ Equation (1)
    $\Lambda_i.MutedSub \leftarrow \mathcal{N}_{AB}$       $\longrightarrow$ Equation (14)
    $\Lambda.insert(i, \Lambda_i)$
end for
```

B. Algorithm for finding Λ *map*

Identification of VMUEs of Femto i can be determined from ζ, considering the conditions $\zeta_x^j \leq \phi$, $\zeta_x^i \neq \Upsilon$ and $\zeta_x^i \geq \psi$. Algorithm 1 constructs Λ map, which maps Femto i with appropriate transmission power level (*i.e.,* equivalent to VMUEs interference level) and ABSF requirement (*i.e.,* proportional to the number of VMUEs in the territory of Femto i). Femtos interfering with MUE x_j is represented as κ_{x_j}. Υ denotes no interference scenario between Femto and MUE. Λ_i indicates the value of optimal muting power during ABSF and pattern (*i.e.,* number of required ABSFs and their interval according to each Femto i). Γ is an intermediate map, which is used for getting actual Λ map. Γ_i contains a vector of ζ_x^i values according to each VMUE, which resides in the territory of Femto i. Apart from VMUEs detection and non-uniform muting discussed above, UEs prioritization during scheduling is done on the core principles of Proportional Fair Scheduling algorithm. Let p denote the total number of UEs available. At the beginning of each subframe τ, for each RB group r and for each UE, a priority metric gets calculated as follows:

$$\mathcal{PM}(\tau)_r = \underset{x=x_1,\dots x_p}{\arg\max} \frac{\mathcal{AR}_x(r,\tau)}{\mathcal{TT}_x(\tau)} \qquad (16)$$

$\mathcal{AR}_x(r,\tau)$ is the maximum achievable rate in subframe τ and $\mathcal{TT}_x(\tau)$ is the total data transmitted in previous subframes. UE x_i with highest $\mathcal{PM}(\tau)_r$ gets opportunity to get scheduled.

C. Algorithm for finding Ω *queue*

Algorithm 2 finds the Ω queue, which stores information about interfering Femtos and is used to perform non-uniform ABSF muting. $\Omega_i.subD$ represents the number of subframes for which Femto i needs to mute, $\Omega_i.timer$ is the number of ABSFs, and $\Omega_i.powL$ is the optimal transmission power level during ABSF. In Algorithm 2, a round robin Ω queue is used for Femto muting. Although, Algorithm 2 can be modified according to various other metrics like users priority and Femto muting constraints, in our algorithm, we chose a scenario where all users and Femtos have equal priority.

Algorithm 2 Algorithm for Formation of Ω

```
Inputs : $\Lambda$ , $\Omega$, and $i \in \mathcal{F}$
Output : $\Omega$

Use $\Lambda$ map to determine $\Omega$
for each $i \in \Lambda$ do
    if $i \notin \Omega$ then
        Create a tuple for a new $i$
        $\Omega_i.cellid \leftarrow \Lambda_i.cellid$
        $\Omega_i.subD \leftarrow \Lambda_i.MutedSub$
        $\Omega_i.timer \leftarrow \Lambda_i.MutedSub$
        $\Omega_i.powL \leftarrow \Lambda_i.Power$
        Insert $\Omega_i$ at the end of $\Omega$
    else
        Override the previous subframe demand for $i$
        $\Omega_i.subD \leftarrow \Lambda_i.MutedSub$
        $\Omega_i.timer \leftarrow \Lambda_i.MutedSub$
        Delete $\Omega_i$ from $\Omega$
        Insert $\Omega_i$ at the end of $\Omega$
    end if
end for
for each $i \in \Omega$ do
    if $i \notin \Lambda$ then
        Delete Tuple $\Omega_i \in \Omega$
    end if
end for
```

V. PERFORMANCE EVALUATION

We have compared RrMute with three other different schemes given in the previous section in NS-3 [8]. As discussed earlier, we simulate power level muting based on the degree of interference suffered by VMUEs and ensure fairness

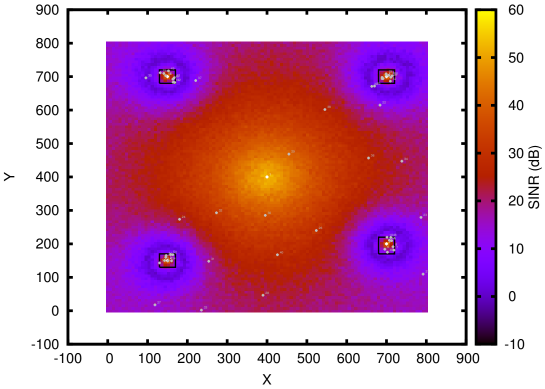

Figure 4: REM of simulation setup

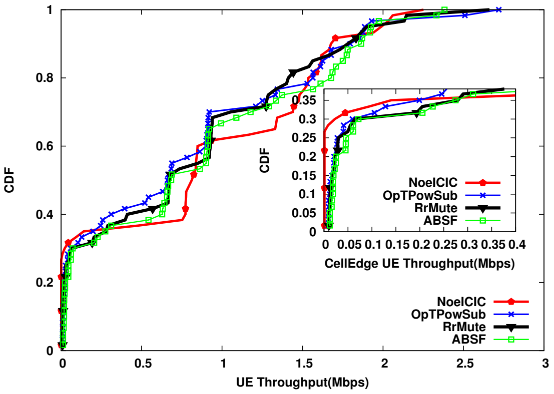

Figure 5: CDF plot for all UEs and inner CDF plot depicts throughput enhancement for VMUEs

Table II: NS-3.24 Simulation Parameters

Parameter	Value
Cell Bandwidth	10 MHz
Traffic	Downlink
Macro Transmission Power	46 dBm
Femto Transmission Power	23 dBm
Number of FUEs per Femto	5
Minimum Distance between Macro and Femto	300 m
Application	TCP BulkSendApplication

among VMUEs and non-VMUEs. Hence, we modified the proportional fair (PF) scheduler implemented in NS-3.

A. *Simulation results discussion for static scenario*

In this experiment, all UEs are static and 20 non-VMUEs are deployed in Macro coverage region. FUEs and VMUEs are also deployed inside the building (*i.e.,* each building is served by a Femto), and each Femto has five VMUEs deployed in its territory as shown in Fig. 4. OpTPowSub, RrMute, and ABSF significantly improve throughput of VMUEs, which can be seen in Fig. 5. ABSF achieves a maximum enhancement in VMUEs performance as no user data transmission taking place while muting. In the case of OpTPowSub and RrMute, data transfer at a Femto is still taking place during ABSF but with reduced transmission power, which gives RrMute less degradation in Femtos throughput while enhancing the Macro throughput. RrMute enhances throughput of 35% of UEs (inner CDF plot) while maintaining the fairness among all UEs.

B. *Simulation results discussion for mobile scenario*

In this experiment, MUEs are moving at speed of 0.25 m/s to 7 m/s uniformly across the Macro coverage region while FUEs are static *i.e.,* deployed inside Femtos coverage regions as shown in Fig. 4. Simulation results (refer Fig. 7) show that when compared to NoeICIC the Macro throughput enhancements with OpTPowSub, RrMute, and ABSF are 1.48%, 3.05%, and 3.37%, respectively. On the other hand (compared to NoeICIC), the average throughput degradation at Femtos (Fig. 6) in the case of OpTPowSub, RrMute, and ABSF are 6.58%, 7.01%, and 13.20%, respectively. Compared to ABSF, RrMute achieves an average of 6.19% throughput improvement which has less degradation in FUEs throughput and also enhances the performance of MUEs compared to NoeICIC and OpTPowSub (Fig. 7) by 3.05% and 1.57%, respectively. But OpTPowSub starts deteriorating as the number of interfering Femtos or VMUEs increases. RrMute is amenable to dense setup and it also provides more favourable opportunities for scheduling of VMUEs during ABSFs.

C. *Simulation results discussion for dense scenario*

In this scenario, all UEs are static (*i.e.,* MUEs and FUEs) and 60 non-VMUEs are deployed in Macro coverage region. FUEs and VMUEs are deployed inside the building (*i.e.,* each building is served by a Femto), and each Femto has five VMUEs present in its territory as given in Fig. 8. As shown in Fig. 10, OpTPowSub, RrMute, and ABSF significantly improve throughput of VMUEs while ABSF achieves the highest enhancement in VMUEs performance. The performance degradation for Femtos is minimized in OpTPowSub and RrMute (refer Fig. 11). Femto throughput degradation is minimized by 15.9% (in the case of OpTPowSub and RrMute) as compared to ABSF while enhancing the Macro throughput by 1.67 times and 2.5 times in case of OpTPowSub and RrMute, respectively. Femto throughput degradation in OpTPowSub is almost same as that in RrMute, whereas RrMute gives more improvement to MUEs as compared to OpTPowSub (refer Fig. 12). Fig. 9 shows that RrMute enhances throughput of cell-edge UEs (inner CDF plot) while maintaining fairness among all UEs in the HetNet system.

VI. CONCLUSIONS AND FUTURE WORK

In this work, we proposed RrMute for muting Femtos to reduce cross-tier interference to Macros in LTE HetNets. Simulation results show that RrMute enhances throughput of victim Macro UEs while minimizing the performance loss to Femtos due to ABSF. Future work includes further enhancing RrMute with software defined networking principles and offloading victim Macro UEs to nearby Femtos.

VII. ACKNOWLEDGMENT

This work was supported by the project ”Converged Cloud Communication Technologies”, Meity, Govt. of India.

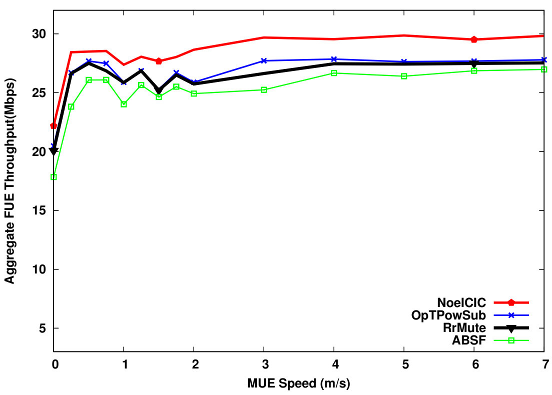

Figure 6: FUE Throughput.

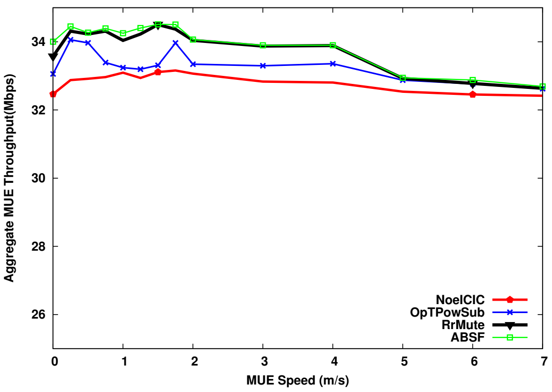

Figure 7: MUE Throughput.

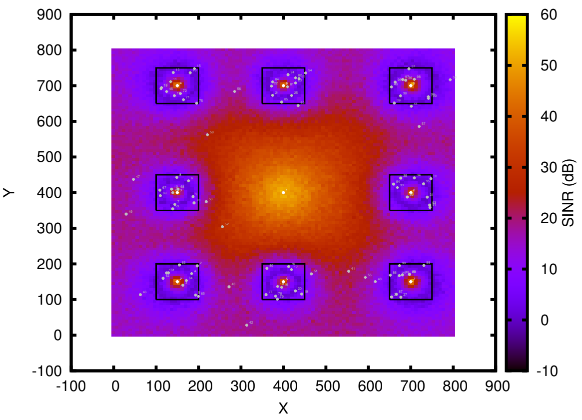

Figure 8: REM of dense Hetnet simulation setup.

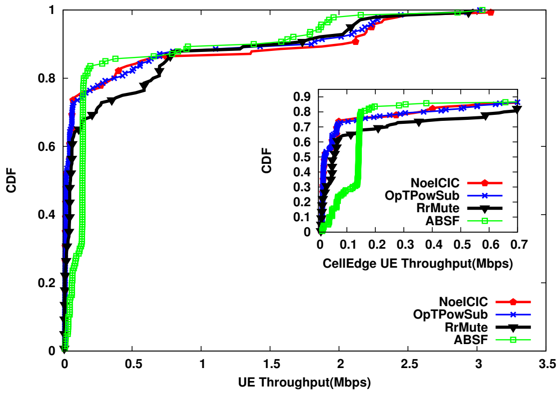

Figure 9: CDF of all UEs and inner CDF plot depicts throughput enhancement for VMUEs.

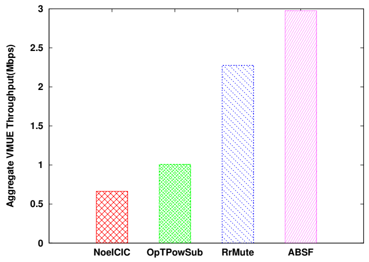

Figure 10: Aggregate VMUEs Throughput.

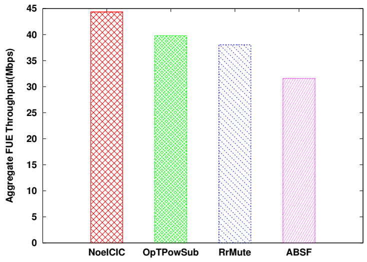

Figure 11: Aggregate FUE Throughput.

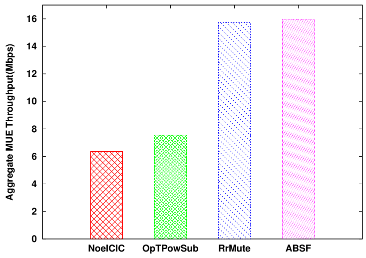

Figure 12: Aggregate MUE Throughput.

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