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Resource Allocation Considerations for Multi-Carrier LTE-Advanced Systems Operating in Backward Compatible Mode

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***Abstract*— in this paper we focus on LTE-Advanced with backward compatibility, which serves a mixture of LTE-Advanced and LTE-Rel'8 users. Aggregation of multiple component carriers (CCs) to form a wide spectrum is assumed in order to fulfill the bandwidth requirement for the next generation systems, thereby leading to a multi-carrier system. Although a LTE-Advanced user can simultaneously access all the CCs, a LTE-Rel'8 user is restricted to operate on a single CC at a time. Different methods for balancing the load across these CCs will affect the system performance. This is investigated through both analytical methods and system level simulations. Bearing in mind that the LTE-Advanced users are scheduled on more CCs than the LTE-Rel'8 users, we propose a simple cross CC packet scheduling algorithm that improves the resource allocation fairness among the two categories of users. This simple scheduling algorithm is shown to be effective in providing better coverage performance with no loss of the overall cell throughput, as compared to independent scheduling per CC.**

I. Introduction

The wireless communication systems have experienced dramatic growth since the introduction of the cellular concept in the 1960s [1]. They are now capable of providing users with high data rate and a variety of service types [2]. In continuation of this, the 3rd Generation Partnership Project (3GPP) has started a study item on Long Term Evolution (LTE)-Advanced [3], which aims at fulfilling the requirements for International Mobile Telecommunications - Advanced (IMT-Advanced) [4]. For this purpose, a wider bandwidth than the 20MHz of the current LTE Rel'8 systems [5] will be used. This wide bandwidth can go up to 100MHz [6]. The current spectrum utilization pattern excludes the possibility of assigning a contiguous wideband; thereby it needs to be obtained via carrier aggregation (CA) of individual component carriers (CCs), where each CC follows the LTE Rel'8 numerology. This leads to multi-carrier LTE-Advanced. In order to allow backward compatibility so LTE Rel'8 and LTE-Advanced users can co-exist, it has been decided to use independent layer-1 transmission, which contains Link Adaptation (LA) and Hybrid Automatic Repeat request (HARQ) etc, per CC in coherence with the LTE Rel'8 assumptions [7].

The migration from single to multi-carrier systems has previously been studied for High Speed Downlink Packet Access (HSDPA) [8], [9]. Two categories of users are specified in [8]: one is capable of simultaneously accessing all the CCs, whereas the other is restricted to operate on only one CC. Most of the studies in literature assume only one type of the users. However, in a backward compatible LTE-Advanced system, there will be a mixture of the two categories of users. Assuming that the objective is to have similar coverage and fairness for different user categories, it is necessary to update the resource allocation in upper layers, so that a LTE Rel'8 user can get comparable resources with a LTE-Advanced user.

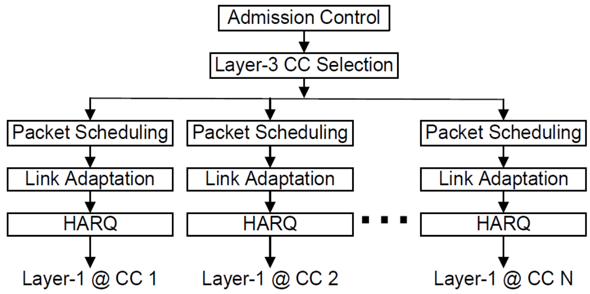

Fig. 1. Structure of a multi-component carrier LTE-Advanced system.

Fig. 1 illustrates the structure for a multi-component carrier LTE-Advanced system. The enhanced NodeB (eNB) first performs admission control to decide which users to serve, and then employs layer-3 CC Selection to allocate the users on different CCs. Different methods for balancing the load across these CCs will affect the system performance. Once the users are assigned onto certain CC(s), the layer-2 Packet Scheduling (PS) is performed. If independent PS per CC is used as pictured in Fig. 1, it cannot capture the difference between the number of CCs scheduled to the LTE-Advanced or Rel'8 users. Therefore the Rel'8 users will suffer from operating over much fewer resources than the LTE-Advance users. In order to ensure the LTE-Rel'8 users get comparable resources as the LTE-Advanced users, cross CC PS is required. Finally, the layer-1 transmission is performed within each CC.

In this paper we will first look into the problem of maximizing the system performance via layer-3 CC load balancing methods, then study the performance of independent and cross CC PS.

The rest of this paper is organized as follows: Section II explains different techniques under investigation; Section III provides the theoretical analysis for the performance with different load balancing methods; In Section IV, the simulation methodology and assumptions are described; Section V shows both analytical and simulation results in a backward compatible system using different load balancing methods and PS algorithms; Section VI concludes the paper.

II. INVESTIGATED TECHNIQUES FOR THE BACKWARD COMPATIBLE LTE-ADVANCED SYSTEM

In a multi-carrier LTE-Advanced system, the LTE-Advanced and Rel'8 users are treated differently, which is shown in Fig. 2. A LTE-Advanced user will be assigned on all CCs in order to increase the user experienced performance and maximize the overall cell frequency domain packet scheduling (FDPS) gain [10]. A LTE-Rel'8 user supports transmission on only one CC, thereby the eNB needs to select a proper CC, and assign it to the user. Two methods for layer-3 CC load balancing are studied:

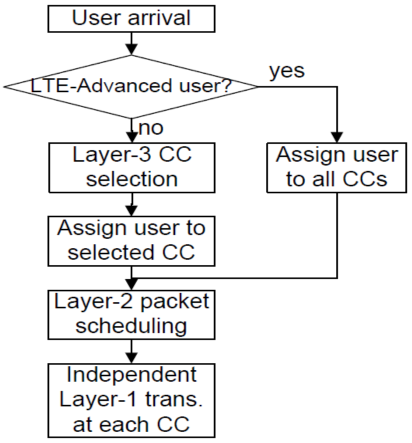

Fig. 2. Different ways to treat the LTE-Advanced users and the LTE-Rel'8 users for a LTE-Advanced system in backward compatible mode.

***Round Robin (RR) Balancing** [11]*

The basic principle for RR balancing is to assign the newly arrived LTE Rel'8 user to the carrier that has the least number of users. Thus, it tries to distribute evenly the load to all carriers. However, there might be small variation for the cell load in different CCs, because the number of users does not necessarily make an exact even over the CCs or because one or more users may leave the system at random.

***Mobile Hashing (MH) Balancing** [11]*

The MH balancing relies on the output from the user's hashing algorithm. The output hash values are uniformly distributed among a finite set, which maps directly on the CC indices. Thereby, it provides balanced load across CCs in the long term. However, at each instant, the load across CCs is not balanced and the system will suffer from reduced trunking efficiency.

After the CC assignment of the new user, PS at layer-2 is performed. This will decide on the resources one user can get within each CC. In our study, we select a commonly used frequency domain packet scheduler, namely Proportional Fair (PF) [12]. PF is aware of the channel condition for each user, and thereby can exploit the channel diversity to offer the FDPS gain compared to a channel blind scheduler. Two kinds of PS algorithms are investigated in this paper:

Independent PS per CC

This is similar to the PS in a traditional single carrier system, which does not consider the transmission characteristics from the other CCs. With the PF scheduler, the resource is assigned to a user that maximizes the metric on each CC [12]:

$$k_{i,j} = \arg\max_{k}\{Metric_{k,i,j}\} \quad (1)$$

where $k_{i,j}$ is the selected user on the i^{th} CC at the j^{th} Physical Resource Blocks (PRB) group. According to [13], each PRB is constituted with 12 consecutive sub-carriers, and one PRB group contains 3 neighboring PRBs. The traditional way to calculate the PF metric is [12]:

$$Metric_{k,i,j} = \frac{R_{k,i,j}}{\widetilde{R}_{k,i}} \quad (2)$$

with $R_{k,i,j}$ denoting the estimated throughput for user k on the i^{th} CC at the j^{th} PRB group and $\widetilde{R}_{k,i}$ the average delivered throughput for that user on the same CC. In the long term, the PF scheduler achieves an equal share of resources within each CC among users with same fading statistics [14]. However, considering the difference in CC assignment between the LTE Rel'8 user and the LTE-Advanced users, a LTE-Advanced user will get N times the resources as a LTE Rel'8 user, where N is the total number of aggregated CCs in the system.

Cross CC PS

By taking into consideration the statistics from all CCs, the packet scheduler can achieve an overall better resource allocation than independent scheduling. In order to reduce the complexity for upgrading the existing LTE systems, we propose a scheduling algorithm that still operates within each CC. The only difference from independent scheduling is that it takes the past user throughput over all aggregated CCs into account, i.e.

$$Metric_{k,i,j} = \frac{R_{k,i,j}}{\sum_{i=1}^{N}\widetilde{R}_{k,i}} \quad (3)$$

With (3), the LTE-Advanced users have a reduced scheduling metric because their overall throughput is higher than the throughput per CC. On the other hand, the LTE Rel'8 users maintain their scheduling metric, because their transmission and reception are restricted on only one CC. They are thereby prioritized as compared with the LTE-Advanced users in resource allocation, which meets the objective of similar fairness for all user categories. The possibility of further improving the single-CC user (Rel'8) throughput is investigated in details in [15], by putting different weights on the scheduling metric for the users.

III. THEORETICAL ANALYSIS OF LAYER-3 CC LOAD BALANCING METHODS

In this section, the performance for different load balancing methods is analyzed theoretically. In order to de-couple the transmission over multiple CCs, we use the simple approach of independent PS per CC. The performance with cross CC PS will later be evaluated based on system level simulations.

Within our analysis, we assume a frequency domain PF packet scheduler, which offers FDPS gain in terms of increase average cell throughput that follows a logarithmic function of the number of users k on each CC [10]. For our modeling purposes, we represent the FDPS gain for a LTE system in [10] with the sample approximation as:

$$G(k)=\begin{cases}1 & k=1\\ 0.11*\ln(k)+1.10 & 1<k\leq 13\\ 1.38 & k>13\end{cases} \quad (4)$$

Now let us consider a general case with N aggregated CCs and K active users per cell. If we assume that a user has probability α of being a LTE-Advanced user, then the probability of having K_a LTE-Advanced users out of the K active users equals:

$$P(K_a)=\binom{K}{K_a}\alpha^{K_a}(1-\alpha)^{K-K_a} \quad (5)$$

A. Throughput analysis with RR Balancing

If the RR carrier balancing method is used, the number of users on each CC equals:

$$\widetilde{K}=K_a+(K-K_a)/N \quad (6)$$

The average cell throughput with K_a LTE-Advanced users is:

$$TP_{cell}(RR,K_a)=CG(\widetilde{K})/G(\infty) \quad (7)$$

where C is the maximum achievable throughput over all CCs.

Combining (5), (6) and (7), we get the performance with α probability LTE-Advanced users:

$$TP_{cell}(RR)=\frac{C}{G(\infty)}\sum_{K_a=0}^{K}P(K_a)G(\widetilde{K}) \quad (8)$$

The average user throughput one each CC is the corresponding per CC cell throughput divided by the average number of users. Because the LTE-Advanced users are scheduled on N CCs, their throughput is expected to be N times that of the LTE-Rel'8 users. As a result, we have the following equation for the user throughput:

$$TP_{user}(RR)=N^{I}\frac{TP_{cell}(RR)}{\sum_{K_a=0}^{K}\widetilde{K}P(K_a)}=\frac{N^{I}}{K}\frac{TP_{cell}(RR)}{\alpha+(1-\alpha)/N} \quad (9)$$

In (9), $I=0$ if the user is LTE-Advanced, and $I=-1$ for Rel'8 users.

B. Throughput analysis with MH Balancing

If MH is used for carrier load balancing, each LTE Rel'8 user has equal probability of selecting any of the CCs, which is $1/N$. It offers balanced load in the long term and the throughput is N times the performance with only one CC. With K_a LTE-Advanced users, the probability for one CC to have k LTE Rel'8 users is:

$$P(k)=\binom{K-K_a}{k}\left(\frac{1}{N}\right)^{k}\left(\frac{N-1}{N}\right)^{K-K_a-k} \quad (10)$$

The cell throughput in this case is (N times the throughput per CC):

$$TP_{cell}(MH,K_a)=\frac{C}{G(\infty)}\sum_{k=0}^{K-K_a}P(k)G(K_a+k) \quad (11)$$

From (5) and (11), the overall cell throughput can be estimated by:

$$TP_{cell}(MH)=\frac{C}{G(\infty)}\sum_{K_a=0}^{K}P(K_a)\sum_{k=0}^{K-K_a}P(k)G(K_a+k) \quad (12)$$

Although the average user throughput on each CC can be estimated using a similar form as with RR, the overall user throughput is dependent on the load condition on all CCs. Due to this correlation, it is non-trivial to formulate the average user throughput and we will evaluate its performance based on simulation.

For both equation (9) and (12), if $G(k)$ equals 1 for all k (other than 0), we obtain the performance with frequency domain channel blind RR packet scheduler.

IV. Simulation Methodology and Assumptions

The performance of the algorithms is evaluated in a quasi static downlink multi-cell system level simulator that follows the LTE specifications defined in [16], including detailed implementations of layer-3 CC selection, layer-2 PS, HARQ and LA functionalities. The simulation scenario is Macro-cell case #1 as defined in [7]. The simulation parameters are summarized in Table I. The link to system mapping is based on the exponential effective metric model [17].

Note that, we aggregate 4 CCs, each of 10MHz to form a wide bandwidth of 40MHz. In case an even wider bandwidth is needed, more CCs can be aggregated together, or the bandwidth per CC can be extended. Simulation campaigns are conducted with 40 simulation runs (5.0 seconds in each run) with constant number of 10 users per cell. Multiple simulation runs are required for this traffic model in order to get sufficient statistics, since the traffic model is static in the sense that the 10 users per cell are active all the time.

Three kinds of throughput measures are used in our study as performance indicators:

- Cell throughput: Average throughput per cell, i.e. equals the summation of the user throughput in each cell.
- LTE-Advanced (or Rel'8) user throughput: Average throughput over all the simulated LTE-Advanced (or Rel'8) users.
- Coverage: The 5th percentile worst user throughput, over the simulated users.

TABLE I
SYSTEM SIMULATION SETTINGS

Parameter	Setting / description
Test scenario	3GPP Macro-cell case #1 (19 sites, 3 cells per site)
Carrier frequency	2 GHz
Aggregation configuration	4 CCs, with 10MHz per CC
Number of PRBs per CC	50 (12 subcarriers per PRB)
Sub-frame duration	1 ms (11 OFDM data symbols plus 3 control symbols)
Modulation and coding schemes	QPSK (1/5 to 3/4) 16-QAM (2/5 to 5/6) 64-QAM (3/5 to 9/10)
User receiver	2-Rx Interference Rejection Combining
HARQ modeling	Ideal chase combining
Max. number of retransmissions	4
Ack/nack & CQI feedback delay	6 ms
CQI frequency domain resolution	1 CQI per 3 PRBs
CQI reporting error	Log normal with 1dB std.
CQI reporting resolution	2 dB
Time domain PS	None (the eNB is able to schedule up to 20 users simultaneously)
Frequency domain PS	Proportional fair
1st transmission BLER target	10%
Number of UEs per cell	10
Traffic type	Full buffer

V. PERFORMANCE WITH DIFFERENT LOAD BALANCING METHODS AND INDEPENDENT / CROSS CC SCHEDULING

In this section, the performance for different carrier load balancing methods is evaluated using the theoretical analysis and the simulation methodology described previously. Different ways to perform the PS at layer-2 are also investigated.

A. Load balancing with independent PS per CC

As discussed before, the RR load balancing method achieves a balanced load across the multiple CCs in a short duration as compared with MH. In term of throughput, RR is also expected to be higher than MH. The relative gain in average cell throughput by using RR over MH is shown in Fig. 3, with different ratios of LTE-Advanced users. Both theoretical estimation and simulation result are shown. The absolute values of average user (both LTE-Advanced and LTE-Rel'8) throughput are summarized in Fig. 4.

From these two figures, we have the following observations:

1. In terms of average cell throughput, there is a good match between the theoretical estimates and the extensive system-level simulations, with maximum 1% deviation between the two. When all users are Rel'8, RR balancing provides ~7% higher cell throughput than MH. However, the gain decreases quickly with the ratio of LTE-Advanced user and it vanishes for the ratio beyond 20%. The reason is that the assignment of CCs to the LTE-Advanced users is always balanced. A high ratio of LTE-Advanced users thereby means a better balancing than with low ratio, hence less room for RR to improve over MH.
2. With the co-existence of both LTE-Advanced and LTE Rel'8 users, the Rel'8 users achieve much lower throughput than the LTE-Advanced user. Because the outage performance is collected from the 5% worst user throughput, a low LTE-Rel'8 user throughput therefore leads to poor coverage performance. MH offers lower throughput for the LTE-Rel'8 users than RR, which will leads to even poorer coverage as compared with RR.

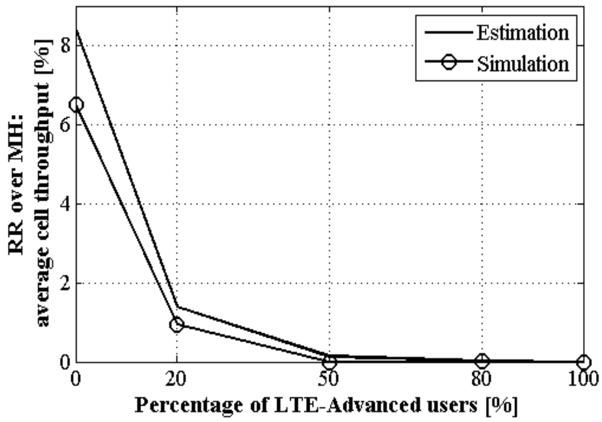

Fig. 3. Gain in average cell throughput by using RR balancing as compared to MH. Performance is evaluated with 10 users per cell and different ratios of LTE-Advanced users. Both estimated and simulated results are shown.

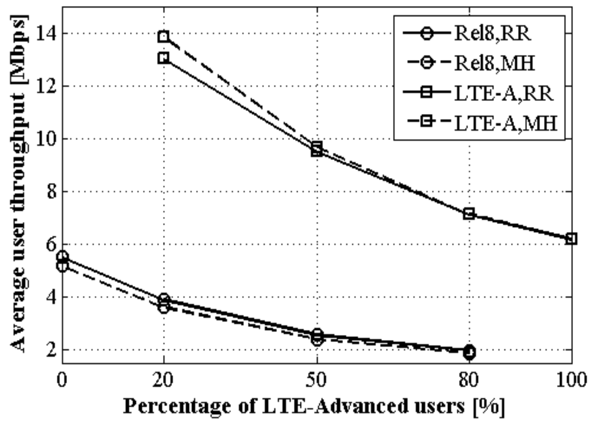

Fig. 4. Average user throughput for the two carrier load balancing methods. Results are obtained via simulation with 10 users per cell and different ratios of LTE-Advanced users.

B. Performance with independent or cross CC PS

We have seen that the load balancing method of RR offers better performance than MH. However, the Rel'8 users still suffer from much lower performance than LTE-Advanced users, which will cause poor coverage. By using cross CC PS as introduced in Section II, we can increase the priority for the Rel'8 users to be scheduled. Thereby cross CC PS is expected to offer better coverage performance than with independent PS per CC.

The performance with independent and cross CC PS is shown in Fig. 5 and Fig. 6 for average cell throughput and coverage, respectively. We are mostly interested in the performance with the load balancing method of RR. However, the performance for MH with independent PS is also presented for reference.

From Fig. 5 we can see that, there is no obvious gain, or loss, by using cross CC PS over independent PS. However, in terms of coverage performance, cross CC PS has a significant improvement over independent PS. When LTE-Rel'8 users are mixed together with the LTE-Advanced users, the gain is 50~90% over independent scheduling, as shown in Fig. 6.

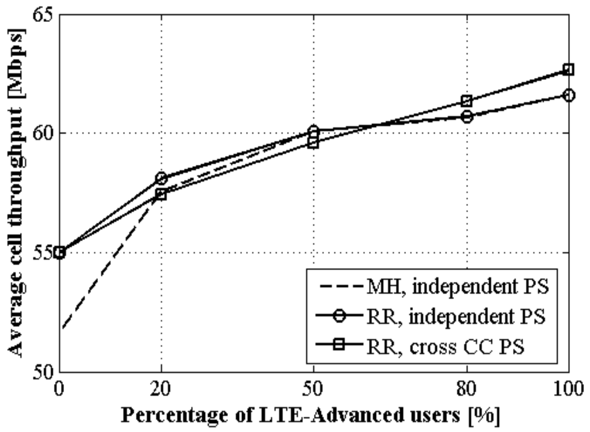

Fig. 5. Average cell throughput for independent or cross CC PS.

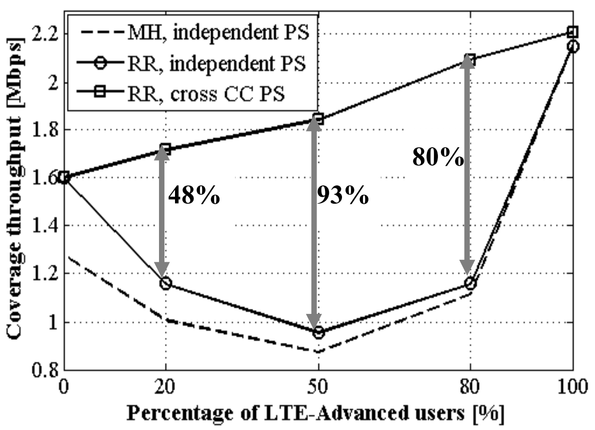

Fig. 6. Coverage performance for independent or cross CC PS.

VI. CONCLUSION

In this paper, we have studied the problem of how to accommodate the Rel'8 users in a multi-carrier LTE-Advanced system. Due to the terminal capability constraints, Rel'8 users can access only one carrier. They are thereby in a disadvantageous situation as compared to LTE-Advanced users, who can simultaneously access all carriers.

Both analytical and simulation results are obtained for two load balancing methods and different component carrier (CC) scheduling. The results show that with low number of users and low percentage of LTE-Advanced users, the load balancing method of RR achieves better performance than the MH balancing. However, the LTE Rel'8 users still suffer from lower throughput than the LTE-Advanced users, because of the independent scheduling per CC.

Motivated by the poor coverage performance, we proposed a cross CC PS algorithm, which is a simple extension of the existing PF scheduler. The cross CC algorithm is aware of the user throughput over all the aggregated CCs, it improves the scheduling priority for the Rel'8 users on its serving CC. As a result, this algorithm is able to significantly improve the performance of the LTE Rel'8 users. In terms of coverage, it offers a gain of 50~90% when LTE Rel'8 users and LTE-Advanced users co-exist in the same system. Despite of the high gain in coverage, it gives no degradation in the average cell throughput, and thereby provides a good solution for the LTE-Advanced systems to work in backward compatible mode.

As continuation of this study, we suggest to conduct further evaluations under more realistic traffic models, as well as including various updates coming from 3GPP as more decisions on LTE-Advanced are coming.

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REFERENCES

[1] S. Z. Asif, "Wireless Communications Evolution to 3G and Beyond," Artech House, Inc. 2007.

[2] E. Dahlman, S. Parkvall, J. Sköld, and P. Beming, "3G Evolution: HSPA and LTE for Mobile Broadband," Elsevier, 2007, ch. 2.

[3] S. Parkvall, E. Dahlman, A. Furuskar, Y. Jading, M. Olsson, S. Wanstedt, and K. Zangi, "LTE-Advanced – Evolving LTE towards IMT-Ad¬vanced," in Proc. IEEE VTC, pp. 1-5, Sept. 2008.

[4] Recommendation ITU-R M.1645, "Framework and overall objectives of the future development of IMT 2000 and systems beyond IMT 2000," June, 2003.

[5] H. Holma and A. Toskala, "LTE for UMTS, OFDMA and SC-FDMA Based Radio Access," John Wiley & Sons, 2009.

[6] 3GPP TR 36.913 v8.0.0, "Requirements for further advancements for E-UTRA (LTE-Advanced)," June, 2008.

[7] 3GPP TR 36.814 v1.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA Physical layer aspects," Feb. 2009.

[8] 3GPP TR 25.825 v1.0.0, "Dual-cell High Speed Downlink Packet Access (HSDPA) operations," June, 2008.

[9] K. Johansson, J. Bergman, D. Gerstenberger, M. Blomgren, and A. Wallén, "Multi-Carrier HSPA Evolution," in Proc. IEEE VTC, Apr. 2009.

[10] A. Pokhariyal, T. E. Kolding, and P. E. Mogensen, "Performance of downlink frequency domain packet scheduling for the UTRAN long term evolution," in Proc. IEEE PIMRC, pp. 1-5, Sept. 2006.

[11] T. W. Wong, and V. K. Prabhu, "Capacity Growth for CDMA System: Multiple Sectors and Multiple Carrier Deployment," in Proc. IEEE VTC, vol. 2, pp. 1608-1611, May, 1998.

[12] A. Jalali, R. Padovani, and R. Pankaj, "Data Throughput of CDMA-HDR a High Efficiency-High Data Rate Personal Communication Wireless System," in Proc. IEEE VTC, pp. 1854-1858, 2000.

[13] 3GPP TS 25.814 v7.1.0, "Physical layer aspects for evolved universal terrestrial radio access," Sept. 2006.

[14] J. M. Holtzman, "Asymptotic Analysis of Proportional Fair Algorithm," in Proc. IEEE PIMRC, vol. 2, pp. F-33-F-37, Oct. 2001.

[15] Y. Wang, K. I. Pedersen, M. Navarro, P. E. Mogensen, and T. B. Sørensen, "Uplink Overhead Analysis and Outage Protection for Multi-Carrier LTE-Advanced Systems," in Proc. IEEE PIMRC, Sept. 2009.

[16] 3GPP TS 36.300 v8.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description," Mar. 2007.

[17] K. Brueninghaus, D. Astely, T. Salzer, et al. "Link performance models for system level simulations of broadband radio access systems," in Proc. IEEE PIMRC, vol. 4, pp.2306 - 2311, Sept. 2005.