SCHEDULING SCHEMES FOR CARRIER AGGREGATION IN LTE-ADVANCED SYSTEMS

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Abstract

Considering the needs of higher data rates and hence wider bandwidths for advanced mobile communication systems, 3GPP standardized carrier aggregation (CA) as one of the important technological components for fourth generation (4G) Long term evolution (LTE) advanced systems. Here the user equipments are assigned carrier component (CC) belonging to different (Inter-band contiguous/noncontiguous) or same spectrum bands (Intra-band contiguous/non-contiguous). The users share the radio resources as per different scheduling schemes like round robin(RR), proportional fair (PF), best channel quality indicator (CQI), max-min, edge prioritized, channel traffic aware etc. Every scheduler has its own characteristic and provides improvement in terms of throughput or fairness. This paper discusses the simulations carried out to study the performance of RR, PF and best CQI schedulers in an urban, CLSM (closed loop spatial multiplexing) environment using an LTE system level simulator.

Keywords: *Carrier Aggregation, Fairness, Round Robin, Best CQI, Proportional Fair Scheduling Schemes, Throughput.*

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1. INTRODUCTION

To cater to the needs of fast processing applications running on innumerable internet connected wireless devices like smart phones, laptops, palmtops etc. Third Generation Partnership Project (3GPP) proposed carrier aggregation technology in LTE Release 10. Carrier aggregation, a promising technology, has been standardized by ITU as a fourth generation technological component for achieving the target data rates of 1 Gbps in downlink [1] and 500 Mbps in uplink [2]. Such high data rates are achievable with wider bandwidths of up to 100 MHz spectrum [2]. The 3GPP LTE systems operating with transmission bandwidths of 1.4 MHz, 4MHz, 5MHz and 20 MHz provided the base for the upcoming 100MHz IMT-Advanced mobile systems i.e. LTE Advanced systems.

In CA, multiple carrier components (CCs) of LTE standards, having different bandwidths and located in same or different frequency bands can be aggregated to obtain the bandwidth of up to 100 MHz for providing the user equipments the transmission speeds of up to 1 Gbps and 500 Mbps in downlink and uplink respectively. The unused or surplus secondary carrier components of one cell can be utilized efficiently by combining it with the primary carrier component of geographically different cell (both the cells being served by different base stations) [2]. This enables efficient utilization of the scarce radio resources (spectrum) of the wireless world.

Figure 1 shows the Radio Resource Management (RRM) framework of an LTE-Advanced system implementing CA with aggregation of 3 carrier components. Allocation of resources to different LTE-Advanced system user equipments is done by layer 2 packet scheduling (PS).

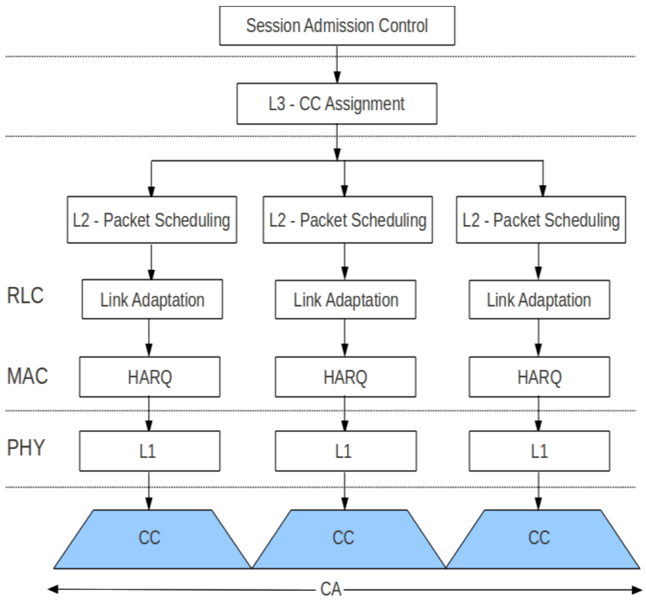

Fig- 1: Radio resource management framework of CA in an LTE-A system

Figure 2 shows the changes required at the medium access control (MAC) and the physical layer protocols so as to ensure compatibility between the R8/R9 and R10 User equipments.

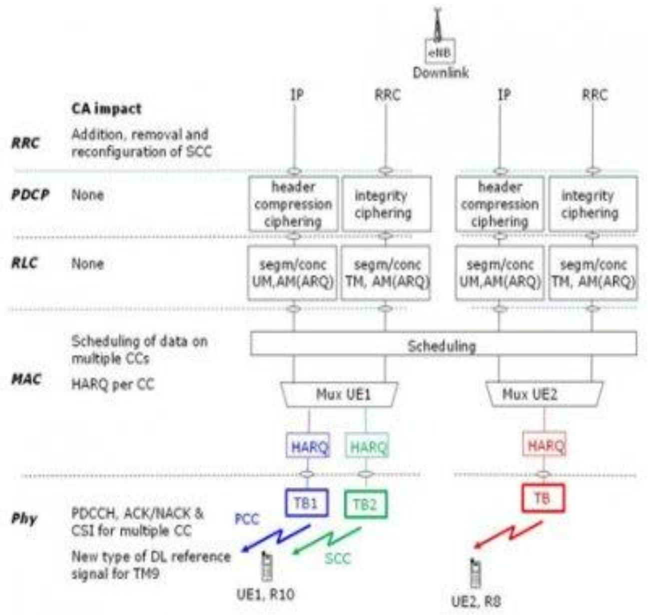

Fig. 2: LTE protocols for the radio interface, with main changes due to introduction of CA.

While the MAC layer is made capable to handle scheduling on multiple CCs, the physical layer should be able to handle the HARQ ACK/NACK per CC and CSI for multiple CC. The RRC layer should support addition, removal and reconfiguration of secondary carrier component (SCC) to enable CA.

2. CA CLASSIFICATION

Figure 3 shows the classification of the CA techniques for implementation in 4G systems for achieving higher data rates.

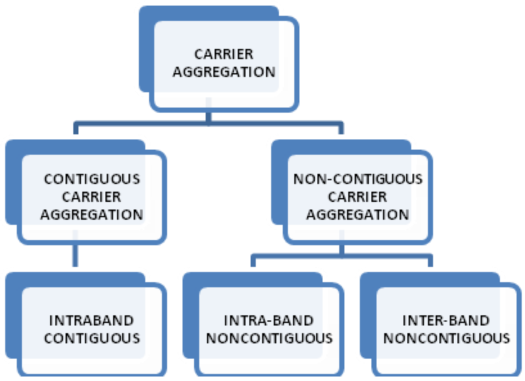

Fig-3: Types of Carrier Aggregation

In contiguous CA, multiple CCs adjacent to each other are aggregated to provide wider bandwidths. If these CCs belong to same spectrum the CA technique is called as Intra-band contiguous CA [5]. The feasibility of this technique (from service provider's point of view) is low because it is difficult for the service providers to find a big chunk of contiguous spectrum. This technique would be feasible when 3.5 GHz bands would be available to providers. When multiple CCs, located apart in the same spectrum band, are allotted to a UE then we have intra non-contiguous CA. In Inter-band noncontiguous CA, multiple CCs belonging to different bands having different properties e.g one belonging to 2100 MHz and other belonging to 800 MHz may be aggregated to provide a wide spectrum. Deployment of CA, with these combinations of CCs with different properties, demands efficient scheduling schemes for reliable transmissions with less errors and delays. In past few years, various carrier scheduling schemes have been proposed for both uplink and downlink CA with contiguous and non-contiguous CC scenarios.

3. PACKET SCHEDULING SCHEMES

Packet scheduling is one of the prime RRM mechanisms. To enable efficient transmission each user is allocated suitable radio resources. This demands for optimized packet scheduling algorithm(s).An appropriate packet level scheduling algorithm which takes into consideration the quality of service (QoS) requirements of each user and achieves a certain level of fairness, leads to an increase in the system capacity and service performance of the service provider. Apart from being efficient the packet scheduling algorithm should also be flexible (work efficiently in diverse traffic scenario) and have reasonable computational complexity (easily implementable) [7]. Broadly two types of packet scheduling schemes have been worked upon by various researchers in the wireless. communication field. As user equipment, located at different geographical locations, experience diverse channel conditions on account of multipath propagation, shadowing etc. channel aware scheduling schemes and channel blind scheduling schemes have been proposed.

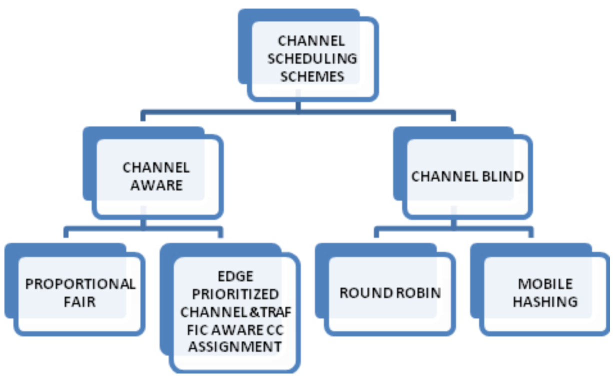

Fig-4: Packet Scheduling Schemes

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Table 1 shows widely accepted packet scheduling (PS) algorithms in wireless systems[8].

Table -1: Scheduling in 3G and LTE systems

Aspect	**WCDMA**	**HSDPA**	**LTE**
Scheduling Speed	TTI=10ms, High RRT and channel	TTI=2ms, Fast scheduling	TTI=1ms, Dynamic Scheduling

	setup time consumption		
Scheduling Controller	MAC-c in RNC	MAC-hs in Node B	MAC of Control plane in eNode B
Scheduling mechanisms	User-Specific PS; Cell-Specific PS	Based on favourable channel condition of user	Frequency-Time based, OFDMA based
Scheduling algorithms	Maintaining capacity for existing user while dividing remaining capacity into new arrivals	Round Robin (RR) Scheduler, Maximum C/I scheduler, Proportional Fair (PF) algorithm	Request Activity Detection (RAD) scheduler and PF scheduler, OFDMA scheduling, Max-Max with OFDM PF

3.1 Round Robin (RR)

RR algorithm allows the users to access the shared resources turn by turn in circular order. There by giving every user an equal opportunity for accessing the shared resources. Being a channel blind PS algorithm, its throughput is comparatively worse than that of other channel aware PS algorithm. However it offers greater fairness and better bandwidth utilization and is the most widely used scheduling algorithm for time sharing systems for scenarios other than the high speed point to point scenarios.

3.2 Proportional Fair (PF)

Kelly et. Al [9] originally proposed PF scheduling as an alternative to max – min scheduler. This technique offers a trade off between the maximum average throughput and user fairness. It increases the degree of fairness amongst the user equipments by selecting users with high relative channel quality (ratio of user's instantaneous achievable data rate and the data rate of user i at time t). PF scheduling algorithm achieves multiuser diversity [10-11] by scheduling users having peak instantaneous channel quality, to transmit during different time slots. The scheduling metric M is defined as [8]:

$$M = \arg\max \frac{r_i(t)}{R_i(t)}$$

Where $r_i(t)$ is instantaneous achievable data rate and $R_i(t)$ is the average data rate of user i at time t.

3.3 Best CQI Scheduling Algorithm

It is designed to give priority of access to users having strongest channel conditions. During downlink communications the BS provides reference signals to the users using which the users carry out CQI measurements for knowing the quality of their channel. There is tradeoff between the cell capacity and fairness to the users, in systems implementing best CQI algorithm [12]. Cell edge users located at larger distances from BS have less probability of getting access to the shared resources.

4. SIMULATION MODEL

The LTE system level simulator [13] with simulation parameters of table 2 has been used to compare the performance of the above 3 scheduling schemes - round robin, proportional fair and best CQI. The scenario considered here is an urban scenario with inter site distances (ISD) of 500 mtrs, with 20 UEs, per eNodeB, placed randomly.

Table -2 System Parameters

Parameter	**Value**
Frequency of operation	2.5 GHz
System bandwidth	20 MHz
Number of Transmitting and receiving antennas	2x2
Transmitting mode	Closed loop spatial multiplexing
Number of UE per eNodeB	20
Simulation time	25 TTI
User speed	5 Km/hr
Channel model	Winner II
eNodeB distances	500
Minimum coupling loss	70
Simulation scenario	Urban
Thermal noise density	-174
Schedulers	Best CQI, Round robin, Proportional fair

5. PERFORMANCE EVALUATION AND ANALYSIS

From the figure 5 it can be seen that the best CQI scheduler provides maximum throughput as compared to the other 2 (round robin and proportional fair), as it assigns the shared resources first to the users with strong channel conditions and then to rest of the users. RR scheduling being a blind channel algorithm does not take into consideration the channel conditions but assigns equal amount of shared resources to all the users in cyclic manner. Systems using RR scheduler have lowest throughput because of ignoring the UE feedbacks (regarding the channel conditions). On the other hand PF scheduling, considering multiuser diversity, provides reasonable throughput for the given scenario.

Statistically it can be seen from the graph of figure 5 that if PF scheduling is implemented, 55% users will have 3 Mbps throughput while under similar conditions with RR schedulers 70% of users and with best CQI schedulers 85% of users have 3 Mbps throughput.

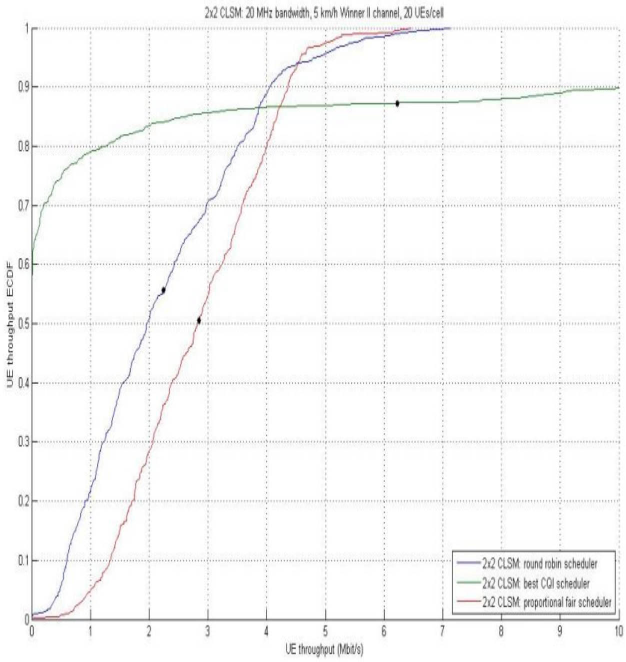

Fig-5: UE throughput for different packet schedulers

The performance of the schedulers changes for throughput beyond 4 Mbps. Using PF scheduler 98% of users have 5 Mbps throughput while the percentages are 95 % and 88% respectively for RR and best CQI respectively for 5 Mbps throughput value. Hence, best CQI scheduler gives uniforml performance for the entire range of throughput. PF schedulers prove to be better compared to RR scheduler in terms of the higher throughput (>4.5Mbps).

Figure 6 gives the throughput for 3 different scenarios (mean, edge, and peak) for all the three schedulers. It can be seen that CQI schedulers perform better than RR and PF schedulers for users near to eNodeB and those in the coverage range of eNodeBs as their channel conditions are stronger as compared to cell edge users. Users near the cell edges having poor channel conditions can have better throughputs with PF (or its variant) schedulers as compared to RR scheduler. The fairness factor is least in case of best CQI and higher in case of PF scheduler. Fairness can be quantified using Jain's fairness index [14],

$$J(T) = \frac{\left(\sum_{k=1}^{K} T(k)\right)^2}{K\left(\sum_{k=1}^{K} T^2(k)\right)}$$

Where T is a vector of simulated user throughputs. J(T) varies from 1 to 0 indicating decreasing order of fairness and is inversely proportional to throughputs.

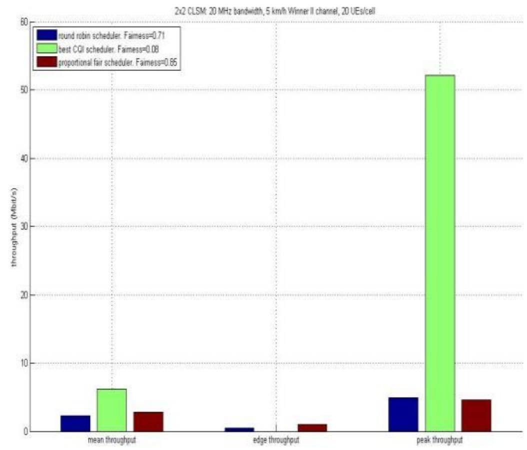

Fig- 6: Mean, Edge and Peak throughput of the RR, PF and best CQI Schedulers

Few of the many proposed schedulers for LTE have been compared, for their fairness, by S. Schwarz and et.al.[16]. The book by S. Caban and et.al. [16] discusses few examples of simulations carried out (using the Vienna LTE simulator [13]) for various scheduling schemes applicable both for LTE as well as LTE-Advanced systems.

6. CONCLUSIONS

The paper discusses the CC assignment and scheduling schemes for enabling CA in LTE-Advanced systems. From the simulation results it can be seen that for a CLSM environment, best CQI scheduler provides better performance as compared to RR and PF schedulers. For lower throughputs (<3.5 Mbps) best CQI scheduler provides 18% improvement in throughput as compared to RR and 30% improvement as compared to PF scheduler. For throughputs greater than 4.5 Mbps, PF scheduler gives about 12% improvement and RR scheduler gives 10% improvement as compared to best CQI scheduler. Also, edge users experience higher throughput when using PF schedulers as compared to other 2 schedulers. Whereas peak and medium throughput is achieved by using best CQI scheduler for urban users in areas away from edges of the cell.

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