International Journal of Engineering Research ISSN:2319-6890)(online),2347-5013(print)
Volume No.3, Issue No.7, PP : 465-468 01 July 2014

A Survey on Cell Selection Schemes for Femtocell Networks

Darshna Prajapati, Vineet Richhariya
Lakshmi Narain College of Technology, Bhopal, INDIA
prajapatidarshana4@gmail.com, vineetrich100@gmail.com

Abstract—With ever increasing number of mobile devices, operators have to search for new alternative to handle user demands. Deployment of additional base stations is always an option to improve coverage of capacity. However, it comes with the cost of incresed operational and capital expenditure. Interestingly, it has been seen that nearly 80% of mobile data demands are originating from indoor home and office users. To handle these indoor demands, deployment of small, low power femtocell access points have been suggested. However, in current deployment scenario, most femtocell are underutilised. To improve user association and resource utilization in femtocell, various cell selection schemes have been suggested. In this paper, we analyse various cell selction schemes available in the literature. Additionally, we look at energy efficiency aspect of these cell selection schemes.

Keywords—Femtocell, cell selection schemes, energy efficiency, performance evaluation

I. Introduction

With availability of smart phones and tablets, users now expect 24X7 connectivity to the Internet. As these Internet devices are getting cheaper and cheaper, the demands for wireless data is increasing. Study shows that cellular data demands are expected to increase 18 fold by the end of year 2020 [1]. To handle these demands, cellular operators are deploying additional base stations, using better modulation and coding techniques. However, they are still unable to satisfy this increasing data demands. Interestingly, nearly 80% of mobile data demands are originating from indoors [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 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 stationshaving highest received signal power [4]. However, such techniques may not be optimal in terms of users' Quality of Service (QoS). Considering users' perspective, expected bitrate based association is suggested in [5][6]. 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 based techniques because it incorporates schedulingopportunities at base stations.

To best of our knowledge, a comprehensive analysis of energy efficiency aspect of cell selection schemes is 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 energy efficiency aspect of these cell selection techniques which was ignored in all previous works.

Rest of the papers is organises 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 discusses performance of various cell selection schemes in terms of network capacity and energy efficiency. Finally, we conclude our work in section V with direction for future research.

II. Introduction to Femtocell Network

Femtocell 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.

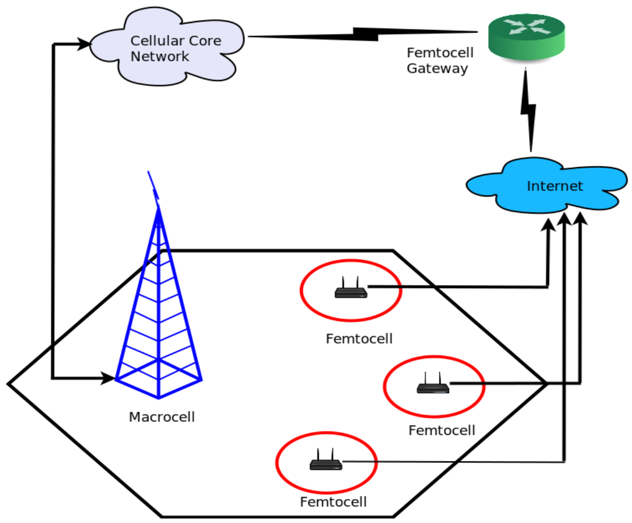

Fig. 1 : Femtocell Architecture

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-organise. 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-organizationand strategic placements in enterprise scenario. Additionally, quite an attention is given on energy efficiency of femtocell.

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 UEs. At the time of cell selection, UEs get associated with the base station (BS) providing highest RSRP [6]. 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.

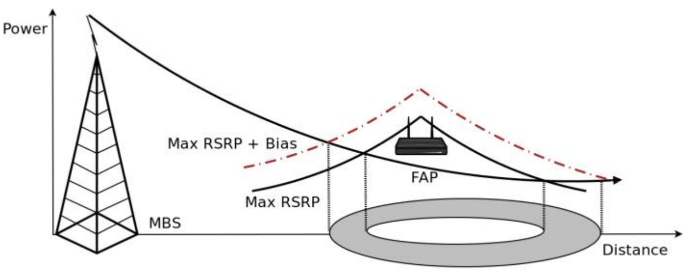

Fig. 2 : Cell Biasing

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 [7]. With cell biasing, a Range Expansion Bias (REB) of λ dB is added to RSRP from FAPs before selection of serving BS. Then,

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

whereλ 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 (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 [5] 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,

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

and if connected to FAP(k) is,

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

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

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

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.

D) **Enhanced Expected Bitrate (E[EB])**

It has been previously suggested in [5] that, if cell selection criteria consider the total number of allotted subchannels to a BS instead of REB, improvement in system throughput is obtained. This results from the fact that expected bitrate received at a UE is proportionate to the scheduling opportunities at the target BS, or in turn to the total number of allotted subchannels to the target BS. However, this scheme ignores the existing load at FAPs, and hence is not optimal in terms of system throughput and energy efficiency.

Enhanced Max Expected Bitrate cell selection scheme for UEs (E[EB]) which uses the number of subchannels allotted per user, rather than total number of subchannels at BS to make user association decisions [6]. E[EB] not only takes care of current load and scheduling opportunities at BS but also incorporates femtocell specific constraints on active connections and path loss. E[EB] would distribute the incoming connection requests such that the UEs may associate with a femtocell expecting better bitrate, even though the signal from another femtocell is stronger. Using this scheme, the expected bitrate obtained at UE i from MBS m is given by,

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

Similarly, the expected data rate at UE i from FAP(k) is,

$$E[EB_{i,k}] = f(i,k,IL)(1 - \alpha) \log_2(1 + \Gamma_{IL}^{i,k})$$

$$+ f(i,k,IF)\alpha \log_2 \quad (1 + \Gamma_{IF}^{i,k})$$

where function f(i, j, l) takes care of user association considering maximum bitrate that can be achievable by UE for a particular resource allocation policy.f(i,j,l) considers proportionate fair allocation of subchannels among UEs for simplicity. Additionally, f(i,j,l) also incorporates femtocell specific constraints so as to restrict UE association to infeasible FAPs.

$$f(i,j,l) = \frac{\frac{1}{log2\left(1+\Gamma_l^{i,k}\right)}}{\sum_j \frac{1}{log2\left(1+\Gamma_l^{i,j}\right)}} \times I_{i,j,l}$$

here$I_{i,j,l}$ is an indicator random variable that takes care of maximum number of users and minimum threshold SINR constraints. $\Gamma_{thresh}$is threshold for downlink SINR. Therefore, according to this cell selection scheme, UE i will select BS j as its serving BS if,

$$CellID_i \; = \arg_j \max E[EB_{i,j}] \; ; \quad \forall j \in \{BS\}$$

This technique is optimal among all cell association schemes. Improved performance in terms of system capacity and energy efficiency is observed.

V.Performance Metrics

In this section, we analyse performance of four cell selection schemes. We analyse received signal quality of UEs in term of received downlink SINR. To analyse overall system performance, we measure system capacity and energy efficiency.

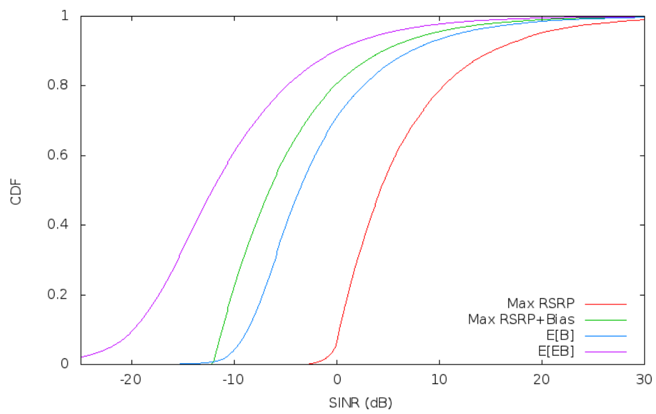

Fig. 3 : SINR of Femto UEs

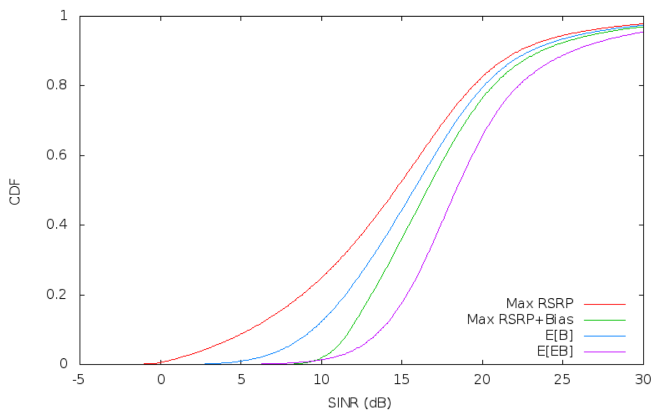

Fig. 4 : SINR of Macro UEs

Figure 3 shows received SINR of femto UEs for four different cell selection schemes. As can be seen that, Max RSRP is best among all schemes as it associates UEs to base station with highest SINR. However, Expected and Enhanced bitrate based association deteriorate signal quality of femtocell users. However, we show improvement in SINR for macro UEs for Expected bitrate based association compared to Max RSRP and bias based association (Figure 4).

Figure 5 represent received bitrate of all UEs for different cell selection schemes. Note that, Enhance bitrate based association perform best in terms of received bitrate as it incorporate offered load in the

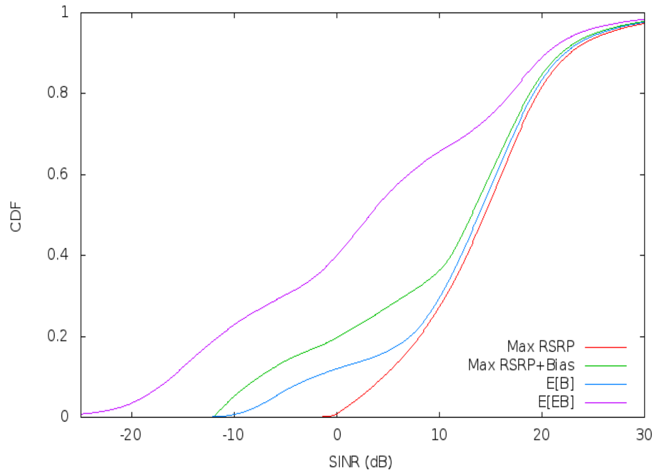

Fig. 5 : SINR of all UEs

cell selection criteria. This results from the fact that UEs' bitrate can be compensated by providing additional bandwidth target base station. Consequently, due to improvement in received SINR of UEs, we also observe improvement in system capacity for Expected bitrate and Enhanced bitrate based cell association (Figure 6). Since, power consumption is of femtocell is mostly taken as constant, we don't see much increase in overall system power consumption.

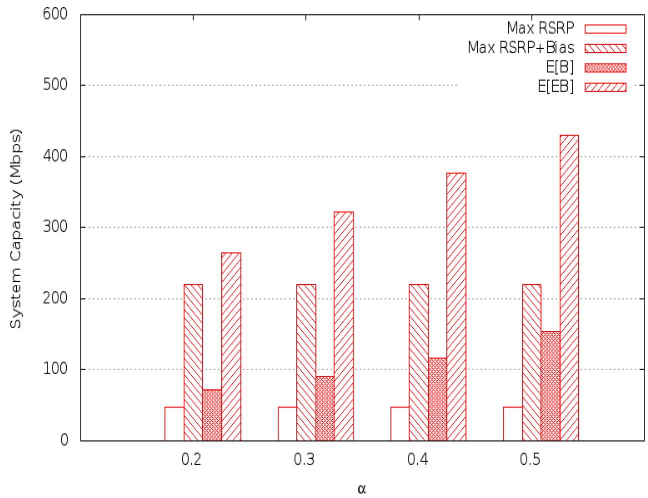

Fig. 6 : System Capacity of Femtocell Network

Lastly, we analyse energy efficiency aspect of these selection schemes. Figure 7 shows, here too, Enhanced expected bitrate based association perform best. Additionally, it keeps increasing with increase infraction of interference free spectrum (α) allotted to target BS.

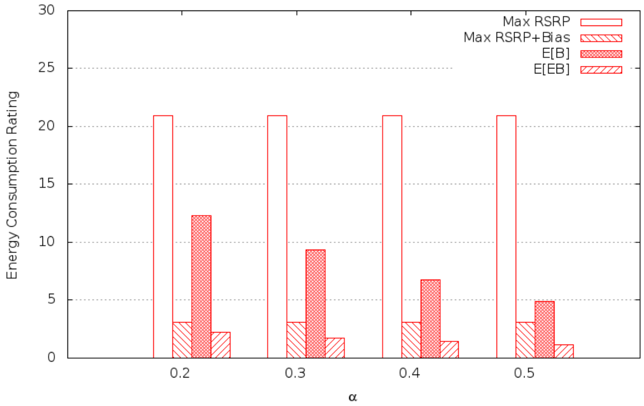

Fig. 7 : Energy Efficiency of Femtocell Network

V.Conclusion

User association and resource utilization in femtocell is limited by their inherent low power transmission and high wall penetrations losses. Use of cell selection schemes based on cell biasing and expected bitrate helps improving gains of femtocell deployments. In this paper, we analyse four different cell selection schemes and discuss their advantages and limitations. Out of all, Enhanced bitrate based association seems to outperform in terms of system capacity and energy efficiency. In future work, we try to analyse energy efficiency aspects of these cell selection schemes considering mobile users' battery life and uplink system capacity.

Acknowledgement

We would like to thank Mr. Rahul Thakur of Indian Institute of Technology Madras, INDIA for providing valuable feedback on this paper.

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