Analysing Energy Efficiency of Cell Selection Schemes for Femtocell Networks with Limited Backhaul Capacity

Deepali Gaur[1], Ajay Kumar Singh[2]

Meerut Institute of Engineering and Technology
Jattiwara, Meerut, Uttar Pradesh, India 250003

Abstract — *Demands of mobile data is ever increasing. To handle these demands operators have to deploy additional base stations such as microcell, picocells and femtocells. Deployment of these low power base stations not only improves network capacity but also improves energy efficiency in a cost effective manner. When multiple base stations are available in the vicinity, mobile users have to associate themselves to one of these base stations. This process of association is commonly known as cell selection scheme. Based on the association, users are assigned transmit power and bandwidth from target base stations. Additionally, the sum traffic passes through the backhaul connecting base station and core network depends upon the users associated with that base station. In this paper, we study the energy efficiency aspect of cell selection schemes for femtocell networks. We also look into the limited femtocell backhaul capacity constraint when user association is done. Obtained results are verified using extensive simulations.*

Keywords — *Femtocell, cell selection schemes, energy efficiency, performance evaluation, backhaul capacity.*

I. Introduction

With increased penetration of smart phones and tablets, users now expect 24x7 connectivity to the Internet. With time mobile devices are getting cheaper and hence the demands for wireless data is further expected to increase. Study shows that cellular data demands are expected to increase 20 fold by the end of year 2022 [1]. To handle these demands, cellular operators are deploying additional base stations such as microcell, picocell, femtocells, and relays to efficiently reusing available wireless spectrum. Interestingly, nearly 80% of mobile data demands are originating from indoor users [2]. Also, these indoor users experience the worst signal quality due to high wall penetration loss.

To overcome this indoor data demand problem, cellular operators are deploying small, low cost, low power femtocell base stations. Femtocell are miniature cellular base stations deployed inside users homes and offices to provide improved coverage and bitrate. Femtocell can remain connected to cellular core network using a wired or wireless backhaul. Femtocell have proved to improve network capacity and coverage by eliminating wall loss and spatial reuse of available spectrum [3].

Inherent low transmission capabilities of femtocell when combined with high path loss limit the users association in femtocell. To reap the gains of femtocell deployment, more users should be offloaded to femtocells. Regarding this, various cell selection schemes have been suggested in the literature. Most basic techniques based on Reference Signal Received Power (RSRP) based association where users get associated with base stations having highest received signal power [4]. However, such techniques may not be optimal in terms of users' Quality of Service (QoS). Another interesting approach is the use of cell biasing for cell selection [5]. Cell biasing gives more priority to femtocell for user association than macrocell. This helps improving user count in femtocell by offloading users from expensive macrocells. Considering users' perspective, expected bitrate based association is suggested in [6][7]. These techniques try to associated users to base stations based on the expected bitrate they might receive. Expected bitrate based association performs better then RSRP and bias based schemes because it incorporates scheduling opportunities at base stations.

To best of our knowledge, a comprehensive analysis of energy efficiency aspect of cell selection schemes with backhaul constraint not done in the literature. In this paper, we analyse various cell selection techniques available for femtocell networks. We explain each of them in details with corresponding advantage and limitations. Additionally, we also look at the energy efficiency aspect of these cell selection schemes which was ignored in all previous works. All cell selection schemes are analysed considering the fact that femtocell are connected to cellular core network using a backhaul of limited capacity. Once this capacity is reached for a femtocell, no new mobile user is allowed to associate with that femtocell.

Rest of the papers is organizes as follows. In section II, we get an overview of femtocell architecture. Section III discusses various cell selection schemes for femtocell based cellular network, along with their advantages and limitations. Section IV explains the energy consumption model of two tier macrocell-femtocell network along with backhaul energy consumption analysis. Section V discusses performance of various cell selection schemes in terms of network capacity and energy efficiency. Finally, we conclude our work in section VI with direction for future research.

II. Introduction to Femtocell Network

Femtocell or Femto Access Points (FAPs) are small, low power base stations deployed inside users' homes/offices to provide improved coverage and bitrate. Femtocell maintains connectivity with cellular core network via wired broadband/ADSL line. In this way, no additional infrastructure such as wired backhaul is required as femtocell can use existing telephone/Internet line for communication. The inherent low transmit power capability of femtocell allow efficient spatial reuse of available wireless spectrum and improve overall spectrum efficiency. Figure 1 represents the basic architecture of femtocell network.

Femtocell differs from other small cell base stations (Microcell and picocell) as they are not deployed by operators to maintain specification requirements. These devices are sold as a secondary infrastructure to users who wish to have better bitrate and coverage inside their home at the cost of few extra dollars in monthly rental. Additionally, unlike other small cells, femtocell allows only registered users to get associated with itself. Hence, the user who paid for the device and monthly rental will get benefits of its deployment. Lastly, since femtocell are user owned devices, they can placed anywhere and even can be turned off when required. The biggest advantage of using femtocell over WiFi is their capability to self-organize. Femtocell are able to perform necessary synchronization/handover efficiently, hence able to circumvent intra and cross-tier interference. Recent research in the field of femtocell focuses on self-organization and strategic placements in enterprise scenario. Additionally, quite an attention is given on energy efficiency of femtocell.

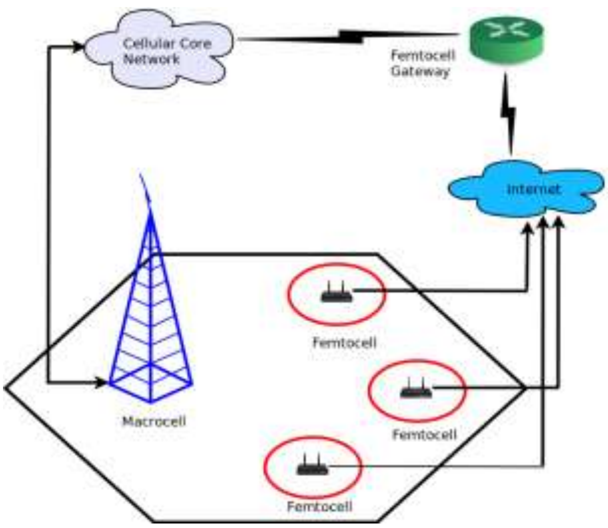

Fig. 1 Femtocell Architecture

III. Cell Selection Schemes

In this section, we analyse various cell selection schemes available in the literature. Additionally, we also discuss the advantages and limitation of each of them.

A. Max RSRP

This scheme considers Reference Signal Received Power (RSRP) based association for User Equipments (UEs). At the time of cell selection, UEs get associated with the base station (BS) providing highest RSRP [7]. So, the i^{th} UE will select the k^{th} BS as its serving BS if,

$$CellID_i = arg_k \max(RSRP_k)$$

All UEs within the inner white region in Figure 2 are associated with the FAP, while those outside it are associated with Macrocell. The advantage of this scheme is that UEs always get associated with BS providing highest SINR. However, disadvantage is that it might not provide UE with highest received bitrate. Additionally, low transmit power and high wall loss limits the user association in femtocell. Out of all four techniques, Max RSRP results in lowest UE association count in femtocells.

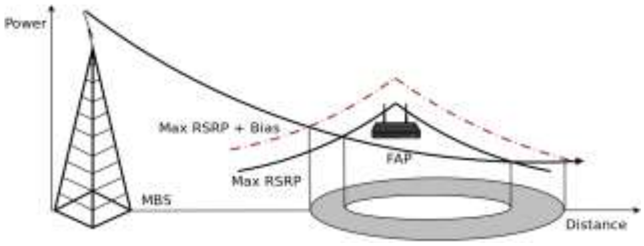

Fig. 2 Cell Biasing

B. Max RSRP + Bias

In order to increase user association in femtocell, concept of cell biasing has been suggested. Cell biasing modifies cell selection/handover criteria in order to improve user association in femtocell by actively pushing UEs in them [5]. With cell biasing, a Range Expansion Bias (REB) of λ dB is added to RSRP from FAPs before selection of serving BS. Then,

$$CellID_i = arg_k \max(RSRP_k + \lambda)$$

where λ is taken as 0 for MBS and some positive value for FAPs. This causes UEs to frequently select FAP as their serving BS. However, the newly offloaded UEs, present in the grey shaded region shown in Figure 2, are subjected to high interference from MBS. To protect their channel link quality, a fraction of bandwidth, alpha, (say α, $0 \leq \alpha \leq 1$) is reserved for these offloaded femtocell users while remaining bandwidth $(1 - \alpha)$ can be shared by both macro and femto UEs. Advantage of this technique is that if offloads more UEs to femtocell even when they might receive high SINR from macrocell. Newly offloaded UEs, however, get benefited by additional bandwidth at femtocells. This technique proved to show improvement in system capacity compared to Max RSRP based cell selection scheme.

C. Max Expected Bitrate (E[B])

It has been previously suggested that, instead of considering biasing value, if scheduling opportunities to UEs are considered for cell selection, improved throughput performance is obtained. Authors in [6] proposed that UEs should select a BS which provides highest expected bitrate, E [B]. The expected bitrate for UE i, if connected to MBS is,

$$E\left[B_{i,m}\right] = (1-\alpha)\log_2\left(1+\Gamma_{IL}^{i,m}\right)$$

and if connected to FAP(k) is,

$$E\left[B_{i,k}\right] = (1-\alpha)\log_2\left(1+\Gamma_{IL}^{i,k}\right)+\alpha\log_2\left(1+\Gamma_{IF}^{i,k}\right)$$

Let {BS} represent the set of all base stations (MBS+FAPs). UE i will select BS j as its serving BS if,

$$CellID_i = arg_j\, max\left\{E\left[B_{i,j}\right];\ j\in\{BS\}\right\}$$

This technique shows further improvement in system capacity compared to Max RSRP + Bias based association. This technique performs optimal because it makes sure that UEs get associated with BS with highest expected received bitrate. However, calculating expected received bitrate considering total bandwidth at target BS is wrong. This might lead to suboptimal user association because received bitrate depends upon allocated bandwidth to UE rather than total bandwidth at target BS.

IV. ENERGY CONSUMPTION MODEL

In this section we present the energy consumption model of MBS and FAPs. Additionally, we also look into the energy consumption associated with backhaul connecting FAPs to cellular core network.

1) MBS Energy Consumption: Compared to a FAP, MBS serves a higher number of UEs over a larger distance. Due to this, its energy consumption is assumed to be load dependent with some fixed zero-load energy loss. The total energy consumption of MBS *b* can be calculated as [8],

$$E_b = E_b^0 + N_{sector} * (\Phi\Phi_m / \rho_{PA}) + CL_b$$

where E_b^0 represents the zero load energy consumption of MBS accounting for battery backup and power supply. N_{sector}, Φ, and ρ_{PA} represent number of sectors, power amplifier efficiency and signal processing overhead, respectively. Here T_m is total input power to transmitting antenna obtained by summing up transmit power of all the subchannels in use. CL_b represents the cooling loss.

2) FAP Energy Consumption: FAP serves quite lesser number of UEs (up to 8 users) within a limited coverage radius (15 meters). Due to this, their energy consumption does not vary significantly with user load. In most cases, their energy consumption is assumed to be independent of user count in them and hence taken to be constant [9]. In this work, we assume that each FAP consumes 10 Watt power when active and serving UEs in its vicinity.

3) Backhaul Energy Consumption: In our system model, we consider that each FAP is connected to core network with a dedicated wired backhaul. Each backhaul has a limited capacity and energy consumption in a backhaul depends upon the amount of data traffic passes through it. Let BH_b^0 be the idle mode energy consumption of backhaul connecting femtocell *b* to the core network. Then, the energy consumption of backhaul can be represented as [10],

$$BK(b) = BH_b^0 + f(\Omega_b)$$

where Ω_b represents the total downlink throughput that passes through the backhaul connecting femtocell *b*. Function f(.) is the step function which maps the downlink throughput to its equivalent energy consumption.

4) Energy Efficiency: To compare energy efficiency performance of different cell selection schemes, we take Energy Consumption Rating (ECR) as performance metric [11]. ECR is the ratio of total energy consumed to total system capacity. ECR can be calculated as,

$$ECR(watts/Mbps) = \frac{Energy\ Consumption}{System\ Capacity}$$

Hence, lower the ECR, more energy efficient the system will be.

V. SIMULATION RESULTS

Our simulation scenario assumes a single MBS deployed along with low power FAPs. Both UEs and FAPs are distributed uniformly in the simulation region. We run the simulation considering full buffer traffic model i.e., UEs always have some data to send. FAPs are assumed to be in Always-ON state unless there are no UEs under its coverage. Snapshots are taken at discrete time intervals. All values are obtained for 95% confidence interval averaged over 60 iterations. The simulation parameters are given in Table I.

Parameter	Value
Bandwidth	10 MHz
No. of Subchannels	256
MBS Transmit Power	43 dBm
FAP Transmit Power	23 dBm
UE Transmit Power	23 dBm
UE Density	100/sq.km
FAP Density	10/sq. km
REB	{2-8} dB
Idle Mode Backhaul Energy	5 watt
Path Loss Coefficient	MBS : 2.5
	FAP: 3.5

TABLE I : SIMULATION PARAMETERS

Figure 3 represents the Cumulative Distribution Function (CDF) of macro UEs for REB = 8 and alpha = 0.4. As can be seen for all cell selection schemes CDF SINR follow the same trend. Here, Max RSRP results in best SINR for macro UEs as more UEs get offloaded to FAPs after biasing. Figure 4 shows the CDF SINR of femto UEs for REB = 8 and alpha =0.4. The best SINR is observed for RSRP based association. This is due the fact that RSRP assigns UEs to base stations based on the received signal strength.

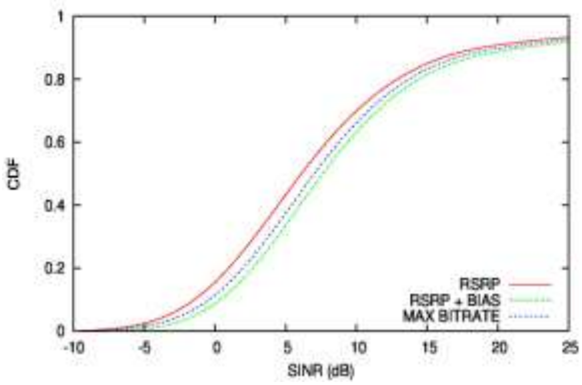

Fig. 3 : CDF SINR of Macro UEs

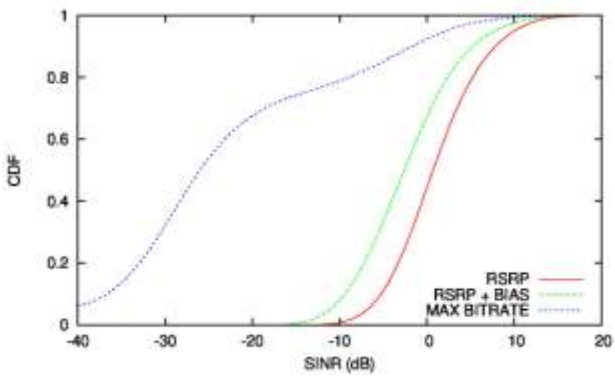

Fig. 4 : CDF SINR of Femto UEs

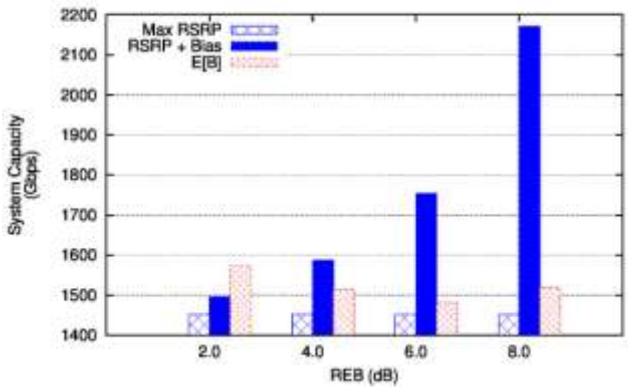

Fig. 5 : System Capacity vs. REB

Figure 5 and 6 represent the system capacity and ECR of different cell selection schemes for varying bias value, respectively. As bias increases, more and more UEs get offloaded to FAPs thereby receiving higher bandwidth from target FAPs. As can be seen in Figure 5 that system capacity for RSRP+Bias increases with increase in REB value. However, capacity of other two schemes remains unaffected as their association criteria do not considers the biasing parameter. Due to this increase in system capacity, the energy efficiency of the system also improves. As can be seen in Figure 6 that ECR keeps decreasing with increase in REB value.

Figure 7 represents the system capacity for different cell selection schemes for varying alpha value. Both Max RSRP and bias based association remain unaffected by varying alpha value. However, we see an improvement in system capacity for E[B] scheme with increase in alpha value. This is due to the fact that will increase in alpha, FAPs are assigned more bandwidth. This results in higher UE association for E[B] scheme, thereby increasing overall system capacity. This increase in system capacity also results in decrease in ECR which can be seen in Figure 8.

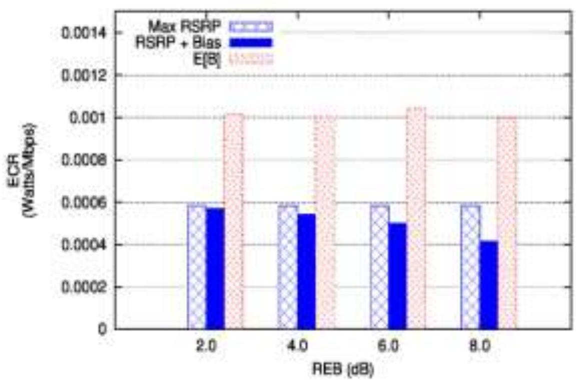

Fig. 6 : ECR vs. REB

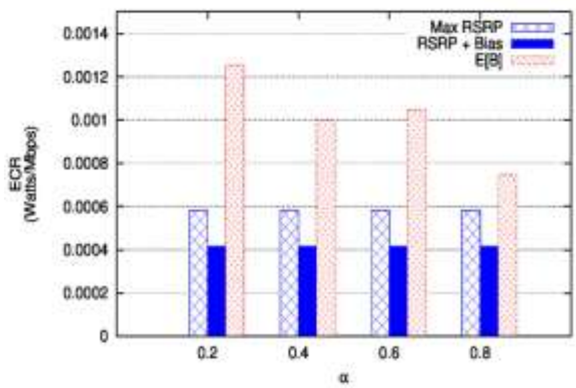

Fig. 8 : ECR vs. Alpha

VI. CONCLUSION

Energy consumption and resource utilization in femtocell is greatly affected by the criteria on which mobile users get associated with femtocell base stations. RSRP and bias based association are most simple approach but they fail to consider system load and resource availability at target base station. Expected bitrate based association proves better that other two schemes as it considers the end user bitrate for performing cell selection. Additionally, finite backhaul capacity also limits the users association in femtocells, even when they have enough wireless resources to support more users. In our future work, we will focus on developing a cell selection scheme which considers the backhaul capacity and energy efficiency into cell selection criteria.

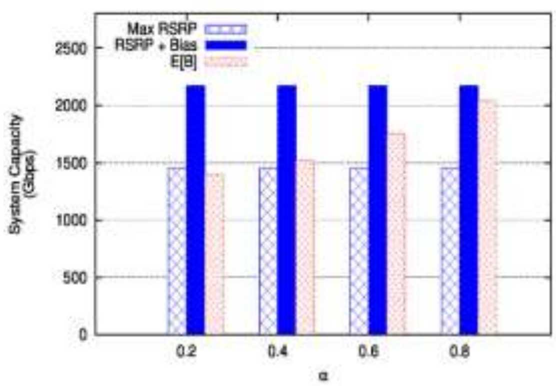

Fig. 7 : System Capacity vs. Alpha

REFERENCES

[1] "LTE heterogeneous networks," White Paper, Qualcomm, August 2012[Online].Available:http://www.qualcomm.com/media/documents/ qualcommresearch-lte-heterogeneous-networks.

[2] V. Chandrasekhar, J. Andrews, and A. Gatherer, "Femtocell networks: A survey," IEEE Communications Magazine, vol. 46,no. 9, pp. 59–67, September 2008.

[3] Andrews, J.G.; Claussen, H.; Dohler, M.; Rangan, S.; Reed, M.C., "Femtocells: Past, Present, and Future," Selected Areas in Communications, IEEE Journal on , vol.30, no.3, pp.497,508, April 2012.

[4] A. Bou Saleh, O. Bulakci, S. Redana, B. Raaf, and J. Hamalainen, "Enhancing LTE-Advanced relay deployments via Biasing in cell selection and handover decision," in Proceedings of the IEEE International Symposium on Personal Indoor and Mobile Radio Communications, September 2010, pp. 2277–2281.

[5] Thakur, R.; Sengupta, A.; Siva Ram Murthy, C., "Improving capacity and energy efficiency of femtocell based cellular network through cell biasing," 11th International Symposium on Modeling & Optimization in Mobile, Ad Hoc & Wireless Networks (WiOpt)pp.436,443, 13-17 May 2013

[6] J. Oh and Y. Han, "Cell selection for range expansion with almost blank subframe in heterogeneous networks," in Proceedings of the IEEE 23rd International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), Sept 2012,pp. 653–657.

[7] R. Thakur, S. Mishra, and C. R. Murthy, "A load-conscious cell selection scheme for femto-assisted cellular networks," in Proceedings of the IEEE 24th International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), Sept 2013,pp. 2378–2382.

[8] Huq, K.M.S.; Mumtaz, S.; Bachmatiuk, J.; Rodriguez, J.; Wang, X.; Aguiar, R.L., "Green HetNet CoMP: Energy Efficiency Analysis and Optimization," IEEE Transactions on Vehicular Technology, vol.PP, no.99, pp.1,1

[9] Deruyck, M.; De Vulder, D.; Joseph, W.; Martens, L., "Modelling the power consumption in femtocell networks," IEEE Wireless Communications and Networking Conference Workshops (WCNCW), pp.30,35, 1-1 April 2012.

[10] Ng, D.W.K.; Lo, E.S.; Schober, R., "Energy-Efficient Resource Allocation in Multi-Cell OFDMA Systems with Limited Backhaul Capacity," IEEE Transactions on Wireless Communications, vol.11, no.10, pp.3618, 3631, October 2012