Enhanced Distributed Resource Allocation and Interference Management in LTE Femtocell Networks

Vanlin Sathya, Harsha Vardhan Gudivada, Hemanth Narayanam, Bala Murali Krishna and Bheemarjuna Reddy Tamma
Department of Computer Science and Engineering
Indian Institute of Technology Hyderabad, India
Email: [cs11p1003, cs09b011, cs09b024, bala, tbr]@iith.ac.in

***Abstract*—Femto cells have been integrated into 4G Long Term Evolution (LTE) cellular network architecture to efficiently address the coverage and capacity issues faced in indoors and at hotspots. Though spectral efficiency increases through *frequency reuse one* at Femtos, it could lead to co-tier interference and cause higher interference for cell edge User Equipments (UEs). This problem is more severe in enterprise and hotspot Femto deployments due to dense placement of Femtos. Existing co-tier interference management techniques do not solve this problem completely. Hence, in this paper, we propose a Variable Radius (VR) algorithm which dynamically increases or decreases the cell edge/non-cell edge region of Femtos and efficiently allocates the radio resources among cell edge/non-cell edge region of Femtos so that the co-tier interference between neighboring Femtos can be avoided. We implemented the proposed VR algorithm on top of Proportional Fair (PF) scheduling algorithm in NS-3 simulator. In our experiments, for 90 UEs the proposed technique (VR + PF) achieved 29% and 38% improvement in average throughput for static and mobile scenarios, respectively when compared to classic PF algorithm without any interference management.**

***Index Terms*—LTE; Femto Cells; Interference Management; Spectral efficiency**

I. Introduction

Due to popularity of smart phones and tablets, there is an exponential increase in the demand for higher data rates. To provide higher data rates, 3GPP proposed 4G Long Term Evolution (LTE) standard. As per traffic statistics given by Huawei and Nokia-Siemens [1], [2], 60% of the voice and video traffic in cellular networks come from indoor environments. The indoor users typically get low data rates because of poor cellular network coverage inside buildings. Into the LTE standard [3], Femto Base Stations (Home eNB/Enterprise eNB) are introduced to provide good coverage and high data rates for the indoor User Equipments (UEs). These Femtos are installed by end users who have broadband wire-line Internet connections. In enterprise Femto networks, a large number of Femtos are deployed in places such as office buildings and hotspot areas. These Femtos can serve 15 to 25 UEs and have coverage of 60 to 70 meters [4]. LTE system comprising of legacy macro BSs and Femto BSs is called as two-tier Heterogeneous Network (HetNet).

Different types of Femto access are defined namely open, closed and hybrid. In open access, all UEs of a given cellular (mobile) network operator are allowed to connect to Femto BS, but in closed access, only authorized UEs are allowed to connect. In hybrid access, both authorized UEs and a limited number of other UEs can connect in a prioritized manner. In case of enterprise networks and hotspots, Femtos are commonly configured for open access. Fig. 1 shows the architecture of LTE Femtocell network, where Femtos are connected to broadband network (Internet) and then eventually connected to Femto Gateway (F-GW) via S1 interface.

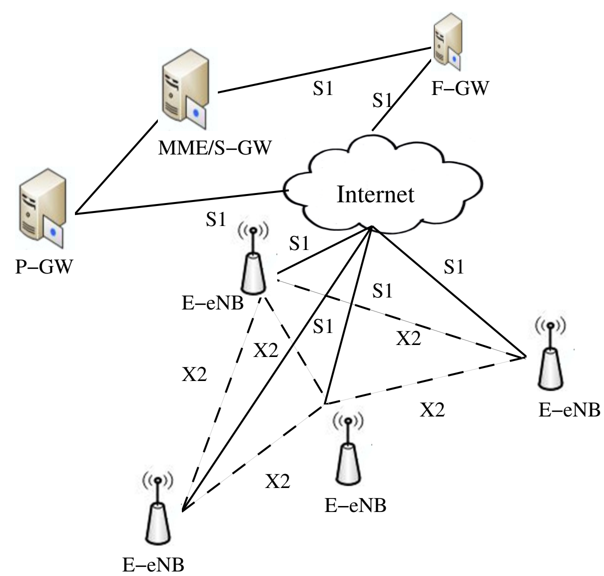

Fig. 1. Architecture of Enterprise LTE Femtocell Network

Interference results in packet loss and low data rates [5]. Two types of interference is possible between macro and Femto BSs of two-tier LTE HetNets namely cross-tier interference and co-tier interference [5]. Cross-tier interference occurs between macro and Femto BSs. It occurs especially when same bandwidth (RB) is allocated to the UEs of both macro and Femto BSs. Co-tier interference occurs when all Femto BSs (also true for macro BSs) share the same spectrum resources through *frequency reuse one*. Due to high UE density, enterprise Femto BSs experience high co-tier and cross-tier interference when compared to Femto BSs used in home environments. In [6], three cross-tier interference management schemes are proposed. First scheme divides spectrum between macros and Femtos, but as number of Femtos increases the spectrum allocated to macros decreases considerably. Second scheme allocates the whole spectrum to both macros and Femtos which can lead to high interference. In third scheme, some part of the spectrum is shared by Femtos and macros. The remaining spectrum is divided between macros and Femtos. But, this scheme is efficient only if UEs count is low.

In this paper, we propose a Variable Radius (VR) algorithm which dynamically increases or decreases the cell edge region of Femtos logically and efficiently allocates radio Resource Blocks (RBs) among cell edge/non-cell edge region of Femtos so that the co-tier interference between neighboring Femtos can be avoided in enterprise deployments. Rest of the paper is organized as follows: Section II describes the related work. Proposed VR algorithm is discussed in Section III. The simulation methodology and results are presented in Section IV. Finally, Section V contains concluding remarks.

II. Related Work

In this section, we review existing works addressing the interference issues due to incorporation of Femtos into LTE systems. In Release 8 [7], X2 interface avoids the interference at the cell edge of two neighboring macro BSs. In this case, eNBs share the information of RBs assigned to cell edge UEs.In Release 11 [7], X2 interface is introduced between Femtos of enterprise femtocell networks to avoid interference and directly route the data and signaling messages among Femtos, thereby reducing the load on Mobility Management Entity (MME) of LTE core network and offers better coordination among Femtos. Two types of interference is possible in two-tier cellular network i.e cross-tier and co-tier. Cross-tier interference can be avoided by dividing the spectrum between macro and Femto cells orthogonally [8], [9]. In their schemes resources are shared between Femtos in a distributed manner by using F-ALOHA scheme, which introduces slotting and contention amongst Femtos. But, in this scheme spectrum can not be reused unlike proposed VR algorithm.

Two types of frequency reuse techniques can be applied to reduce co-tier interference. Fractional Frequency Reuse (FFR) [10] has *frequency reuse three*, which means that only one third of the spectrum is used in a particular cell and therefore leads to inefficient usage of spectrum resource. The other approach is Soft Frequency Reuse (SFR) [11], [12]. In SFR, the cell area is divided logically into two regions based on spectrum allocation: an inner region where major portion of spectrum is available and a cell edge area where a small fraction of the spectrum is available. Since the Shannon capacity at cell edge may be very low, it can be increased by allocating higher power carriers to UEs in this region, where as lower power carriers are allocated to UEs in the inner region. But, SFR was studied only for macros. To improve the spectrum efficiency and throughput for the indoor UEs, SFR technique can also be adapted to enterprise Femto networks. But the drawback of implementing SFR in Femtos is that it can lead to high interference due to overlap of coverage regions of Femtos. Hence, we propose an efficient interference management technique (VR: Variable Radius algorithm) which dynamically increases or decreases the width of cell edge region inside the Femto coverage area to overcome the drawback of SFR for Femtos.

III. Proposed Work

In this work, we consider a two-tier HetNet comprising of macro and Femto BSs in a LTE system. Inside the enterprise buildings we assume that, a large number of Femtos are deployed and configured for open access. We rely on Position Reference Signal (PRS) [13] to get the positions of UEs inside the buildings without GPS. We also assume that the available spectrum is divided between macros and Femtos to avoid cross-tier interference. But, co-tier interference can exist among Femtos due to *reuse factor one* and overlap of coverage regions. To reduce this co-tier interference in enterprise Femto networks, two logical regions namely inner and outer region are assumed inside the Femto coverage area as shown in Fig. 2. The radius of inner region (and hence the width of outer region) changes dynamically. These regions are created logically due to changes in the power transmitted and the average CQI values, but only created virtually by the Femtos in the proposed VR algorithm.

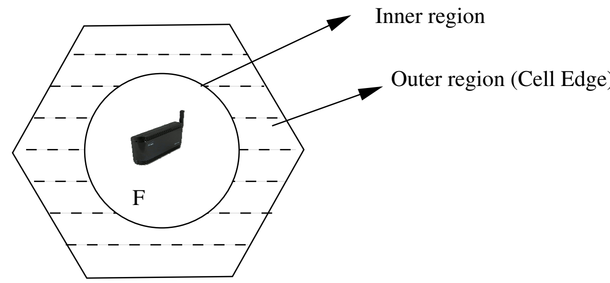

Fig. 2. Regions inside Femto coverage area

Every Femto communicates about the RBs allocated to its cell edge UEs with neighboring Femtos through X2 interface. Femto allocates RBs to its UEs in outer region such that same RBs are not allocated in the outer regions of its neighboring Femtos, thus avoiding the interference. Such an allocation is known as restricted RB allocation. But, since the delay to get the required number of RBs increases, the average throughput for cell edge UEs decrease. For the UEs of inner region, there is no such restriction on RB allocation, unlike cell edge users. Any free RB can be allocated to them.

Let us consider an enterprise Femto deployment scenario with six Femtos namely F1-F6 and randomly placed UEs as shown in Fig. 3 for describing the proposed VR algorithm. The two scenarios of it are given below.

Interference Scenario 1: Initially the width of outer region is zero. In this case, interference occurs if the cell edge UEs in overlapping regions of neighboring Femtos use the same RBs. This results in decrement of data rate and CQI due to poor signal-to-interference-to-noise ratio (SINR) value. According to 3GPP TS [36.301], the CQI values vary from 1 to 15. Active UEs provide CQI feedback to Femto at regular intervals. Femto transmits data with higher modulation scheme like 64-QAM if the UE has higher CQI value. In consummate circumstances caused by very high interference, CQI value becomes zero and the UE may not able to transmit any data.

To reduce this interference, the radius of the inner region is decreased which inturn increases the width of the outer region as shown in Fig. 3. To determine the average CQI of an UE at a distance d from the Femto center, firstly an inner and an outer circle are drawn with the radius as (d - δ) and (d + δ), respectively as shown in Fig. 4. The width of the resultant strip is 2δ (in our experiments, δ is taken as 0.5 m). Secondly, the average of the CQI of all UEs within this strip is calculated and this value is assigned to the UE at distance d. The average CQI is calculated and assigned similarly to every UE at any distance from the Femto within the radius of inner region. Thirdly, the average CQI of all UEs is sorted in increasing order. Fourthly, the first UE whose average CQI value is greater than a threshold CQI value is identified (in our experiments, the threshold CQI is set as 4). The distance of this identified UE from the Femto is the threshold distance and is named γ. Finally, bisection method is used to calculate the mean of the inner region radius r and the threshold distance γ as r = (r + γ)/2.

This mean value (r) is the radius of the inner region. By using X2 interface the interference is avoided in the outer region by exchanging signaling messages between neighboring Femtos for restricted RB allocation. Bisection method is used in general to find the roots of a polynomial. Here Bisection method is used to find the approximate radius value for which the average CQI value at the given radius is equivalent to threshold value.

Using mean value helps us to decrease the effective inner radius from R (cell radius) to r. The advantage of calculating the mean over considering the threshold distance γ, as radius, is that when the threshold distance is very small, a large number of UEs reside in outer region which may lead to unfair allocation of RBs to the cell edge UEs, as very less amount of RBs are catered to cell edge UEs, due to restricted allocation. The threshold CQI value for contraction is the CQI used for indoor data traffic handover i.e., less than -3 dB in terms of SINR. [14] gives the mapping of SINR to CQI.

Interference Scenario 2: When the number of UEs in the outer region increases drastically, due to restricted RB allocation, many RB requests from UEs of the outer region may not get satisfied. This leads to dramatic decrease in the system throughput. In order to overcome this problem, the inner region has to be expanded to accommodate the excess UEs of the outer region as shown in Fig. 5.

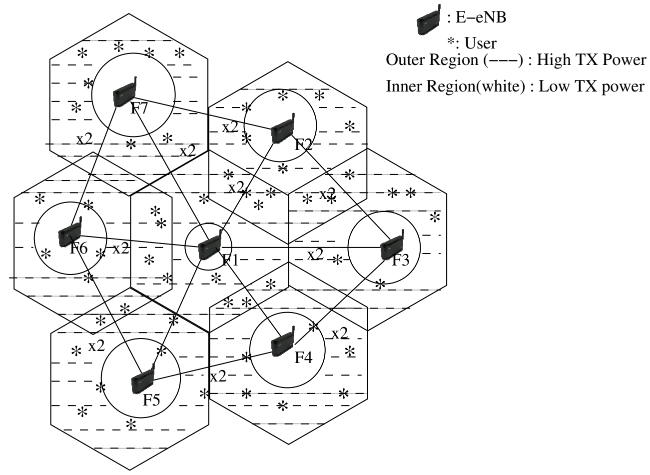

Fig. 3. Reducing the inner regions of Femtos

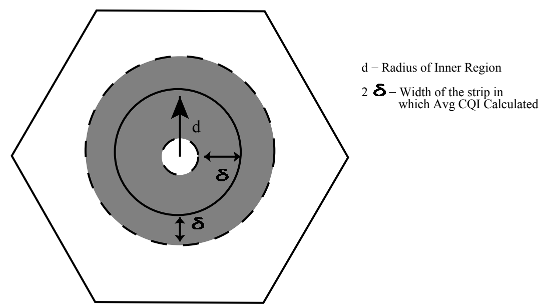

Fig. 4. Calculating Avg CQI value in the strip

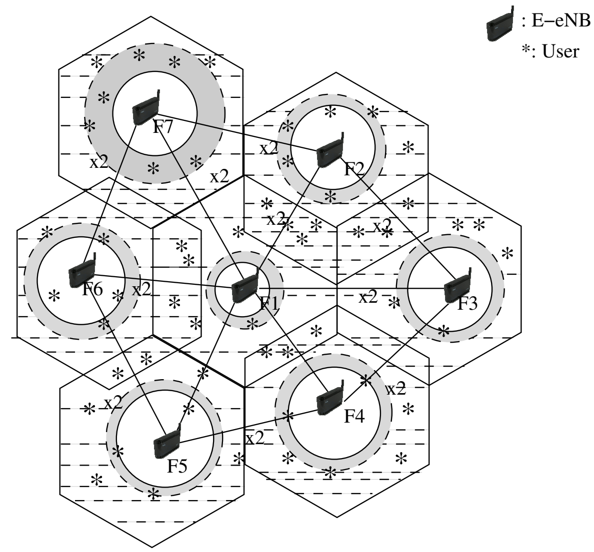

Fig. 5. Increasing the Inner regions of Femtos

Depending upon the fail ratio (FR) the radius increases, where FR is defined as, $FR = \frac{RejectedRequests(RR)}{AcceptedRequests(AR)}$, where RR is the number of unsatisfied requests coming from outer region due to restricted RB allocation and AR is the number of requests coming from outer region that can be satisfied in some subframe. Due to unavailability of RBs certain requests cannot be satisfied in a particular subframe and these requests are excluded in AR. The radius of inner region will remain the same if FR is less than or equal to the threshold value and this value can be set by the network operator. If FR is greater than threshold value, the radius of inner region is increased. The radius is incremented by δ' such that $RR-(AR/2)$ unsatisfied UEs from outer region are brought into the inner region. Thus, the excess UEs of outer region are brought into the inner region and the FR reduces below $FR\_Threshold$. Hence, the UE load in the outer region reduces and the throughput increases. The proposed VR algorithm (refer Algorithm 1) will therefore reduces the interference efficiently in a large scale deployment of Femto networks.

Algorithm 1 Variable Radius Algorithm

Input $CQI\_Threshold$: *Handover CQI threshold*
Input $FR\_Threshold$: *Threshold Fail Ratio*
Input R : *Radius of Femto*

$r \leftarrow R$ {Initialize Radius of Inner Region}
while $true$ **do**
  $CQI \leftarrow CalculateCQIInnerRegion()$; {Calculates average CQI for a given inner region }
  if (CQI $<$ $CQI\_Threshold$) **then**
    DecreaseRadius $\leftarrow$ **true**;
  else
    DecreaseRadius $\leftarrow$ **false**;
  end if
  FR $\leftarrow CalculateFRUEsOuterRegion()$; {Calculates Fail Ratio of UEs in cell edge region }
  if (FR $>$ $FR\_Threshold$) **then**
    IncreaseRadius $\leftarrow$ **true**;
  else
    IncreaseRadius $\leftarrow$ **false**;
  end if
  if ((IncreaseRadius) && (DecreaseRadius)) || ((!IncreaseRadius) && (!DecreaseRadius)) **then**
    Continue;
  else
    if (DecreaseRadius && !IncreaseRadius) **then**
      $CQI\ array \leftarrow Sort(CQI$ inner region)
      $\gamma \leftarrow Search(CQI\ array)$ {finds threshold distance γ of the first UE whose AVG CQI along circumference of circle with radius $d > CQI\_Threshold$ }
      $r \leftarrow (r + \gamma)/2$; { (where δ is the width of the region containing users whose AVG CQI $< CQI\_Threshold$)}
      $PFScheduling()$; {Proportional Fair Algorithm}
    else
      $r \leftarrow r + \delta'$; { (where δ' will bring RR-(AR/2) unsatisfied users of outer region nearest to the boundary between inner and outer regions into inner region)}
      $PFScheduling()$;
    end if
  end if
end while
end

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Number of Femto cells	6
Number of UEs per Femto	10, 15
UE Deployment	Random
Femto coverage range	70 m
Femto BandWidth	5 MHz (25 RBs)
Duplexing Mode	FDD
Scheduling Algorithm	PF, VR+PF
Simulated Traffic	Downlink (Video)
Mobility of Mobile UEs	1m/s
Mobility of Static UEs	0.1m/s
Mobility Model	Building Mobility Model
Application Data Rate	4 Mbps
Frame Duration	10 ms
TTI	1 ms

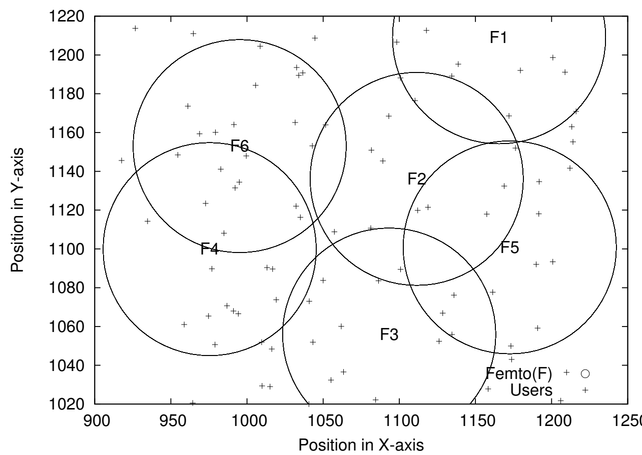

Fig. 6. Positions of six Femtos with 90 UEs

IV. SIMULATION METHODOLOGY AND RESULTS

In NS-3 simulator six apartment buildings scenario is created and in each apartment one Femto is placed randomly. Simulation parameters are given in the Table 1. The VR algorithm is implemented in NS-3 on top of the Proportional Fair (PF) scheduling algorithm to ensure fairness to all the UEs. We modified the building mobility model in NS-3 to introduce limited mobility for indoor UEs. We restrict the users from entering into the other room, as we are not dealing with handovers in this work. In real life, even static users will have some mobility. In order to replicate the same scenario in the simulator, we assigned the mobility rate as 0.1 m/s even for the static users. Each UE has single downlink flow from its connected Femto. The $CQI\_Threshold$ is the CQI value used for indoor data traffic handover. It varies between 4 and 6 and it is less than -3db in terms of SINR. The $FR\_Threshold$ is set as 0.5. The metrics used for performance evaluation are area spectrum efficiency in b/s/hz/m*m and throughput in Mbps. The results shown in this work are the averaged values after running simulations for 10 different seed values. Fig. 6 shows the positions of 90 indoor UEs (6 Femtos and 15 UEs in each Femto).

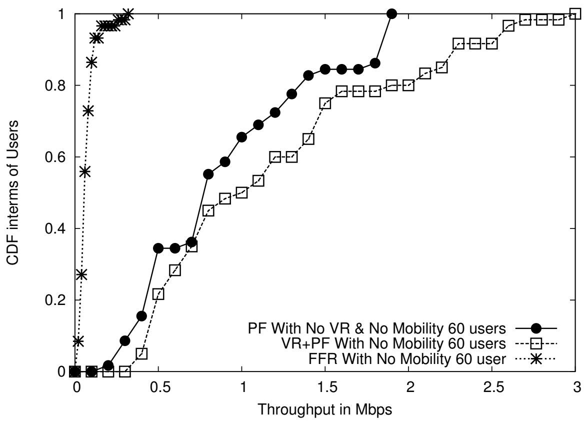

Fig. 7. Throughput for 60 static UEs inside the building

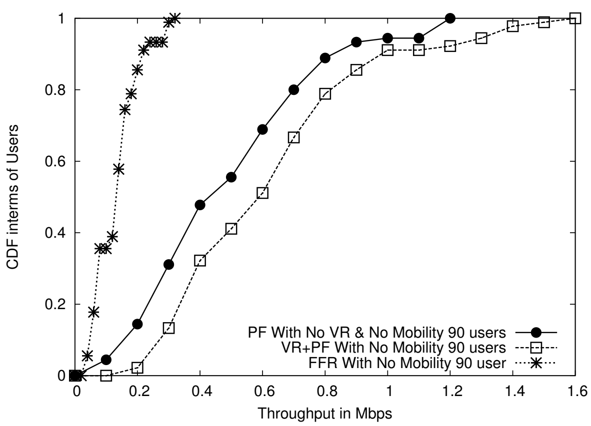

Fig. 8. Throughput of 90 static UEs inside the building

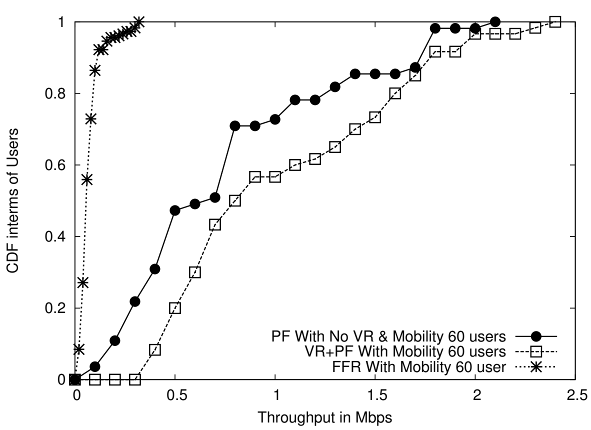

Fig. 9. Throughput of 60 mobile UEs inside the building

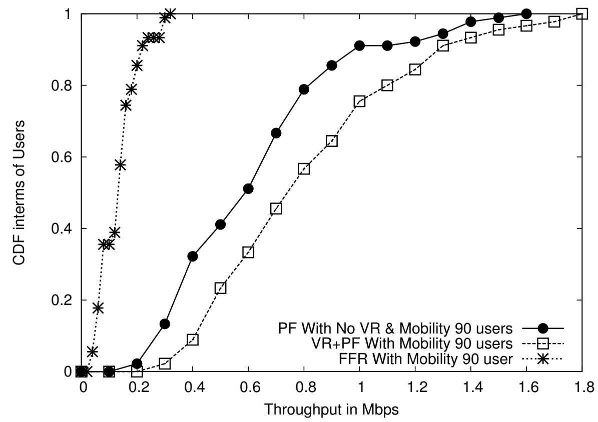

Fig. 10. Throughput of 90 mobile UEs inside the building

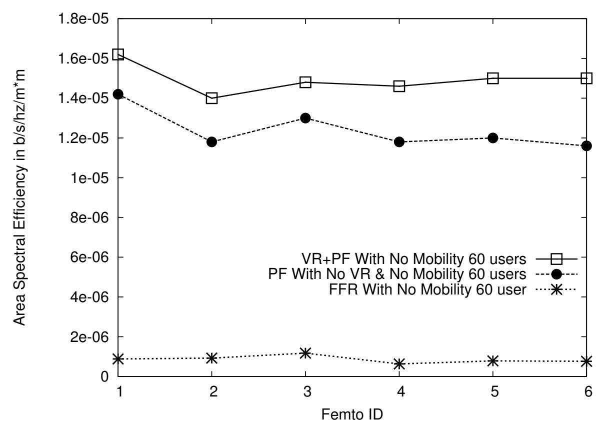

Fig. 11. Area Spectrum Efficiency of Femtos with 60 static UEs

1. Throughput Results: In Figs. 7 and 8, average throughput of VR+PF algorithm is compared against classic PF scheduling and FFR for 60 and 90 static UEs (i.e., one flow per UE), respectively. Average throughput for 60 static UEs is increased by 27% when VR algorithm is employed in PF. For 90 static indoor UEs, the average throughput is increased by 29% when VR algorithm is employed in PF. In Figs. 9 and 10, achieved throughput of VR+PF algorithm is compared against PF and FFR for 60 and 90 mobile UEs, respectively. Average throughput for 60 mobile UEs is increased by 37% when VR+PF algorithm is used. For 90 UEs the average throughput is increased by 38% when VR+PF algorithm is used. Since the inner region radius changes dynamically more number of UEs can be served by the inner region and thus it increases the average throughput. Bisection method makes sure that UEs who are supposed to be in the outer region will come inside the inner region, even though they have interference with neighboring Femtos. It is observed that proposed VR algorithm also performs better in mobile scenarios because UEs mobility there is enough potential for interference management and load balancing in outer regions and the average CQI values of UEs with high mobility vary at much faster rate when compared to UEs with low mobility.

2. Area Spectrum Efficiency Results: In Figs. 11 and 12, area spectral efficiency of VR+PF, PF and FFR are compared for 60 and 90 static UEs, respectively. In Figs. 13 and 14, area spectral efficiency of VR+PF and PF are compared for

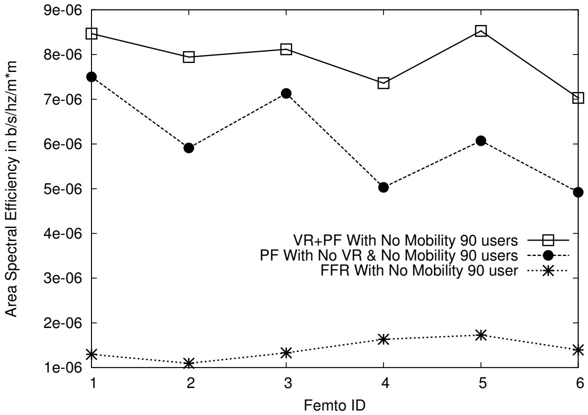

Fig. 12. Area Spectrum Efficiency of Femtos with 90 static UEs

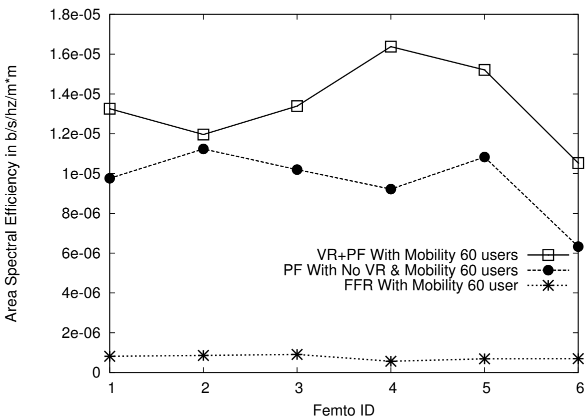

Fig. 13. Area Spectrum Efficiency of Femtos with 60 mobile UEs

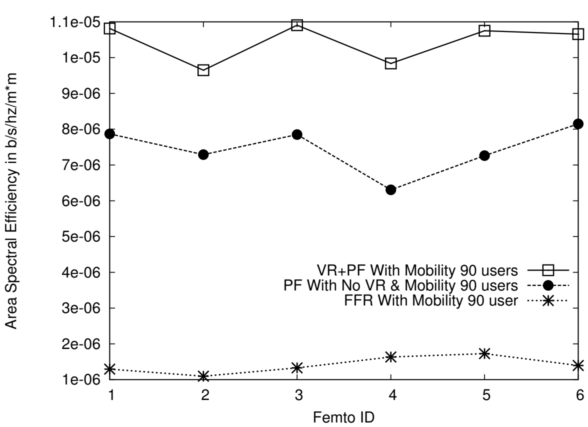

Fig. 14. Area Spectrum Efficiency of Femtos with 90 mobile UEs

60 and 90 mobile UEs, respectively. In order to be more precise, area spectral efficiency of each of six Femto is plotted separately in the graphs. Area spectral efficiency of Femtos has increased considerably as the interference is avoided in the outer overlapping regions of Femtos by restricted RB allocation with the help of communication over X2 interface.

V. Conclusions and Future work

The proposed VR algorithm dynamically increases or decreases the radius of inner regions to avoid co-tier interference among Femto BSs. All Femtos need not increase/decrease their inner region radius by same amount at the same time as VR algorithm depends on the user count and overlap with neighboring Femtos. In VR, using FR the radius of inner region is increased. We intend to determine the optimal value of FR in our future work. We also have to define a function to vary δ based on UE density. Also, the proposed VR needs to be modified to include the cases of handovers between Femtos.

Acknowledgment

This work was supported by the Deity, Govt of India (Grant No. 13(6)/2010CC&BT).

References

[1] S. Nielsen, "Lte evolving towards local area in release 12 and beyond." Future Radio in 3GPP, Nokia Corporation, 2012.

[2] "Views on rel-12 and onwards for lte and umts." Future Radio in 3GPP, Huawei Technologies, 2012.

[3] "Small Cells Forum." http://smallcellforum.org/smallcellforum.

[4] "Enterprise multi-femtocell deployment guidelines." Qualcomm Inc., 2011.

[5] N. Saquib, E. Hossain, L. B. Le, and D. I. Kim, "Interference management in ofdma femtocell networks: Issues and approaches," *IEEE Wireless Communications*, vol. 19, no. 3, pp. 86–95, 2012.

[6] M. Andrews, V. Capdevielle, A. Feki, and P. Gupta, "Autonomous spectrum sharing for mixed lte femto and macro cells deployments," in *IEEE INFOCOM Conference on Computer Communications Workshops, 2010*, pp. 1–5, 2010.

[7] "3GPP Releases." http://www.3gpp.org/releases.

[8] V. Chandrasekhar and J. Andrews, "Spectrum allocation in tiered cellular networks," *IEEE Transactions on Communications*, vol. 57, no. 10, pp. 3059–3068, 2009.

[9] J. Yoon, M. Y. Arslan, K. Sundaresan, S. V. Krishnamurthy, and S. Banerjee, "A distributed resource management framework for interference mitigation in ofdma femtocell networks," in *ACM MOBIHOC 2012*, pp. 233–242, 2012.

[10] P. Lee, T. Lee, J. Jeong, and J. Shin, "Interference management in lte femtocell systems using fractional frequency reuse," in *The 12th International Conference on Advanced Communication Technology (ICACT 2010)*, vol. 2, pp. 1047–1051, IEEE, 2010.

[11] Y. Yu, E. Dutkiewicz, X. Huang, M. Mueck, and G. Fang, "Performance analysis of soft frequency reuse for inter-cell interference coordination in lte networks," in *International Symposium on Communications and Information Technologies (ISCIT 2010)*, pp. 504–509, 2010.

[12] M. Al-Shalash, F. Khafizov, and Z. Chao, "Interference constrained soft frequency reuse for uplink icic in lte networks," in *IEEE PIMRC 2010*, pp. 1882–1887, 2010.

[13] J. A. del Peral-Rosado, J. A. López-Salcedo, G. Seco-Granados, F. Zanier, and M. Crisci, "Joint channel and time delay estimation for lte positioning reference signals," in *6th ESA Workshop on NAVITEC 2012*, pp. 1–8, 2012.

[14] M. T. Kawser, N. I. B. Hamid, M. N. Hasan, M. S. Alam, and M. M. Rahman, "Downlink snr to cqi mapping for different multiple antenna techniques in lte," in *International Conference on Future Information Technology (ICFIT 2010)*, 2010.