QoS Performance Evaluation of Disjoint Queue Scheduler for Video-Applications over LTE-A HetNets

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ABSTRACT

Long Term Evolution-Advanced (LTE-Advanced) supports both the use of Carrier Aggregation (CA) and the use of Heterogeneous Networks (HetNets). The main contribution of this paper was in modifying the LTE-Sim simulator to support the use of Disjoint Queue Scheduler (DQS) for a HetNet deployment of a macro-cell and a variable number of pico-cells. Then evaluating and comparing the Quality of Service (QoS) performance of the DQS based MLWDF, with DQS based EXP-Rule, and with SC MLWDF. The QoS performance evaluation is based upon the average users' throughput, Packet Loss Rate (PLR), and average packet delay.

Experimental results showed that the use of the DQS can double the pico-cells' users throughput with a loss of fifth of the macro-cell's users throughput. The use of the DQS also increased the PLR and the packet delay values for both type of users. The use of both DQS schedulers, the DQS based MLWDF and DQS based EXP-Rule had a similar fluctuating performance in terms of average users' throughput and PLR. However, the the DQS based MLWDF had a slightly better performance in terms of packet delay.

Keywords

Long Term Evolution-Advanced (LTE-A), Heterogeneous Network (HetNet), Carrier Aggregation (CA), Disjoint Queue Scheduler (DQS), Modified Largest Weighted Delay First (MLWDF), Exponential Rule (EXP-Rule), Macro-cell, Pico-cell, LTE-Sim, Quality of Service (QoS)

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ICCCNT '16, July 06-08, 2016, Dallas, TX, USA

ACM 978-1-4503-4179-0/16/07.

<http://dx.doi.org/10.1145/2967878.2967883>

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1. INTRODUCTION

Heterogeneous Networks (HetNets) are networks which consists of macro-cells, and low power nodes such as pico-cells or femto-cells. HetNets allow cellular network operators to support higher data traffic by offloading it to a smaller cells such as pico-cells [13].

Meanwhile, Carrier Aggregation (CA) allows the network to aggregate more than one carrier in-order to provide higher bandwidth. Here, each separate carrier which is being aggregated is called a Component Carrier (CC). Figure 1 shows the principle of carrier aggregation. In 3GPP Release 8/9, User Equipment (UE) can receive at most one Carrier Component (CC) up to 20 MHz of bandwidth. Meanwhile, Release 10/11, UE can receives two CCs up to 40 MHz of bandwidth. In Release 12, a UE can receive three CCs with up to 60 MHz of bandwidth. Carrier aggregation in the uplink and the downlink directions is completely independent as long as the number of uplink carriers cannot exceed the number of downlink carriers [7] [3]. In addition, three types of carrier components allocation were defined by the Third Generation Partnership Project (3GPP) including, intra-band continuous, intra-band non-continuous, and inter-band non-continuous as Figure 2 shows [14].

Figure 1: The principle of carrier aggregation

Carrier aggregation has four main deployment scenarios. Some of them are recommended for homogeneous network deployments, whereas others are recommended for HetNets deployments. The four main deployment scenarios are shown in Figure 3 [8]. In Figure 3, the macro-cell has three sectors. The coverage areas in blue “light shading” refers to Frequency 1 (f_1), and it is called the primary frequency. The coverage areas in purple “dark shading” refers to Frequency 2 (f_2), and it is called the secondary frequency. (f_1 is greater than f_2).

Figure 2: Carrier aggregation cases

In Scenario 1, both the (f_1) and (f_2) carrier components are operating at the same band or the frequency separation is small. This leads to similar coverage. In Scenario 2, the (f_1) and (f_2) carrier components are operating at different bands or the frequency separation is large, and this leads to a different coverage. Hence (f_1) will be used to provide sufficient coverage, and (f_2) will be used to provide extra throughput. Next in Scenario 3, both (f_1) and (f_2) are operating at different bands, but (f_2) is used to increase the cell-edge throughput by directing (f_2) antennas to (f_1) cell boundaries. These three scenarios are best suited for homogeneous networks layout. However, for a heterogeneous networks layout, it is best to use Scenario 4, in which (f_1) is used by the macro-cell, and (f_2) is used by the pico-cell. In this scenario, the CC that is provided by the macro-cell, has a lower frequency which will result in a higher coverage. Meanwhile the carrier component that is provided by the pico-cell have a higher frequency and lower coverage [8]. A larger view of Scenario 4 is shown in Figure 4 [10].

There are two main deployment approaches for LTE-A HetNets using CA “Scenario 4”. One approach uses a centralized architecture, and the other one does not use a centralized architecture. Both approaches consider the macro-cell to be the Primary Cell (PCell) in each sector, and the pico-cells to be the Secondary cells (SCells). More detailed differences of these two approaches are listed in Table 1 [10].

1.1 Contribution

The first contribution of this paper was in modifying the LTE-Sim simulator to support the use of Disjoint Queue Scheduler for a HetNet deployment of a macro-cell and a variable number of pico-cells. The use of the DQS will allow the user to be scheduled on multiple carrier components,

Figure 3: The four main deployment scenarios for CA [8]

Table 1: centralized vs. non-centralized architecture approach

Centralized architecture	Non-centralized architecture
The same spectrum deployment is used for the three sectors of the 3-sectored macro-cell.	Different spectrum deployment will be used in each sector of the 3-sectored macro-cell.
Higher spectral efficiency will be achieved because all the spectrum frequencies are available in each sector.	Multiple frequency bands might not be used most efficiently.
Very challenging to limit inter-cell interference.	Inter-cell interference is minimized.
Centralized processing for synchronization and tight coordination is needed.	Such synchronization and tight coordination is not necessary.
Very challenging to provide mobility between cells using the same frequency.	Providing mobility is not a challenge.

Figure 4: The deployment of HetNets “3-sectored macro-cell, and pico-cells” using carrier aggregation [10]

e.g. the carrier components of both the macro-cell and the pico-cell at the same time.

Then, the second contribution was in comparing the QoS performance of a three cross carrier aggregation scenarios. The first aggregation scenario included the use of the DQS that is based on the MLWDF algorithm, and it was called “DQS MLWDF”. The second aggregation scenario included the use of the DQS that is based on the EXP-Rule algorithm, and it was called “DQS EXP-Rule”. The third aggregation scenario included the use of the MLWDF and the use of a single carrier only, i.e, users are scheduled to a single carrier, either the macro-cell carrier or the pico-cell carrier, and it was called “SC MLWDF”.

2. RELATED WORK

The main difference between scheduling in LTE and LTE-A with CA is in the ability of scheduling the same user to different Carrier components as long as the user exists in the coverage of both carriers. If we take a quick look at the recent literature on Radio Resource Management (RRM) techniques for LTE-A with CA, we can see that the general structure of these schedulers could be classified into two main structures, the Joint Queue Scheduler (JQS) as shown in Figure 5 and the Disjoint Queue Scheduler (DQS) as shown in Figure 6 [8].

Figure 5: Joint Queue Scheduler (JQS) [8]

Figure 6: Disjoint Queue Scheduler (DQS) [8]

In both scheduling structure, the scheduling process is divided into two stages; the first stage is performed at the carrier level and it is called the CC selection and management, and the second one, which comes after is performed at the sub-carrier level and it is related to the packet scheduling. In the DQS, there is a separate algorithm for each stage, and it is used to reduce the complexity as in [22] [18]. However, in the JQS, the two stages scheduling process is performed by one algorithm, and it is used to improve the performance as in [22] [21]. In the DQS, each user has one traffic queue

on each CC. However, in the JQS, each user has only one joint queue for all the CCs, and this queue is shared by all the CCs. This pool of CCs is considered by the JQS scheduler as one carrier when it maps users’ traffic to all the RBs in all the CC [8].

In regards to the CC selection and management algorithms, the most used algorithms in terms of load balancing are; the random selection, circular selection, least load, and modified least load. The benefit of using the Random selection as in [15] [16] of carrier components for users, is that it allows for an effective load balancing over the long term. However, it leads to an unbalanced loading in the short term. The use of the circular selection as in [22] [20] provides better performance than the Random selection. However, it is inefficient when the users packet sizes are significantly different. The use of the Least Load algorithm as in [6] [17] result in choosing the carrier component with the least traffic load. Hence, a better performance is achieved if compared with another schemes that don’t consider the traffic load. The use of the Modified least load (M-LL) as in [22] perform load balancing while taking into consideration the varying channel gain. However, it requires an accurate estimation of future average user rates.

In regards to the packet scheduling, there are lots of packet scheduling algorithms, each has its own unique utility function, whether to increase the throughput, or to decrease the delay, or to improve the fairness. A good classification of these algorithms that is based on their characteristics is found in [5]. One of these algorithms classes that is related to this work is the QoS-aware/channel-aware algorithms’ class. The Modified Largest Weighted Delay First (MLWDF) [2] and Exponential Rule (EXP-Rule) [12] algorithms are an example of the QoS-aware/channel-aware class. The MLWDF scheduling algorithm is designed to support multiple real time data users by taking into account their different QoS requirements. And its delay function is bounded by the Largest Weighted Delay First (LWDF) scheduler. The LWDF metric is based on the system parameter, representing the acceptable probability for the i -th user, in which a packet is dropped due to deadline expiration [2]. In regard to the EXP-Rule scheduling algorithm, its delay function is bounded by an exponential equation [12]. Both the MLWDF and the EXP-Rule uses the Proportional Fairness (PF) [4] scheduler to achieve channel awareness. The PF scheduler makes a trade-off between users’ fairness and spectrum efficiency. It schedule users in a fair way by taking into account both the experienced channel state and the past data rate when assigning radio resources. And its objective function aims to obtain satisfying throughput and at the same time, guarantee fairness among flows [14] [5].

3. EXPERIMENTS

3.1 Experimental Set-up

In this paper, two different network deployments were used. The first one consisted of one macro-cell that is served by one transmitter with a power of 43 dB, and 10 pico-cells. The other one consists of one macro-cell and 20 pico-cells. In both deployments all the pico-cells lie inside the coverage of the macro-cell, and each pico-cell is served by one transmitter with a power of 30 dB. The bandwidth of the

Table 2: Experimental Parameters

Parameter	Value
Macro-cell transmission range “cell radius”	500 m
Macro-cell’s sector numbers	one sector
Macro-cell’s antenna type	Omni-directional
Pico-cell transmission range “cell radius”	50 m
Macro-Cell frequency band and bandwidth	Band-20, 20MHz
Pico-Cell frequency band and bandwidth	Band-7, 20MHz
MUE to PUE “MUE:PUE” percentages	9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, 1:9
Users’ distribution in each cell	Random
Users’ movement’s speed and direction	3Km/h, random
Traffic type	Video
Video Bit-rate	440 Kbps
maximum delay	0.1 sec
Frame structure	FDD

macro-cell and of each pico-cell was fixed to 20 MHz. For both network deployments, the three cross carrier aggregation scenarios were used.

Also, in this paper, users which were in the coverage of the macro-cell coverage area only were called “MUEs”, and users which where in the coverage of the macro-cell in addition to one of the pico-cells were called “PUEs”. In all scheduling scenarios, the percentage of MUEs to PUEs (MUE:PUE) was varied over nine different percentages in-order to study the optimal percentage of macro-cell users to pico-cell users.

In regards to the total number of users, it is chosen to be 200 in all experiments, and this number choice was based on researching the related work that exists in the literature which uses the LTE-Sim simulator as its simulation framework, i.e. [8] [11] [14] [13] [19] [1] [9], we can see that they all consider the maximum number of users to be 200 users or less, and this is due to the simulator performance limitations.

In regards to the total experimental running time, for each percentage in each scenario in each network deployment, the running time was 50 sec “which is equal to 50,000 Transmission Time Intervals (TTI), in which the scheduling process is repeated every TTI”, and each experiment was repeated three times and the final results were averaged, then the final results were used in the plots that are shown in Figure 8, so the total number of experiments that was done is equal to 324 experiments, resulting in a total running time of 16,200 seconds. More detailed parameters of these experiments are also listed in Table2.

3.2 Experimental Results

The LTE-Sim simulator takes into account both signalling and data traffic. However, in its traces, it only displays data traffic. Overall, the generated data traffic traces were used

to measure key QoS parameters such as the average user throughput, Packet Loss Rate (PLR), and average packet delay. These measured QoS values were then plotted by using the MUE:PUE ratio for the x-axis, i.e, see plots in Figure 7.

3.2.1 Average User’s Throughput

it is defined as the average amount of received packets for each user per second. These values are measured per macro-users, and pico-users separately. Now according to Figure 7-a, the use of the “DQS MLWDF” and “DQS EXP-Rule” aggregation scenarios has a similar fluctuating performance. However, this performance differed from the use of the “SC MLWDF” aggregation scenario. With regard to the PUEs, the average user’s throughput values increased significantly from 17_KBps “in what it was in the “SC MLWDF” aggregation scenario” to 30_KBps. This is because the PUEs were scheduled to both radio bands, i.e, the macro-cell’s band and the pico-cell’s band. Meanwhile, for the MUEs, their average throughput values dropped from 17_KBps “in what it was in the “SC MLWDF” aggregation scenario” to 13_KBps. This occurs since the macro-cell’s radio band was shared by both the MUEs and the PUEs. Finally, in terms of (MUE:PUE) percentages, the average throughput per MUE and PUE remained constant except at 9:1 and 1:9 it dropped 4_KBps.

According to Figure 7-b, doubling the number of pico-cells did not affect the throughput values, i.e, they remained almost the same for both the PUEs and MUEs in all the aggregation scenarios. This occurred because the network did not reach its maximum value of throughput per user. This is also why the optimal MUE:PUE percentage could be considered as any percentage of the nine tested percentages.

3.2.2 Packet Loss Rate (PLR)

it is measured by dividing the difference between the total transmitted and received packets for all users over the total transmitted packets. These values were measured per macro-users and per pico-users separately. According to Figure 7-c, when the the “SC MLWDF” aggregation scenario was used, the PLR values for the PUEs and MUEs showed almost a symmetric reverse results. This is due to the fact that traffic was offloaded in an equal gradual amount from the macro-cell to the pico-cells. The decrease in PLR values for an increase in the amount of offloaded traffic is due to the decreasing number of packets in the waiting queues that are competing for the same resource blocks. In general, this will lead to a lower rate of dropped packets from these queues. The optimal MUE:PUE percentage regarding the minimal PLR values in this aggregation scenario was seen to be 5:5. Namely, at this percentage value the PLR value dropped to almost zero for both the MUEs and PUEs.

Now with regard to both aggregation scenarios, the “DQS MLWDF” and “DQS EXP-Rule”, they showed a similar fluctuating performance in terms of PLR also. The PLR values in regards to the MUEs increased to 0.22, and it remained close to this value despite the decrease in their percentages. Regarding the PUEs, the PLR values increased to 0.13, and it remained mostly around this value despite the increase in their percentages until the number of MUEs and PUEs

Figure 7: The Experimental results

was equal. Then, the PLR values started to increase with an increase in their percentages. All this is likely because the users which were being offloaded from the macro-cell to the pico-cells were still competing with the MUEs, and they were still sharing macro-cell's resources, e.g., radio bands and waiting queues. The optimal MUE:PUE percentage for the minimal PLR values in both aggregation scenarios was found to be about 5:5.

According to Figure 7-d, when the number of pico-cells was doubled, a slight improvement in the PLR values was seen for PUEs in both aggregation scenarios, the "DQS MLWDF" and "DQS EXP-Rule" were used. However, the PLR remained the same when the "DQS MLWDF" aggregation scenario was used. This is due to the fact that the available resources for the PUEs were increased.

3.2.3 Average Packet Delay

it is measured as the time which a packet takes to travel from the source to destination. It includes the propagation and waiting time of the packet. Meanwhile, The average packet delay is measured by dividing the sum of a total packet delays that were successfully received over the total number of packets. These averaged values were measured per macro-users and per pico-users separately.

Now according to Figure 7-e, when the "SC MLWDF" aggregation scenario was used, the average packet delay values started to decrease for the MUE with a decrease in their percentages. This occurs since traffic was being offloaded gradually to pico-cells, which resulted in a gradual release of the available resources, e.g., the waiting queues. This allowed the packets to be outputted for transmission quicker.

Also in both aggregation scenarios, the "DQS MLWDF" and "DQS EXP-Rule", the average packet delay remained almost the same for the MUEs with a decrease in their percentages, but with a slightly better performance to the use of the "DQS MLWDF" aggregation scenario. This is due to the fact that the users which were being offloaded from the macro-cell to pico-cells were still sharing the macro-cell band. Also the macro-cell's transmitter was still generating packets for those users, so its waiting queue has almost the same number of packets.

Now with regard to PUEs, the average packet delay values are also shown in Figure 7-e. These values started to increase for the PUEs with an increase in their percentages. However, the minimum delay value was 0.01 sec when the "SC MLWDF" aggregation scenario was used, but it was 0.03 sec when the "DQS MLWDF" aggregation scenario was used, and it was 0.032 sec when the "DQS EXP-Rule" aggregation scenario was used. The increase in all the aggregation scenarios is due to gradual traffic offloading from the macro-cell to the pico-cells which gradually fills the waiting queues of the pico-cells transmitters with packets. In addition to this, the PUEs receive packets from the macro-cell's transmitter, and it is much further than the pico-cell transmitter yielding a higher transmission time which leads to a higher delay values.

Finally, according to Figure 7-f, doubling the number of

pico-cells resulted in almost an identical delay values, except for the case when "SC MLWDF" aggregation scenario was used and at an equal users percentages. Also, the average packet delay increased slightly for both the MUEs and PUEs. The optimal MUE:PUE percentage for the least equal delay was observed to be 5:5.

4. CONCLUSION

The paper provided a comparative study on the effects of using the disjoint queue scheduler for video applications in a HetNet deployment with a one macro-cell and a variable number of pico-cells on the users' QoS. Users were classified into macro-cell users or pico-cell users based on their location and service coverage. And the QoS parameters which were studied include user average throughput, packet loss rate, and average packet delay. In-order to test this, the LTE-Sim was modified to support the use of disjoint queue scheduler in a HetNet deployment with a one macro-cell and a variable number of pico-cells. Experimental results show that the average pico-cells user throughput almost doubled when disjoint queue scheduler was used. However, this increase came with a cost of decreasing the average macro-cell user throughput by a factor of about 0.2. Also, the Packet Loss Rate (PLR) values increased with the use of the disjoint queue scheduler, increasing on an average of almost three to four times for pico-cells users, and five to six times for macro-cell users. The use of both DQS schedulers types, the DQS based MLWDF and DQS based EXP-Rule had a similar fluctuating performance in terms of average users' throughput and PLR. The average packet delay values also fluctuated between minimum and maximum values depending upon the percentage of macro-cell to pico-cells users. However, the maximum value did not change with the use of the disjoint queue scheduler. Nevertheless, the minimum values increased five times for the macro-cell users and three times for the pico-cells users. The optimal users percentages for minimal PLR and average packet delay were at an equal number of users from different types. The use of the DQS based MLWDF had a slightly better performance than the DQS based EXP-Rule in terms of packet delay. Experimental results also show that doubling the number of pico-cells will not make significant QoS improvement unless the number of users was increased in a way that will congest the network. Upon the experimental results, it is recommended to use the disjoint queue scheduler for non-real time video traffic.

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