Dynamic Almost Blank Subframe Scheme for Enhanced Intercell Interference Coordination in LTE-A Heterogeneous Networks

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***Abstract-* In LTE-A heterogeneous network, traffic load may be distributed unequally because the transmission power of macro eNodeB (eNB) is higher than pico eNB. To address the coverage problems resulting from nodes with different transmission powers, cell range expansion (CRE) technique has been proposed as a cell selection technique. However, in this case, the intercell interference (ICI) problem can occur on both data and control channels when users connect to pico eNB. To mitigate ICI problem, a new dynamic almost blank subframe (ABS) scheme is proposed in this paper. In this scheme, a fuzzy logic system is deployed to monitor the system performance and then obtain the required number of ABSs. Simulation results show that the cell throughput and user throughput can be improved using the proposed dynamic ABS scheme.**

Keywords-* *LTE-Advanced, HetNet, picocell, intercell interference, almost blank subframes (ABS), fuzzy logic.

I. INTRODUCTION

Heterogeneous network (HetNet) is one technique to increases the coverage and capacity in LTE-A networks. A HetNet consists of macrocells as well as low power nodes (i.e., femto, pico, relay nodes). The goal of using low power nodes is to offload the traffic from the macrocells, enhance coverage and throughput, and increase the spectral efficiency by spatial reuse of spectrum. Picocell is one of the important enhancements which can be deployed efficiently in local regions with high volume of traffic and improves the overall system capacity and coverage of outdoor or indoor regions in inadequate macro penetration [1]. Pico eNodeBs (eNB) have lower transmission power than macro eNB and work in open access mode. The open access mode means that any user in the network can automatically connect to the eNBs [2-3]. In order to coordinate between macro eNB and pico eNB, messages are exchanged through X2 interface [4].

Although the picocell can enhance the capacity and coverage, new challenges arise for network management. In HetNet, the cell selection is performed using the cell range expansion (CRE) technique in which an offset value is added to downlink reference signal received power (RSRP) of the pico eNB. By this technique, the user equipment (UE) selects a pico eNB as the serving cell even in the case that pico eNB is not the strongest eNB. Although the CRE significantly mitigates interference in the uplink, the downlink signal quality of UEs located in the range expanded area (RE UE) is reduced which leads to decrease of their signal to interference plus noise ratio (SINR). Note that a range expanded area is an area around a picocell where UEs connect to pico eNBs because of receiving RSRP plus an offset value. In the range expanded area, both data and control channels will suffer from interference because they are not planned for too low SINR. Consequently, picocells may become underutilized due to the severe interference. Therefore, one of the important aspects of HetNets is intercell interference (ICI) management.

In time domain, the interference problem can be mitigated using subframe utilization. This utilization is performed across different cells through almost blank subframes (ABS). ABSs are subframes without any activity or only transmitting the reference signals from macro eNB [5]. UEs located in range expanded area are scheduled within subframes that overlap with the ABSs of the macrocell as shown in Fig.1. Moreover, pico eNB can also transmit to its UEs during non-ABS periods. Consequently, the ratio of ABSs has a direct influence on throughput of UEs located in macrocells and picocells.

To mitigate ICI in macrocell- picocell scenario, several enhanced intercell interference coordination (eICIC) schemes have been proposed for time domain in [6-11]. Moreover, [12] has provided a good survey on ICIC in LTE and LTE-A. Our paper proposes a new dynamic approach to share the radio resources in time domain between macrocell and picocell so that the interference can be mitigated sufficiently while the throughput of macro UEs is not scarified. For this purpose, a fuzzy logic system is deployed to calculate the ABS

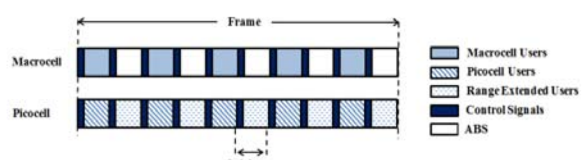


Fig.1. ABS configuration in time-domain

ratio such that the system performance can be improved for co-channel deployment. Note that in co-channel deployment, all network nodes use the same frequency to avoid bandwidth segmentation.

The rest of the paper is organized as follows. The challenges in macrocell-picocell scenario are underlined in Section II. Section III describes the proposed dynamic ABS scheme. The simulation results are depicted in Section IV. The conclusion is given in the final section.

II. CHALLENGES IN MACROCELL-PICOCELL SCENARIO

Using nodes with different transmission powers can lead to new challenges in HetNets. One challenge in macrocell-picocell scenario is cell selection technique. Due to difference between transmission power of macro eNB and pico eNB, cell selection based on the strongest downlink RSRP is not the best strategy because UEs connect to a higher power node instead of the lower power nodes at the shortest pathloss distance. One solution is CRE technique in which an offset value is added to RSRP received from pico eNB so that the UE preferentially selects a pico eNB as the serving cell even when it is not the strongest cell as shown in Fig.2.

$$Servingcell\_ID = \arg\max_{\{k\}} (RSRP_{k,m} + offset\_value) \quad (1)$$

Different offset value from 0 to 20 dB can be added to RSRP received by UEm from eNB k. When the offset value is set to 0, CRE acts as the maximum RSRP technique. Note that the offset value is only added to RSRP received from pico eNBs while for macro eNBs, the offset value is set to 0. By this technique, interference in the uplink can be mitigated as depicted in Fig.2 (b). However the SINR of UEs located in the range expanded area decreases due to high interference impacted from macro eNB. SINR on resource block n (RBn) for UE connected to pico eNB could be calculated using:

$$SINR_{n,m} = \frac{P_n^i H_{n,m}^i}{\sum_{k}^{mc} P_n^k H_{n,m}^k \delta_n^k + \sum_{j,j\neq i}^{pc} P_n^j H_{n,m}^j \delta_n^j + P_N} \quad (2)$$

where P_n^i and $H_{n,m}^i$ are the transmit power from the serving pico eNB i on RBn, and the channel gain from the serving pico eNB i to UEm on RBn, respectively. Number of interfering picocells and macrocells are shown by pc and mc, respectively. Parameters P_n^j and P_n^k are the transmit power from interfering picocells and macrocells. Moreover, $H_{n,m}^k$ and $H_{n,m}^j$ represent the channel gain from the interfering macrocell k and picocell j to UEm on RBn. δ_n^k and δ_n^j are set to 1 or 0 to indicate whether the neighbouring cell k or j allocates RBn to its UEs or not. P_N is the noise power. Note that a pair of RB called physical resource block (PRB) is the smallest unit that can be allocated to a UE. Moreover, the time domain allocation unit is called transmission time interval (TTI) and equals 1 ms. According to (2), the UEs located in range expanded areas suffer strong downlink interference

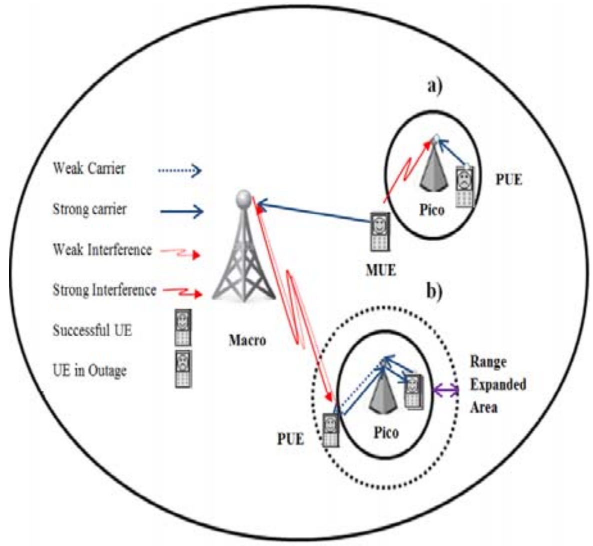


Fig.2.a) Macro UE (MUE) interferes on the uplink of a nearby picocell; b) Using cell range expansion to mitigate pico uplink interference present in Fig.2 (a).

resulted by the macro eNB because the transmission power of macro eNB is higher than pico eNB.

III. THE PROPOSED DYNAMIC ALMOST BLANK SUBFRAME SCHEME

In this section, a dynamic ABS scheme is proposed in time domain to improve throughput of system. In the proposed scheme, the ABS ratio is calculated dynamically based on three important parameters including the throughput of macro UEs, throughput of UEs located in range expanded area (RE UE), and number of RE UEs connected to pico eNB and UEs connected to macro eNB as shown in Fig. 3. In this decentralized procedure, each macro eNB monitors these metrics for a specified time window (e.g., 50 TTI) and then obtains the next ABS ratio using fuzzy logic system. This procedure can be continued until the system performance reaches to the desired values.

In this scheme, a fuzzy logic system (FLS) is deployed [13] since it can work in real-time and be designed easily [14]. A FLS is an expert system based on several defined "IF...THEN" rules. It could simultaneously work with numerical data and linguistic information using a nonlinear mapping between input data and scalar output data. Since FLS deploys linguistic terms, the previous information can be gathered easier using the experience of an operator. The main difference between FLS and conventional rule base controller is that FLS can simultaneously trigger several rules which lead to smoother control. The proposed scheme is executed in four steps as follows:

Step 1: Inputs and Output

In the ABS scheme, when the numbers of ABSs and non-ABSs are not corresponding to number of macro UEs and RE UEs, ABS scheme cannot sufficiently improve the throughputs for these UEs. This can be worse for REUE because the impacted interference is higher for them. Consequently, the throughputs and number of macro and RE

UEs can be the suitable metrics to determine the ABS ratio such that the total system performance is improved. Therefore, the following parameters are considered as the inputs and output of ABS ratio module:

1) Input 1: number of RE UEs connected to pico eNB to number of UEs connected to macro eNB.
2) Input 2: Average throughput of UEs connected to macro eNB.
3) Input 3: 5 % throughput of RE UEs connected to pico eNB.
4) Output: ABS ratio

Note that 5 % throughput is 5^{th} percentile point of the cumulative distribution function (CDF) of the user throughput which indicates the minimum throughput achieved by 95% of UEs. This metric is used to calculate the throughput of UEs located in areas with lower SINR. According to Fig.3, inputs are directly extracted from the system performance and then fed back to the module. By this feedback, the FLS can monitor the system performance obtained by current ABS ratio and then change the ABS ratio to improve the system performance.

Step 2: Fuzzificatin

In FLS, each input and output is fuzzified using different membership functions. Membership function consists of several curves which define the mapping from a given point in the input or output space with a membership degree between zero and one. In the proposed scheme, inputs and output are fuzzified as follows:

- Input 1 is fuzzified using three membership functions named "Small", "Medium" and "Large" with Z-shaped, Triangular-shaped and S-shaped membership functions depicted in Fig.4 (a).

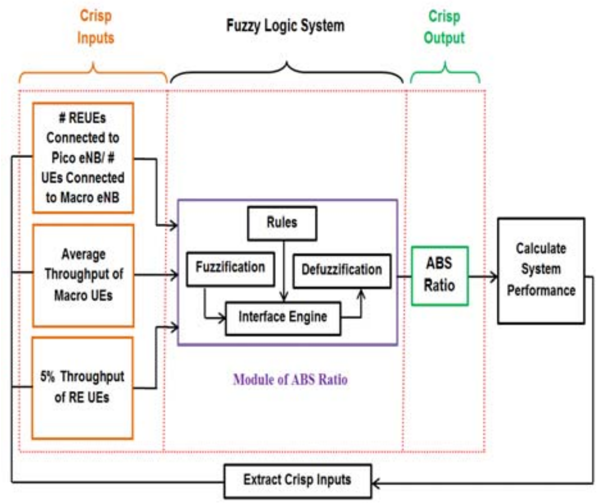
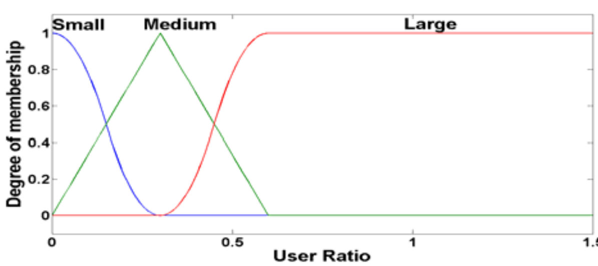


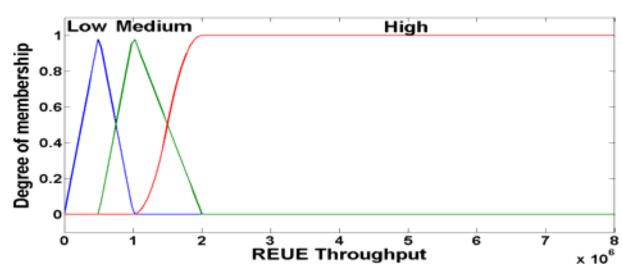
Fig.3. Block diagram of the proposed scheme

- Inputs 2 and 3 are fuzzified using three membership functions "Low", "Medium" and "High" with Z-shaped, Triangular-shaped and S-shaped membership functions as shown in Fig. 4(b) and (c).
- For output, three membership functions are defined called "Decrease", "Constant", and "Increase" with Triangular-shaped (see Fig.4 (d)). After each iteration, the output is added to/subtracted from the previous ABS ratio to find the new ABS ratio.

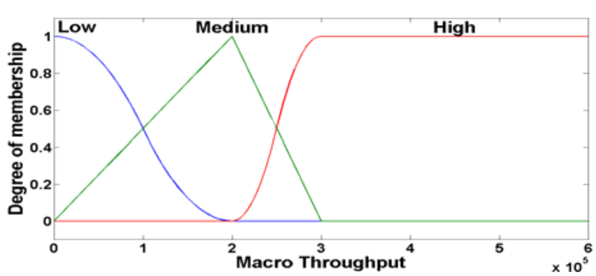
Note that the range of membership functions can be tunned based on network model, number of UEs, and system requirements until the desired performance is obtained.



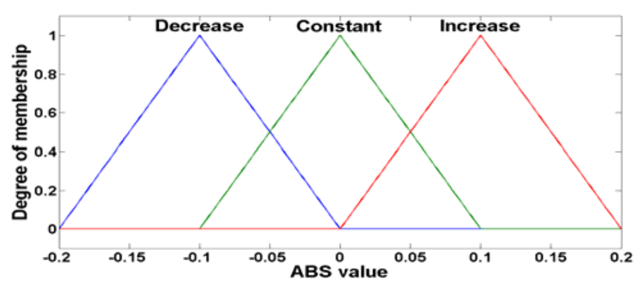
(a) Membership functions of user ratio



(b) Membership functions of RE UE throughputs



(c) Membership functions of macro UE throughputs



(d) Membership functions of ABS ratio

Fig 4. Examples of membership functions used for inputs and output

If (User Ratio is Medium) and (REUE Throughput is High) and (Macro Throughput is High) then (ABS value is Constant) (1)
If (User Ratio is Medium) and (REUE Throughput is High) and (Macro Throughput is Medium) then (ABS value is Decrease) (1)
If (User Ratio is Medium) and (REUE Throughput is High) and (Macro Throughput is Low) then (ABS value is Decrease) (1)
If (User Ratio is Medium) and (REUE Throughput is Medium) and (Macro Throughput is High) then (ABS value is Constant) (1)
If (User Ratio is Medium) and (REUE Throughput is Medium) and (Macro Throughput is Medium) then (ABS value is Constant) (1)
If (User Ratio is Medium) and (REUE Throughput is Medium) and (Macro Throughput is Low) then (ABS value is Decrease) (1)
If (User Ratio is Medium) and (REUE Throughput is Low) and (Macro Throughput is High) then (ABS value is Increase) (1)

Fig.5. Example of fuzzy rules

Step 3: Interface Stage

In the inference stage, mapping of inputs to outputs are defined by a set of "IF-Then" rules to control the output value. According to number of inputs and membership functions, 27 rules are defined. An example of these rules is shown in Fig.5. This step selects appropriate rules and then finds their results.

Step 4: Defuzzification

In the defuzzification step, the crisp output value is achieved using the aggregation of the selected rules and the centre of gravity approach defined in FLSs. The crisp output of ABS ratio module is added to/ subtracted from previous ABS ratio. The new ABS ratio indicates the number of subframes that macro eNB should be muted during them and pico eNB schedules RE UEs on those subframes to avoid interference.

IV. SIMULATION RESULTS

This section evaluates the proposed scheme using a system level simulation. System level simulations are required to reflect the influence of interference management methods on the performance of the new mobile network technologies. The network topology is composed of a set of cells and network nodes including macro eNBs, pico eNBs and UEs which are distributed within cells. In this work, a well-defined area is used for simulation where the eNBs and UEs are located and the UE movement and transmission are simulated. The simulation parameters are given in Table I based on parameters specified by 3GPP [2]. The metrics used for evaluation are explained as follows:

- *Average percentage of the muted UEs*: number of macro UEs which RBs are not allocated to them for data transmission to total number of UEs.
- *User Ratio*: number of RE UEs connected to pico eNB to number of UEs connected to macro eNB
- *# UEs connected to pico eNB*: percentage of UEs connected to pico eNB located in both range expanded area and basic coverage.
- *5 % REUE throughput*: It is 5th percentile point of the cumulative distribution function (CDF) of the RE UE throughput.
- *Average macro UE throughput:* It equals to the average throughput of UEs connected to macro eNB.
- *Average macrocell throughput*: It is defined as the cell throughput for macrocell without considering picocells.
- *Average picocell throughput*: It equals the summation of throughputs of picocells corresponding to each macrocell.

The ABS ratio calculated by the proposed fuzzy scheme for cell 1 (the cell located in the centre) is depicted in Fig.6. Table II shows when the offset value is low, a few numbers of UEs are located in range expanded area, while the large number of UEs are offloaded to this area for the higher offset values. For example, the ratio of RE UEs to macro UEs equals 0.10 when offset value is set to 9 dB. That is more UEs connect to macro eNBs due to receiving the higher RSRP from the macro eNB. By increasing of offset value to 15 dB, this ratio goes up to 1.03. Therefore, the proposed scheme

TABLE I: SIMULATION PARAMETERS

Parameter	**Value**
Cellular Layout	Hexagonal grid, 7 cells, wrap around
Inter-site distance	400 m
Minimum distance between macro and pico	75 m
Carrier frequency	2 GHz
Carrier bandwidth	10 MHz
Pico distribution	4 picos/ macro
Total macro Tx power	46 dBm
Total pico Tx power	30 dBm
Macrocell pathloss	128.1+37.6 log(R),R in km
Picocell pathloss	30.6+36.7 log(R), R in m
Minimum required throughput	200 Kbps
Time window	50 TTI

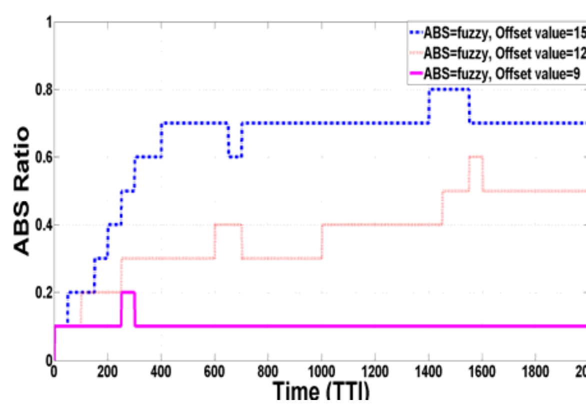


Fig.6. ABS ratios in cell 1

Table II: Average Percentage of the Muted UEs (%)

Offset Value	# UEs connected to pico eNB (%)	User Ratio	Average Percentage of the Muted UEs (%) ABS ratio= Fuzzy	ABS ratio= 0.1	ABS ratio= 0.2	ABS ratio= 0.3	ABS ratio= 0.4	ABS ratio= 0.5	ABS ratio= 0.6	ABS ratio= 0.7	ABS ratio= 0.8
9 dB	24 %	0.10	15.97	16.85	23.05	26.83	26.92	31.10	34.03	40.21	43.74
12 dB	43 %	0.45	12.99	5.74	8.41	14.08	17.64	21.6	25.2	27.86	36.14
15 dB	62 %	1.03	17.75	2.67	6.47	8.22	11.72	13.43	16.52	19.54	20.55

selected higher ABS ratio for offset value = 15 dB than offset values = 12dB and 9 dB. Moreover, the percentage of the muted UEs for different offset values and ABS ratios are presented in this table. When the offset value is low (e.g., 9 dB), more UEs connect to macro eNB. In this case, number of RBs is not enough for macro UEs and hence some macro UEs cannot send data. It will be worse when the ABS ratio increases because the number of subframes that macro UEs have to be muted increases. However, when the offset value increases (e.g., 15 dB), number of UEs offloaded to picocell increases which yields to decrease of number of the muted UEs. Since the proposed fuzzy scheme changes ABS ratio based on the defined inputs, the percentage of the muted UEs is lower than the corresponding static ABS ratios.

When a small ABS ratio is used, more non-ABS are assigned to macro UEs while the number of ABSs that can be allocated to RE UEs is low. Consequently, the throughput of macro UEs increases while the throughput of RE UEs is degraded as shown in Fig.7. In contrast, if the ABS ratio increases, the subframes that can be allocated to macro UE will decrease and the number of ABS assigned to RE UEs will increases. Therefore, the increase of ABS ratio can lead to increase of the RE UE throughput at expense of reduction of macro UE throughput depicted in Fig.8. It can be concluded that there is a trad-off between macro UE and RE UEs throughputs when ABS scheme is applied. On the other hand, the increase of RE UE throughput can increase the picocell throughput (see Fig.9). However, for larger ABS ratios, the throughput of macro UEs reduces significantly which lead to decrease of macrocell throughput as shown in Fig.10. In order to keep the trade-off between throughput of macro UEs and RE UEs as well as satisfy the minimum required throughput for macro UEs, the proposed dynamic scheme set ABS ratio between 0.1 and 0.2 for offset value equals 9 dB (see Fig.6). This is because a lower number of UE are located in range expanded area, and hence a lower number of ABSs are needed to support them. As the result, more non-ABSs can be allocated to macro UEs to satisfy their minimum required throughputs.

By increasing of offset value to 15 dB, more UEs are located in range expanded area. As a result, the 5% pico UE throughput reduces because UEs far from the pico eNB are connected to the pico eNB while they suffer high interference impacted by macro eNB. In this case, if the ABS ratio is set to small value (e.g., 0.1 or 0.2), the number of ABS cannot support all of RE UE and then pico eNB has to schedule them on non-ABS. Since the interference on non-ABS is high for RE UEs particularly for RE UEs far from pico eNB, the picocell throughput and RE UE throughput decrease as shown in Figs.7 and 9. To overcome this problem, the proposed fuzzy scheme dynamically changes the ABS ratio between 0.6 and 0.8 as shown in Fig.6. This is because the proposed scheme tries to keep the trade-off between throughput of RE UEs and minimum required throughput of macro UEs while the user ratio is considered. As shown in Figs 7 and 8, the 5% throughput of RE UEs and average throughput of macro UEs are more than static ABS ratio=0.7. Since the higher ABS ratio is selected for offset value= 15 dB, the average picocell throughput of fuzzy scheme is higher than offset values= 9 dB and 12 dBs while its average macrocell throughput is lower.

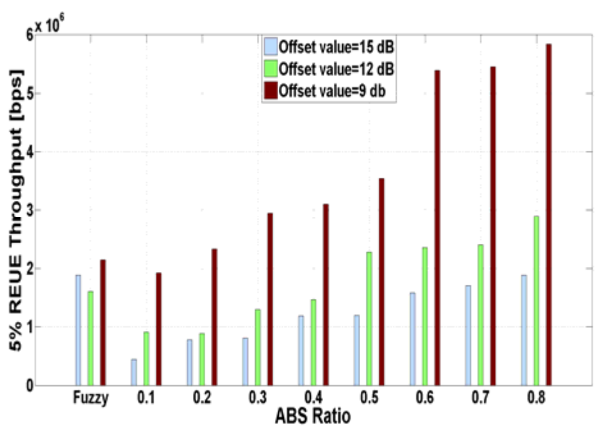


Fig.7. 5% RE UE throughput

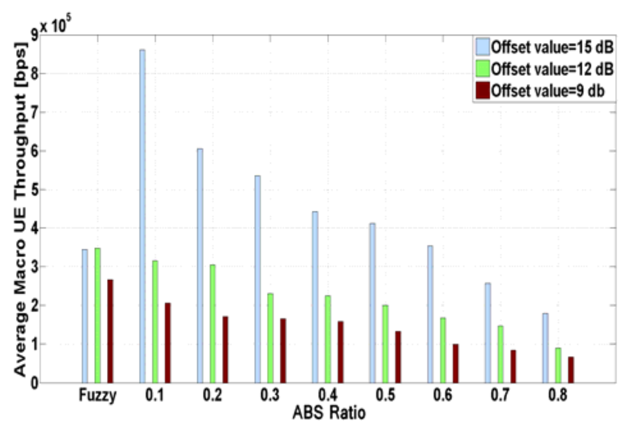


Fig.8. Average macro UE throughput

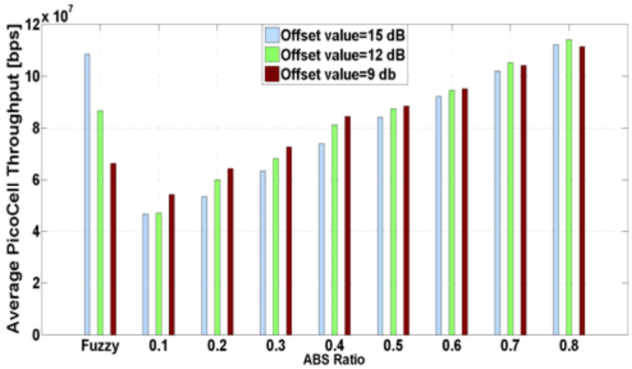


Fig.9. Average picocell throughput

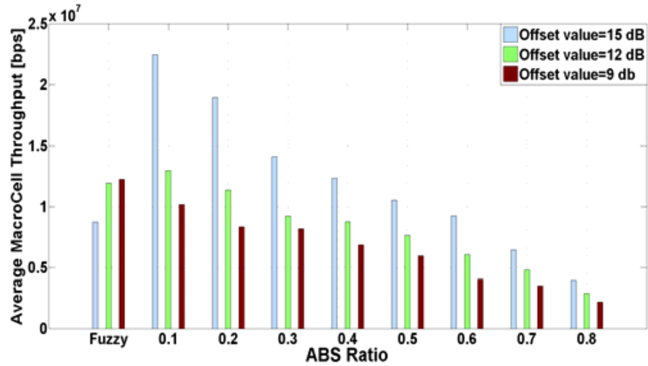


Fig.10. Average macrocell throughput

V. CONCLUSION

In this paper, a dynamic ABS scheme has been proposed to overcome the ICI problem in macrocell-picocell scenario. In the proposal scheme, the ABS ratio is selected based on system performance and using a fuzzy logic system. The simulation results show that the proposed scheme can keep the trade-off between RE UE throughput and minimum required throughput of macro UEs compared to static ABS ratio schemes.

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