Engineering Journal issn: 0125-8281

Article

Comparative Study of Scheduling Algorithms in LTE HetNets with Almost Blank Subframe

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Abstract. The trend and human lifestyle have been changing, which lead to the tremendously increasing demand for data usage over wireless communication systems even on the go. Traffic offload has been used for LTE Heterogeneous Networks (HetNets) to optimize overall system capacity via load balancing mechanisms among network tiers. In this work, the two main techniques used for interference coordination in the multi-tier systems i.e. Almost Blank Subframe (ABS) and Cell Range Expansion (CRE) have been focused on. Resource scheduling is one of the major issues in LTE HetNets aimed at efficient radio resource allocation. Based on the implementation of ABS and CRE mechanisms, this work investigates the system performance while different scheduling schemes are implemented. Five scheduling schemes including Round Robin (RR), Best-Channel Quality Identification (Best-CQI), Maximum Throughput (Max-TP), Proportional Fairness (PF), and Resource Fairness (RF) are considered here. The simulation studies include a comparison of the LTE HetNet system performance under different ABS and CRE configured parameters as well as employing different scheduling mechanisms. System performance is observed in terms of the average throughput, the peak throughput, the edge throughput, and the fairness index. The results provide recommendations on the system configurations as well as the choice of a scheduler that can be considered or suitable for different scenarios and network planning objectives. Coined from these results, the Best-CQI and the Max-TP mechanism offer the highest peak throughput and the high average throughput. The RR, PF, and RF provide the high cell edge throughput and fairness index, however, the peak throughput has been compromised.

Keywords: LTE scheduling algorithm, almost blank subframe, multitier traffic offload.

ENGINEERING JOURNAL Volume 25 Issue 8
Received 31 March 2021
Accepted 21 July 2021
Published 31 August 2021
Online at https://engj.org/
DOI:10.4186/ej.2021.25.8.39

1. Introduction

The number of mobile users along with the demand for data transmission over mobile communication systems has been increasing dramatically. With the limited radio resource, Heterogeneous Network (HetNet) has been deployed to enhance system capacity and provide spectrum efficiency, while the system coverage and reliability can also be guaranteed. With the implementation of HetNet, different network tiers operate in the collocated area to provide increased system capacity. The load level of each tier should be optimized. One of the key complementary technologies in HetNets is traffic offloading or data offloading. Another important issue concerning HetNet implementation occurs since the system consists of multiple network tiers including macrocell, microcell, picocell, and possibly femtocell. It is the interference from their transmissions on the same bandwidth, which could lead to the link performance deterioration. This should be well managed to guarantee the link Quality of Service (QoS).

To cope with interference that occurred between different network tiers, the Inter-Cell Interference Coordination (ICIC) and the enhanced Inter-Cell Interference Coordination (eICIC) have been introduced in the 3GPP release 8 and 11 [1], [2], respectively. The ICIC has been introduced for interference cancellation between the macrocells using the frequency domain concept and the eICIC is used for the interference cancellation between different network tiers such as macrocell and picocell by using time-domain techniques. The key techniques proposed in eICIC are the Almost Blank Subframe (ABS) and the Cell Range Expansion (CRE). Aimed at increasing system capacity by offloading users from the macrocell to the small cells, the CRE mechanism extends a coverage area of the small cells by adding a bias level of power to the Reference Signal Received Power (RSRP) obtained from the small cell Base Stations (BSs) according to the set biasing factor [3], [4]. As a result, some users, most likely be at the cell edge, can be offloaded to the small cells. However, the offloaded users, who are likely to be the cell edge users of the small cells, can be interfered by the overpowering macrocell transmission. Hence, these users might experience bad link quality. This is the result or side effect of the mechanism from the trade-off between the capacity and the link quality. To reduce the effect of such over powering macrocell transmission, the ABS technique has been introduced with the objective of interference cancellation between BSs [5]. With the ABS mechanism, a suitable ABS ratio should be set. It is an important factor that affects the number of allocated Resource Block (RB) in the LTE-Advanced system as this parameter determines the percentage in the time domain that a macrocell BS can transmit its signal.

Along with the implementation of interference coordination techniques mentioned before, data scheduling is a very important process affecting the spectrum efficiency of the system. In [6], [7], [8], [9], the LTE system embedded with different scheduling mechanisms has been studied and the system performance has been evaluated. The effect on macro-femto cells and the system performance of the LTE-Advanced networks have been focused on. Nonetheless, the LTE-Advanced system investigated in the previous work was not integrated with the ABS and CRE mechanisms.

The more recent works have proposed the modified Proportional Fairness (PF) Scheduler [10], [11] to offer better resource allocation. In [12], a predictive scheduler using the utility-based scheduling approach based on QoS-aware energy and jitter-efficient downlink was proposed. The energy efficiency and the packet delay jitter for real-time applications are optimized.

Different scheduling schemes, i.e. Round Robin (RR), Best-Channel Quality Identification (Best-CQI), Maximum Throughput (Max-TP), Proportional Fairness (PF), and Resource Fairness (RF) have been focused on in this work for comparison study. The LTE-Advanced system performance is investigated here with an implementation of the five different schedulers along with different CRE and ABS configuration parameters. System level simulator has been used for our evaluation and it was adapted from the Vienna downlink system level simulators [9]. The results are obtained in terms of the throughput performance including the peak throughput, the average throughput, the edge throughput, and the fairness index.

2. Interference Coordination in LTE

2.1. Inter-cell Interference Coordination (ICIC)

The ICIC is a technique used for mitigating cell edge interference between macrocell BSs. Figure 1 shows the interference between two signals from the macrocell A and the macrocell B even though the user is in the range of macrocell B but still can get the interference from macrocell A's transmission. The two BSs coordinate by communicating with each other via the X2 interface. This method was proposed in the 3GPP release 8 [1].

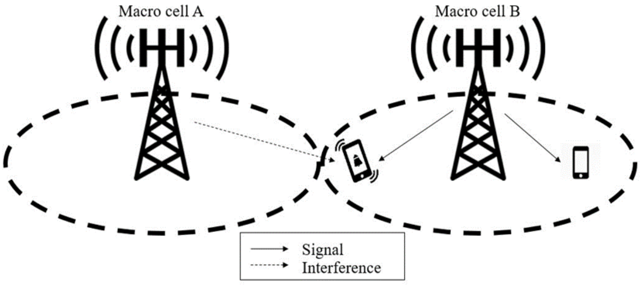


Fig. 1. Inter-Cell Interference Coordination scenario.

2.2. Enhanced Inter-Cell Interference Coordination (eICIC)

The eICIC technique is a technique that has been further developed from the ICIC technique to mitigate cell edge interference. The method focuses on the interference caused by different network tiers in the Heterogeneous Network (HetNet). From Fig. 2, the user that attaches to the small cell is affected by the interference from the macrocell BS [13].

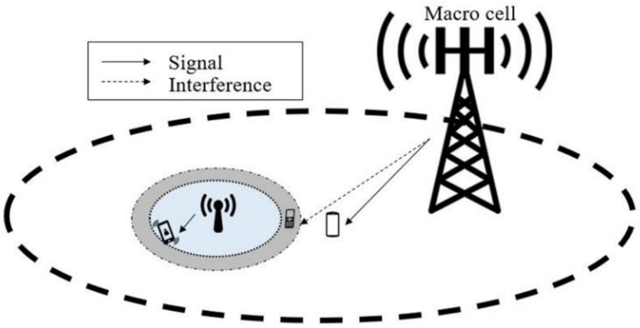
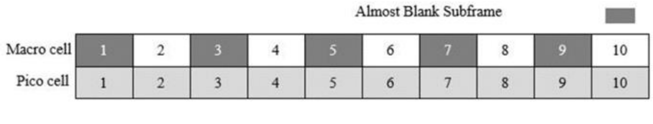


Fig. 2. enhanced Inter-Cell Interference Coordination scenario.

Aimed at offloading traffic from the macrocell to the smaller cells, the CRE mechanism is employed. The concept is to expand the small cells coverage area by applying a certain level of the CRE bias value to the RSRP obtained from the small cell transmission. In such a case, several users earlier located outside the small cell's coverage but within the newly expanded boundary, can be offloaded to the small cell. So, these offloaded users, most likely be the cell edge users, are prone to interference from the higher transmission powering macrocell. This could lead to poor link quality for the offloaded users. To reduce the co-channel interference from the overpowering macrocell, the ABS technique is utilized.

By using ABS, the macrocell transmission is managed in the time domain. Based on the chosen ABS ratio, the macro cell can only transmit in a certain period of time. Figure 3 shows the timeslot allocated for macrocell and small cell transmission as the ABS ratio is set to 0.5. In the figure, the macrocell is muted on the shaded subframes, which are 50% of the time. The white time slots represent the transmitted time slots. In this work, the pattern of blank subframes is not our focus. For example for the ABS ratio of 0.5, the on-off alternating subframe pattern is implemented.



Macro cell	1	2	3	4	5	6	7	8	9	10
Pico cell	1	2	3	4	5	6	7	8	9	10

Fig. 3. ABS with ABS ratio of 0.5.

3. Downlink Scheduling Mechanisms

This section discusses the concept of five scheduling mechanisms that are studied in this work. The $\gamma_{(n,m)}$ represents a scheduling metric for the nth user of the mth RB.

3.1. Round Robin Scheduling (RR)

A round robin scheduling has been designed to provide simplicity and an equal share of resources among all users. With this scheduler, all active users are allocated an equal amount of resources according to the randomly sorted list of users.

Since the channel quality and the current situation of the system are not taken into account, the RR scheduling mechanism is simple and it generally offers a lower throughput but better resource fairness when comparing with the other schedulers. (1)

$$\gamma^{RR}_{n,m} = T_i - \bar{T}_p \tag{1}$$

where T_i is an instantaneous time. $\bar{T}_p$ represents the time before the user was scheduled [14]. Figure 4 displays the flow of the RR scheduler as the active users have been scheduled with allocated RBs.

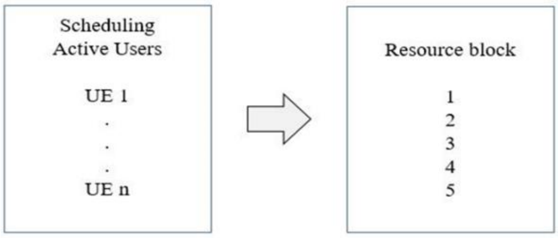


Fig. 4. RR scheduler flow.

3.2. Best Channel Quality Identification Scheduling (Best-CQI)

The concept of the Best-CQI scheduling is to provide the RB with the best channel quality to the users with the best radio link condition using the following argument;

$$\gamma^{BCQI}_{n,m} = \varsigma_{n(\tau)} \tag{2}$$

where ς represents the CQI value. *n* is a number of users and *m* represents the number of RB. Using this scheduling scheme, the service quality of the cell edge users could be compromised since the technique gives priority to the users with the better CQIs. [9]. Normally Best-CQI offers the higher throughput through resources assignment, which depends on the uplink CQI feedback from all UEs. As a result, this mechanism usually provides the highest CQI value [15]. Figure 5 shows the active users, who have been scheduled to metric M and allocated the resource block following the priority metric M.

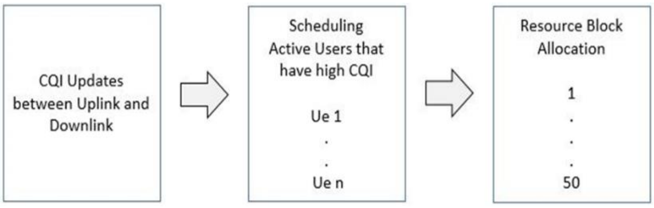


Fig. 5. Best-CQI scheduler flow.

3.3. Maximum Throughput Scheduling (Max-TP)

Based on the Max-TP scheduling mechanism, the users with the larger Signal to Noise Ratio (SNR) are offered high priorities and are allocated more resources. As a result, the total throughput or spectrum efficiency can be maximized. The n^{th} RB signal of the k^{th} user at t^{th} TTI (Transmission Time Interval) is expressed by:

$$\gamma_{k,m}(n) = \frac{s_{k,m}(n)\, g_{k,m}(n)}{N_0 B/N} \tag{3}$$

where $s_{k,m}(n)\, g_{k,m}(n)$ represents the allocated transmission power and the gain on the n^{th}sub-carrier at t^{th} TTI. N_0 represents the Power Spectral Density (PDF) of AWGN. B is the bandwidth and N is the number of sub-carrier. [16]. Figure 6 shows the scheduling flow after the SNR update. The active users with high SNR will get higher priority in this approach.

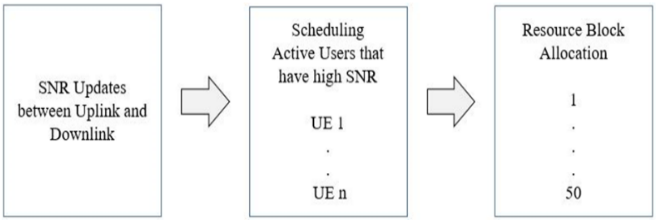


Fig. 6. Max-TP scheduler flow.

3.4. Proportional Fairness Scheduling (PF)

This scheduling algorithm is the combination of the two schedulers including the RR and the BEST-CQI scheduler. While the RR scheduler provides low throughput with high fairness and the Best-CQI scheduler offers high throughput with low fairness, the PF scheduler tries to combine both benefits and provides service quality and fairness as well as maximizes the throughput of cell edge users. This is done by giving higher priority to the users with low throughput. Nonetheless, the best average throughput may not be offered by this scheme. It is because the high peak throughput offered by the previous method has been compromised to achieve fairness. The PF scheduler allocates the RBs to users by using the priority metric, M [17]:

$$M = \frac{R_i(\tau)}{\bar{R}_i(\tau)} \qquad \mathrm{M} = \operatorname{argmax} \frac{\mathrm{R_i}(\tau)}{\bar{\mathrm{R}}_\mathrm{i}(\tau)} \tag{4}$$

where Ri is an instantaneous rate and $\bar{R}_i$ represents an average throughput [9]. The PF scheduler provides at least a minimal level of service to all users. Figure 7 shows the PF scheduler's flow as active users have been scheduled and allocated the resource block after the CQI updated process.

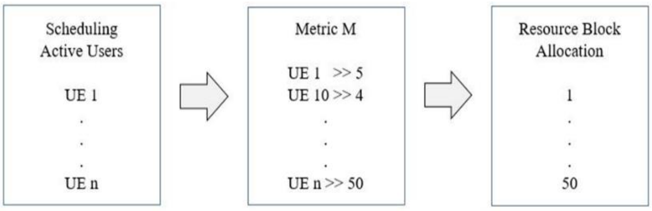


Fig. 7. PF scheduler flow.

3.5. Resource Fairness Scheduling (RF)

The RF scheduler tries to maximize the sum of all users' data rates. At the same time, satisfied fairness is offered through the following equation;

$$\|b_k\|_1 = \frac{N}{K} \forall k \tag{5}$$

where $\|b_k\|_1$ is the number of RBs given to the user k, which is equal to the ratio between a total of RBs, N, and the total number of users, K [18]. Figure 8 shows the RF scheduling flow, in which active users have been scheduled and allocated with an equal amount of resource block.

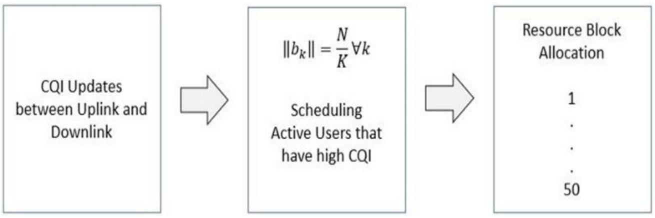


Fig. 8. RF scheduler flow.

4. Simulation Model and Scenarios

The LTE-Advanced HetNet system performance under the implementation of eICIC techniques as well as the utilization of different scheduling mechanisms is observed via the simulation model. The simulator was adapted based on the Vienna LTE system level simulator [9]. For our studies, the adaptation has been done to integrate the CRE and ABS mechanisms as well as some schedulers.

The ABS and CRE mechanisms have been integrated over in the link measurement model, which is used to measure transmission link quality. Additionally, the resource allocation specifically used by the five different scheduling mechanisms as mentioned has been adapted. The adapted simulation model has been used here to observe the system performance under five different scheduling schemes as well as CRE and ABS configuration parameters.

4.1. Simulation Scenario

This work focuses on the multitier LTE-Advanced HetNet scenario as shown in Fig. 9. The scenario includes three small cells located within the macrocell's coverage area. In the middle, the macrocell is generated with three sectors. Three small cells are located around the macrocell.

From Fig. 9, the three small cells' coverage areas can be expanded by using the CRE technique to offload some macrocell users located in the gray coverage areas. The dotted lines display the co-channel interference caused by the macrocell downlink transmission.

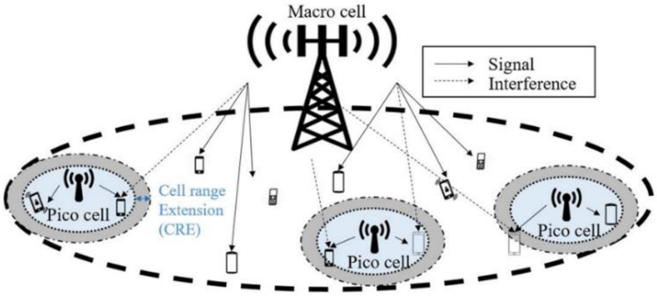


Fig. 9. Two-tier HetNet simulation scenario.

The plot of user distribution in the multitier network coverage area is illustrated in Fig. 10. The macrocell BS is located at the center represented with the red circle. The three small cells collocated in the same coverage area are also plotted as the three red circles located near the edge.

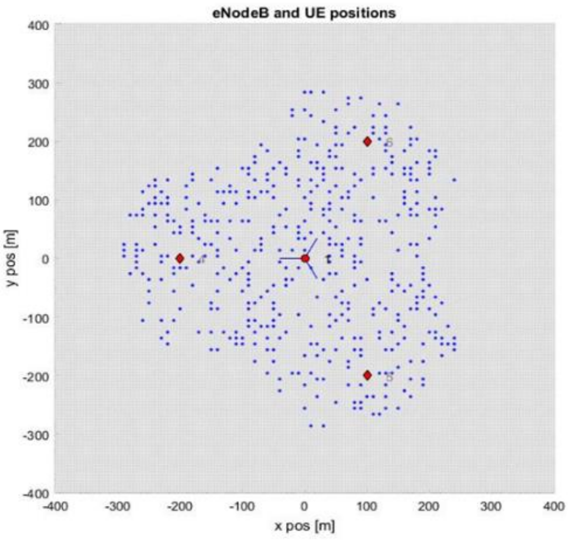


Fig. 10. User distribution in the test scenario.

The number of UE generated as seen in the figure is 500 to simulate the high user density area, which means high data traffic demand. This scenario has been implemented to study the HetNet objective in offloading the users from the macrocell in the high-density situation along with the comparison of the system performance under different CRE, ABS, and scheduler configuration settings.

4.2. Simulation Parameters

Table 1 presents the simulation parameters employed in this study. Most of the parameters presented in the table refer to those given in the 3GPP recommendations.

Table 1. Font type and size list for EJ's template.

Parameters	Value
System Frequency	2.1 GHz
Bandwidth	10 MHz
Distance between small cell BSs	500 m
Number of UEs	500 UEs
Transmitter power of macrocell	46 dBm
Transmitter power of small cells	30 dBm
UE distribution	Uniformly distribution and hot spot
Number of RB	50 RBs
CRE bias value	5dB / 8dB / 11dB / 14dB
ABS ratio	0.1 / 0.3 / 0.5 / 0.7 / 0.9
Scheduler types	Round Robin (RR), Proportional Fair (PF), Best-channel Quality (Best-CQI), Maximum Throughput (Max-TP), and Resource Fairness (RF)

5. Comparative Results and Discussion

5.1. The Simulation Results of LTE System with and without CRE

Using our adapted simulation model presented in the previous section, the simulation scenario shown in Fig. 9 was implemented. The initial set of results is presented in this section. The LTE HetNet system is embedded with the CRE implementation to observe the traffic offloading effect as the small cells' coverages are expended. The congested traffic scenario has been created with 500 UEs. The simulation results are obtained in terms of the peak throughput, the average throughput, the cell-edge throughput, and the fairness index for the system without CRE implemented and the system with CRE implementation.

In this study, the scheduler is fixed as a round robin scheduler to observe solely the effect of implementing the CRE mechanism with different CRE bias values.

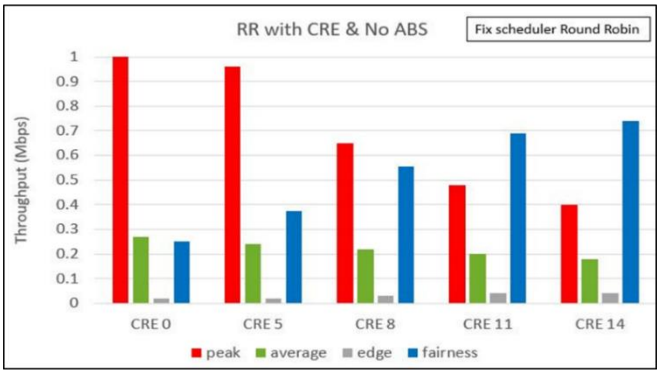


Fig. 11. System performance for different CRE configurations.

Illustrated in Fig. 11, the first four bars on the left side of the plot represent the simulation results obtained from the traditional LTE-A system without implementation of the CRE mechanism (labeled with CRE0 in the figure), hence no ICIC offloading technique being employed. The rest of the plot presents the simulation results obtained from the system with CRE implementation using different CRE bias values i.e. 5, 8, 11, and 14 dB. It can be seen that the traditional system offers the highest peak throughput and average throughput. This is because a much lower number of users are served by the small cells in comparison with the macrocell although they operate on the same bandwidth. Hence, the users supported by the small cells tend to achieve very high throughput leading to higher average throughput as well as peak throughput. On the other hand, the system embedded with the CRE mechanism offers a higher cell edge throughput and fairness index. This is because some users can be offloaded from the stronger signal of the macrocell to the expanded coverage area of the small cells for better resource sharing. The results show that the higher the CRE bias values (with the maximum level of 14 dB), the better the fairness. In other words, CRE allows more equalized throughput for all the users.

5.2. The Simulation Results of LTE System with CRE and ABS

This section provides the simulation results observed from the system integrated with both CRE and ABS mechanism along with the results obtained from the traditional system as a reference. The scheduler is fixed here as the round robin scheduler to see solely the effect of CRE and ABS configuration settings. Figures 12-15 present the simulation results for the peak throughput, the average throughput, the cell edge throughput, and the fairness index, inconsequently. Each plot consists of five groups of four-colored bars. Each group represents the results of the system operated with different ABS ratios i.e. no ABS, 0.1, 0.3, 0.5, 0.7, and 0.9. The four-colored bars illustrated the results for the system operated with different CRE bias values i.e. no CRE, 5, 8, 11, and 14.

From Fig. 12 illustrating the peak throughput performance, the results go in line with that presented in Fig. 11 for the system implemented with solely CRE mechanism, in which the more CRE bias value, the lower the peak throughput. This can be seen via the reducing trend in each group of the four-colored bars. For different ABS ratios, the peak throughput results are in similar ranges with slightly higher values for the ABS ratio of 0.9. This causes by the highly reduced interference from macrocell since it has been blanked for 90% of the time allowing the small cells' users to achieve a higher throughput.

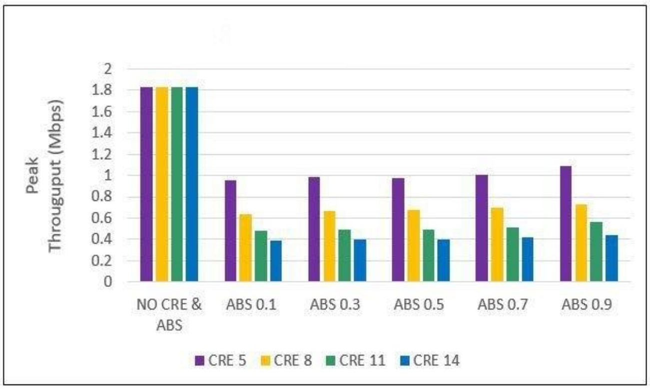


Fig. 12. Peak Throughput Performance for the System with CRE and ABS.

A similar trend of results can be seen for the average throughput performance as shown in Fig. 13 for a similar reason. When implementing CRE, the higher the CRE bias value, the lower the average throughput. However, varying ABS ratio does not offer an obvious trend. This is because although several users are offloaded from the macrocell to provide the system fairness, more blank subframes offer lower interference to those small cells' users.

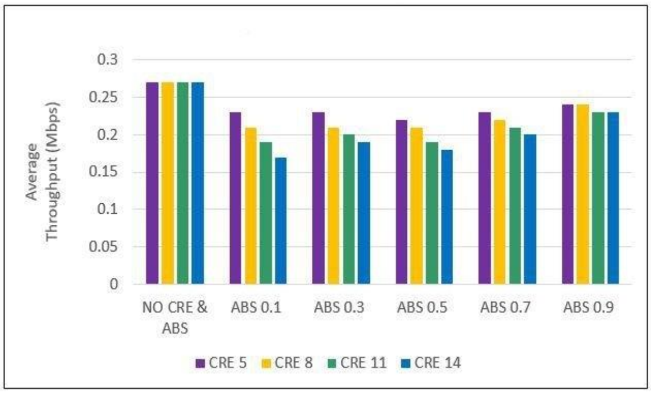


Fig. 13. Average Throughput Performance for the System with CRE and ABS.

Figures 14 and 15 present the cell edge throughput performance and the fairness index. It can be seen here for the cell edge throughput that for each four-colored bars of the same ABS ratio, the higher CRE bias values being set, the better cell-edge throughput can be achieved. Nevertheless, for the ABS ratios of 0.5, 0.7, and 0.9, the overall trend of cell-edge throughput performance gets worse, especially at the ABS ratio of 0.9.

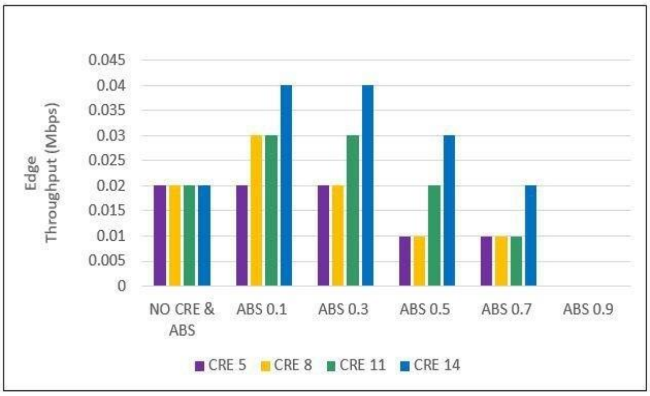


Fig. 14. Cell Edge Throughput Performance for the System with CRE and ABS.

Refers to the definition of cell-edge throughput calculation, the five-percentile of all user's throughput has been used in this work to calculate the cell edge throughput. As a result, all users are considered in the calculation including the macrocell users with the weak received signal. These users would hardly achieve any data transfer at all under the implementation of the ABS mechanism with the ABS ratio of 0.9 (90% of blanked subframes). From the cell edge throughput results shown in Fig. 14, the best performance could be offered by using the configurations of CRE bias of 8, 11, or 14 with an ABS ratio around 0.1 to 0.3. However, earlier results have shown that the higher the CRE bias value, the peak, and average throughput would get worse. When looking at the performance in terms of fairness index given in Fig. 15, the best set of results is offered with the ABS ratio of 0.3.

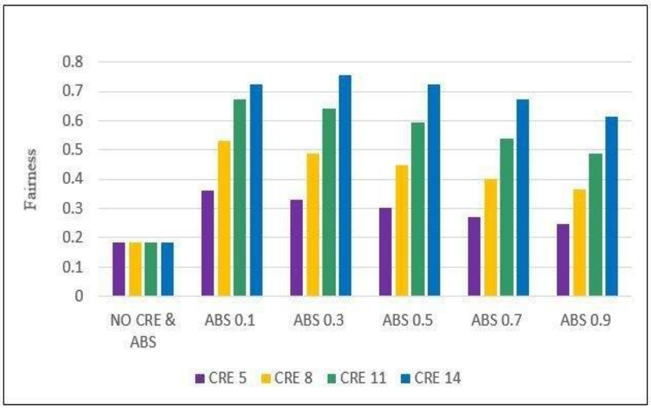


Fig. 15. Fairness Index Performance for the System with CRE and ABS.

5.3. The Simulation Results of LTE System with CRE and ABS using Different Schedulers

This section discusses the simulation results for the system implemented with both ABS and CRE mechanisms along with the system performance comparison when using the five different schedulers i.e. RR, PF, RF, Best-CQI, and Max-TP.

5.3.1. Peak Throughput Performance

Figure 16 presents the simulation results for the peak throughput performance of the system using the five schedulers for the CRE bias value of 5, 8, 11, and 14 dB, respectively. The general effect of varying the CRE bias values to the peak throughput and average throughput has been discussed in the previous section 5.2. In section 5.2, the results show that by increasing the CRE bias values, the peak throughput and the average throughput decrease. It can be seen in this section as for the overall results shown in Fig. 16 that it follows the same conclusion as given in section 5.2. The overall peak throughput results presented with a CRE bias value of 14 dB are in general lower than that presented with a CRE bias value of 11, 8, and 5 dB. When looking into each plot of Fig. 11, it can be seen that when varying the ABS ratio, different schedulers offer different trends. For the system using RR scheduler, shown with the grey bars in each figure, the results go in line with that presented in the previous section 5.2 (Fig. 12). As the ABS ratio increases, the peak throughput increases and in general offering lower levels than that of the traditional system. This is due to the offloading effect. For PF, and RF scheduler, varying ABS ratio does not show the obvious trend or effect towards the peak throughput performance. In general, using RR, PF, and RF scheduler offers a lower peak throughput than that of the traditional system since these three schedulers have been designed to provide a certain level of fairness among users. On the other hand, the trend of the peak throughput performance offered by the Best-CQI, and Max-TP scheduler is different. For these two schedulers, the peak throughput is always higher than that of the RR, PF, and RF scheduler. This is because the mechanism of the Best-CQI and Max-TP schedule is designed to enhance those users with better signal or throughput performance. As when increasing the ABS ratio, the peak throughput reduces for the system operating with the Best-CQI and Max-TP schedule. This is in contrast with the results from the system operated with the RR scheduler. The best configuration to achieve the highest peak throughput is by using the CRE bias value of 5 dB and ABS ratio of 0.1.

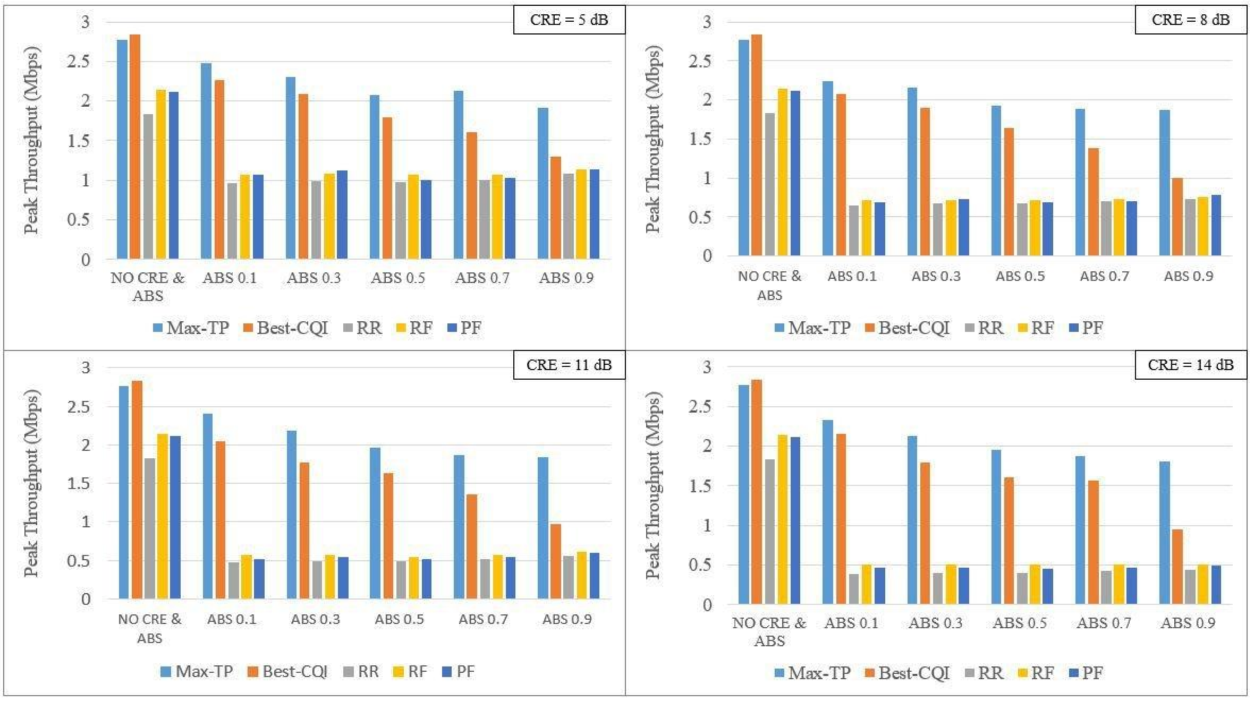


Fig. 16. Peak Throughput Performance with Schedulers Comparison.

5.3.2. Average Throughput Performance

Figure 17 displays the simulation results for the average throughput observed from the system using the five schedulers for the CRE bias value of 5, 8, 11, and 14 dB, respectively. A similar trend to the peak throughput performance, the higher ABS ratio results in lowering the average throughput for all values of CRE bias. This is caused by the increasing amount of blank subframes operated by the macrocell users. Again, the three schedulers including RR, PF, and RF offer lower average throughput in comparison with that offered by the Best-CQI and Max-TP scheduler. The best value for the average throughput can be achieved with the CRE bias value of 5 dB and the ABS ratio of 0.3.

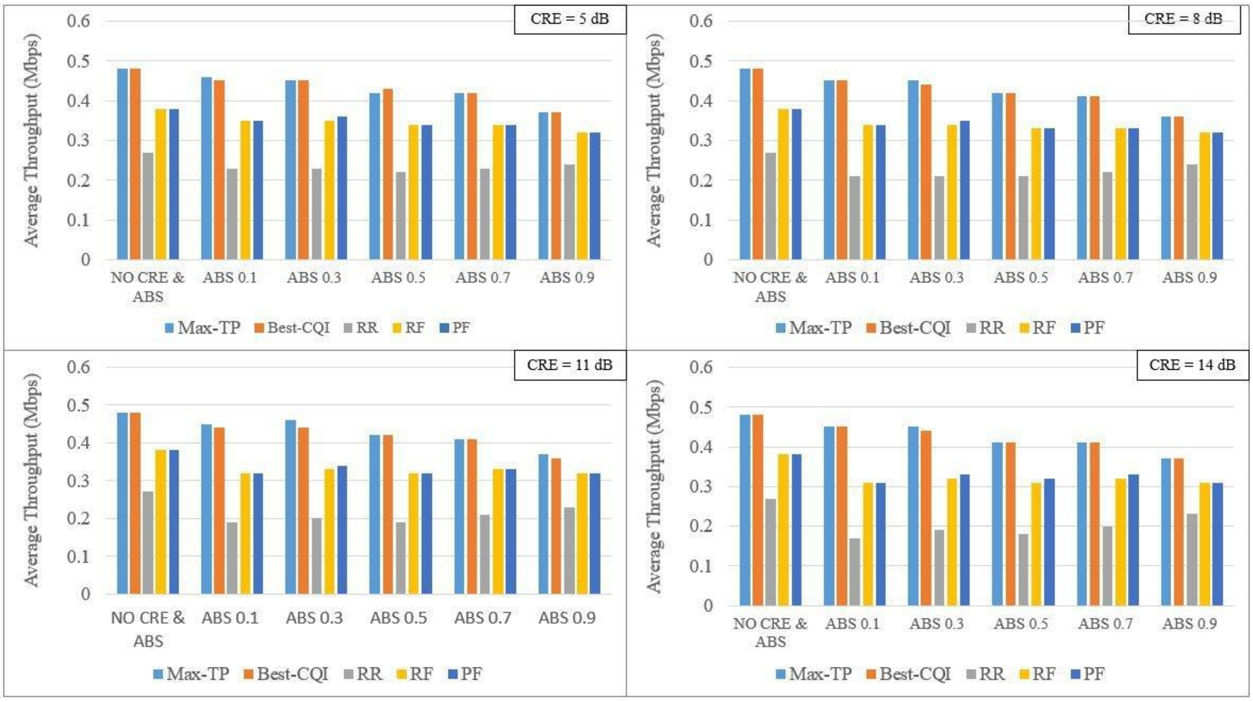


Fig. 17. Average Throughput Performance with Schedulers Comparison.

5.3.3. Cell Edge Throughput Performance

The simulation results for the cell edge throughput performance are given in Fig. 18 for the LTE-A HetNet system employing the five schedulers. The CRE bias value of 5, 8, 11, and 14 dB have been configured. Comparing the results of the four plots in Fig. 18, it is obvious that increasing the CRE bias value could allow better cell edge throughput in general. This follows the same trend as the results shown in section 5.2. Note that the number of users generated in this study is considered as a high traffic situation.

When implementing the Best-CQI and Max-TP scheduler, it can be seen that the offered cell edge throughput is low regardless of the ABS ratio and CRE bias value. This is because the two schedulers are designed to enhance the already-good condition users. On the other hand, the RR, PF, and RF along with certain ABS and CRE configurations offer a better cell edge throughput than that of the traditional system. When varying the ABS ratio, the trend of the cell edge throughput looks slightly like a bell shape with the high cell edge throughput at ABS ratio of 0.1, 0.3, or 0.5. For the RR scheduler, the configuration that offers the best cell edge throughput performance is at a CRE bias value of 14 dB and ABS ratio of 0.1 or 0.3. For the PF and RF scheduler, the configuration that offers the best cell edge throughput performance is at a CRE bias value of 14 dB and ABS ratio of 0.3 or 0.5. Among the three schedulers, the best cell edge throughput is offered by the PF scheduler.

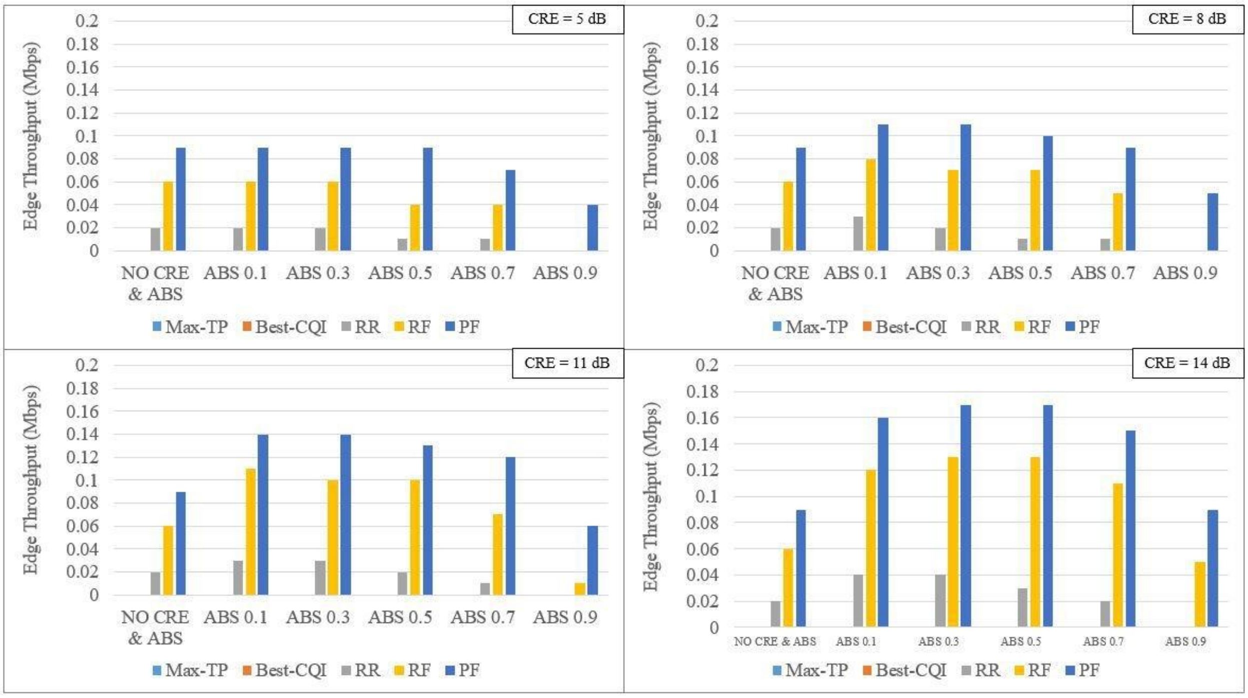


Fig. 18. Cell Edge Throughput Performance with Schedulers Comparison.

5.3.4. Fairness Performance

Figure 19 illustrates the simulation results for the fairness index performance of the system using the five schedulers for the CRE bias value of 5, 8, 11, and 14, respectively. Jain's fairness is the index that measures the equality of every user resource block allocation. If all the users get the same amount of resource blocks equally, then the fairness index is 1. In such a case, the system is considered 100% fair. On the other hand, the fairness decreases because each user does not get the same amount of resource blocks so the value of fairness gets nearer to 0 [15].

Figure 19 demonstrates that the performance in terms of fairness is highly similar to the cell edge throughput and the results deviated with the ABS and CRE configurations as well as the behavior of each scheduler in the same way presented for the cell edge throughput. In general, increasing CRE bias value increases fairness. For Best-CQI and Max-TP, increasing the ABS ratio increases fairness. On the other hand, RR, PF, and RF offer the best fairness when implementing with ABS ratio around 0.1, 0.3, or 0.5.

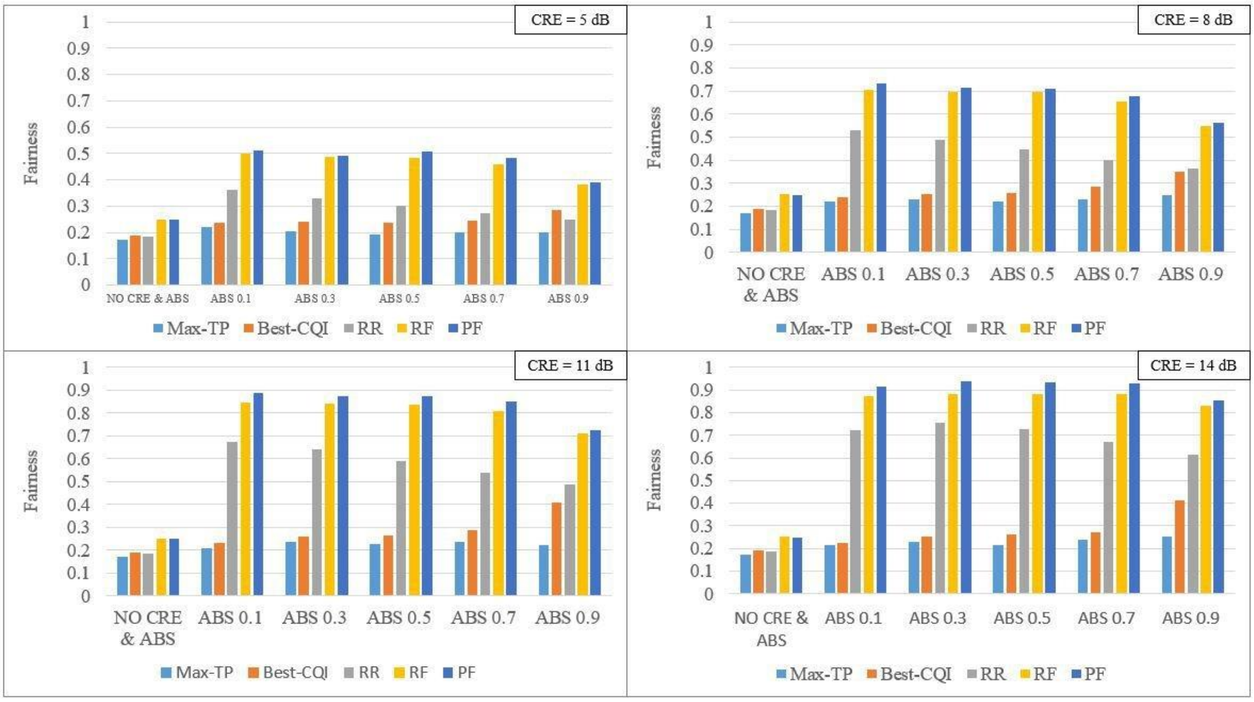


Fig. 19. Fairness index Performance with Schedulers Comparison.

6. Conclusions

In this work, the major eICIC techniques including CRE and ABS mechanisms for the LTE-A HetNets have been studied. The effect of their configuration setting on the overall system performance has been investigated. Major contributions are the comparative study of the system performance as the LTE-A system is integrated with the CRE and ABS mechanisms and operating with the five different types of schedulers i.e. RR, Best-CQI, Max-TP, PF, and RF. The system performance has been observed via the system level simulator adapted here in terms of the peak throughput, the average throughput, the cell edge throughput, and the fairness index.

For the system integrated with the CRE mechanism, it can be concluded that by increasing the CRE bias value (up to 14 dB), the peak throughput and the average throughput are decreasing. On the other hand, the cell edge throughput and fairness index are increasing. Increasing CRE (up to a certain level) means part of the traffic running on the macrocell is offloaded to the underutilized small cells allowing better resource sharing. For the system integrated with the CRE and the ABS mechanisms, the more CRE bias value, the lower the peak throughput and the average throughput, while the higher the cell edge throughput and the fairness index can be achieved. For different ABS ratios, the peak throughput and the average throughput results are in similar ranges with slightly higher values for the ABS ratio of 0.9. For the effect of the ABS ratio towards the cell edge throughput and the fairness index, the ABS ratio of around 0.3 offers the best outcomes.

As for the performance comparison of the system integrated with CRE and ABS techniques as well as operating with the five different schedulers, the general conclusion gained earlier on the effects of varying the CRE bias value and ABS ratio seems to go in line with these set of results. Using higher CRE bias values typically provides better results in terms of the cell edge throughput and fairness. Although the best configuration setting should refer to the detailed results presented in section 5, the five schedulers can be grouped into those offering the high peak throughput and average throughput, which are the Best-CQI and Max-TP, and those offering high cell edge throughput and fairness index, which include RR, PF, and RF. The Best-CQI and Max-TP schedulers are beneficial for the users located in the close range to the base station, however, they are not helping users located around the edge at all. Instead, RR, PF, and RF try to offer a fair share of the resource among users based on different decision-making criteria.

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DOI:10.4186/ej.2021.25.8.39

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