Qualcomm, Technologies, Inc.

Qualcomm Research

DC-HSUPA

February 2015

Qualcomm Research is a division of Qualcomm Technologies, Inc.

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Introduction

Adoption of smartphones is increasing globally, resulting in increased data traffic over HSPA networks. Users have come to expect 'always-on' connectivity, and in particular expect a consistent and 'always-good' user experience.

To be prepared for this smartphone era, the Third Generation Partnership Project (3GPP) has been working on the enhancements to Wideband Code Division Multiple Access (WCDMA) systems since Release 5. For one example, Dual Cell High Speed Downlink Packet Access (DC-HSDPA) was standardized by Release 8 and its deployments are currently occurring world wide.DC-HSDPA significantly boosts the capability of HSPA networks in providing satisfactory data service in the downlink. As a natural continuation, Dual Cell (DC) on uplink, so-called DC-HSUPA, was introduced in Release 9. This uplink DC operation is able to significantly improve the uplink data services in HSPA networks as elaborated below.

Brief Feature Description

As shown in Figure 1, DC-HSUPA enables the use of adjacent uplink carriers for an aggregated data pipe of 10MHz. The power amplifier requirements are the same as for the legacy single cell (SC) operation, which means that the maximum total power of both carriers is 24dBm or ≈250 mW. In other words, the two uplink carriers must share the total transmit power.

DC-HSUPA uses separate fast power control for each carrier as indicated by the fact that the DPCCH is

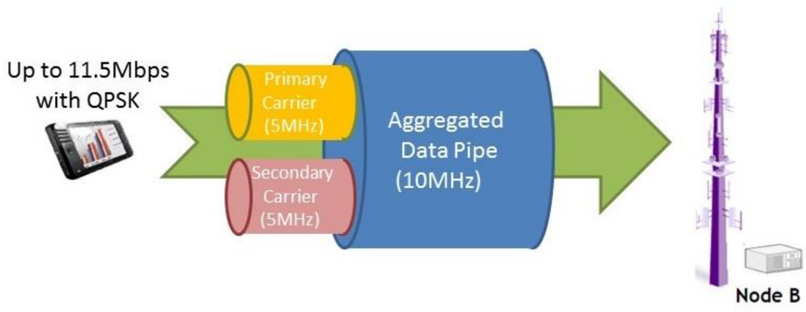
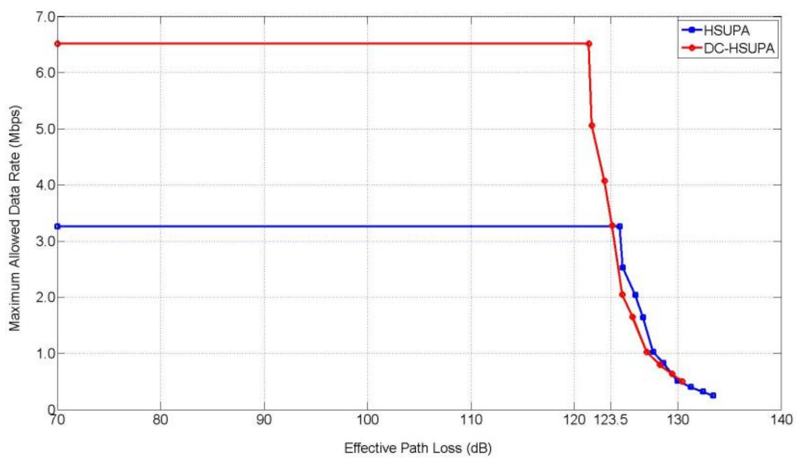


Figure 1: DC-HSUPA concept.

transmitted on both carriers. The presence of respective E-DPCCH and E-HICH on both carriers enables two HARQ engines running independently and, hence, a DC-HSUPA UE can transmit two independent transport blocks in each 2ms-TTI. A DC-HSUPA UE is specified to listen to E-AGCH and E-RGCH's on both carriers to receive respective serving grants determined by the NodeB according to the possibly significantly different loading conditions across carriers. Smart phone traffic is bursty and un-predictable in nature. Coordination at the connection management level as deployed by present day networks cannot eliminate the loading imbalance experienced in the PHY/MAC layers. Moreover, A DC-HSUPA UE is specified to maintain respective active sets on both carriers to exploit the proven soft-handover benefits for smooth handover.

Being a continuation of DC-HSDPA, DC-HSUPA shares the same motivation — to double the link data rate through carrier aggregation and to achieve better radio resource utilization through load balancing across carriers. Though the limited UE transmit power compared with that of NodeB may limit the UL data rate realization and the UL packet scheduling cannot simply exploit the multi-user diversity as in the DL, we will show with below intuitive examples that DC-HUSPA is able to significantly boost the UL system performance.

Figure 2 shows the dependence of achievable data rates (taking into account HARQ re-transmissions) on the effective path loss (EPL, including propagation loss, shadowing, antenna pattern gain, and building/vehicular penetration losses). The figure is based on a simple link budget analysis that assumes around 8dB RoT throughout the system and other cell interference contributes around 33% to the total interference. It can be observed that DC-HSUPA almost doubles the data rate compared to HSUPA until a certain limit in EPL, of approximately 120dB, beyond which the UE will suffer inadequate total transmit power to fully exploit DC. On the basis of Figure 2, we can predict that HSPA networks will significantly benefit from DC-HSUPA because, per network planning experience, ≥ 60% of the coverage area will have ≤ 120dB EPL in typical cellular lay-outs when the inter-site-distance (ISD) is smaller than 1.1km..

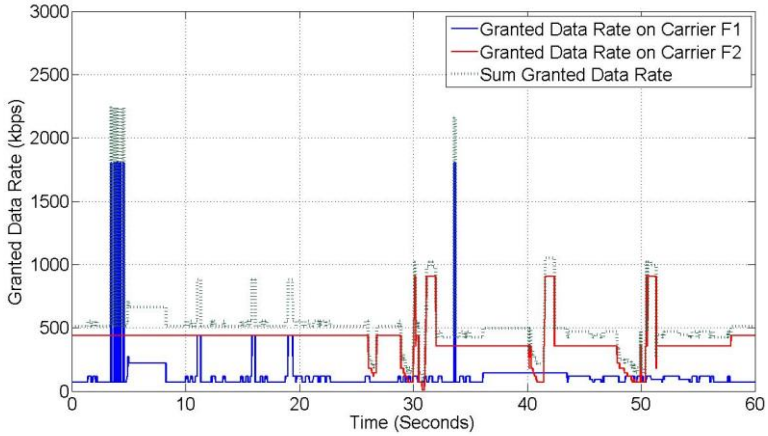


With DC-operation, a UE can use either or both the carriers on a TTI-by-TTI basis without radio bear re-configuration. This enables TTI-level load balancing when this capability is properly exploited by the network, which can lead to improved user experience for DC vs SC in scenarios with medium to high loading levels as shown in Figure 3. Fig. 3(a) plots traces of the granted data rates simultaneously received by two

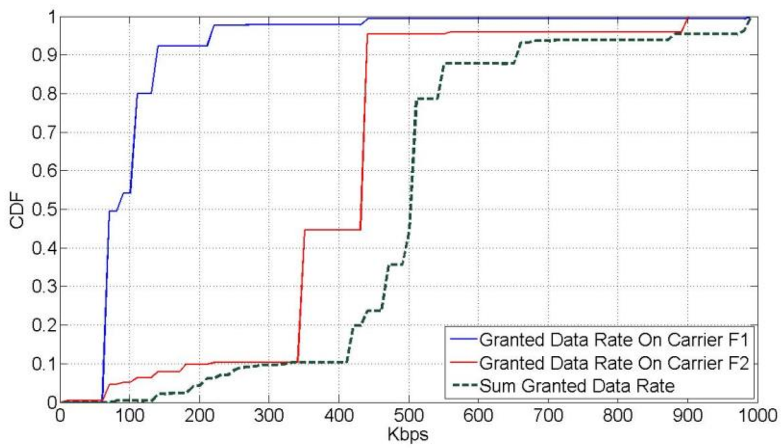
Figure 2: DC-HSUPA doubles the data rate before reaching the effective path loss limit.

HSUPA UEs served by the same operator on two different carriers F1 (in blue) and F2 (in red), respectively. These traces were obtained in the “busy hours” and, hence, the two UEs, especially the one on carrier F1, are not well-served. In particular, as shown in Fig. 3(b) the median data rate of the trace in blue is less than 100kbps. Though the trace in red provides a much larger median data rate, its 10-th percentile data rate is less than 200kbps. In the same situation a DC-HSUPA UE can have remarkably improved user experience as indicated by the sum granted data rates plotted in dark green. Per Fig. 3(b), the DC operation can offer about 550% and 15% improvements in median data rate, and about 500% and 60% improvements in 10-th percentile data rates over SC on F1 and SC on F2, respectively.

Last but not least, DC-HSUPA provides more power efficient solutions for achieving over 5Mbps data rate as illustrated in Figure 4. It shows the dependence of transport block size and effective code rate on E-TFCI. To achieve over 5Mbps data rate, HSUPA needs to utilize ≥ 10kbits transport blocks which, unfortunately, have close to one effective code rate considering one HARQ transmission. On the other hand, DC-HSUPA is able to achieve a similar data rate by transmitting in parallel two smaller transport blocks, say around 6kbits, which have the effective coding rate of ≈0.5. Per communication theory, reasonably smaller effective coding rate will lead to improved power efficiency as observed in our over-the-air (OTA) trials as detailed in the third part of the section of **System Performance Benefits**.



(a)



(b)

Figure 3: DC-HSUPA can utilize serving grants from both carriers for significantly improved user experience.

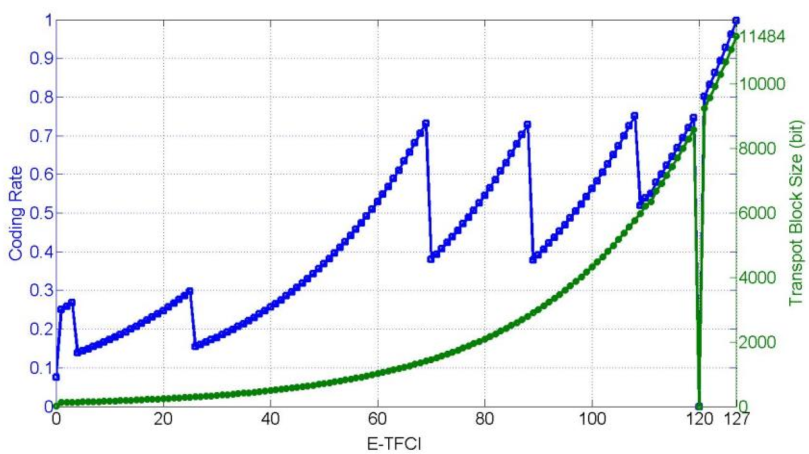


Figure 4: DC-HSUPA can achieve >5Mbps data rate using transport blocks with much more coding gains.

Application Performance Gains

In this section we present the application performance gains of DC-HSUPA measured on a prototype platform developed by Qualcomm Research. In particular, we measure FTP file upload time reduction, using HSUPA as the baseline, as one metric of application performance gain. As we are depending more and more on the smart phones for variety of daily activities, the importance of battery life is more prominent than before. This has motived us to measure the difference in energy consumption between a DC-HSUPA UE and a HSUPA UE running the same FTP uploading application, with typical configurations for RRC-state transition and enabling CPC.

In performing the prototype measurements we compare the performance of a DC-HSUPA UE (E-DCH Category 8) with that of a HSUPA UE (E-DCH category 6) when they are running the same FTP application and served by two respective prototype NodeBs with the same configurations. Each UE is assumed to be the only UE in the system. As a consequence, the DC-HSUPA UE receives the same serving grant (SG) across two carriers as the SG received by the HSUPA UE. Due to the limitation of our prototype NodeB, the SG is limited to grant transport block sizes no larger than 3605 bits. Each UE is connected to the corresponding NodeB through a channel emulator that emulates the fading channels according to the specified 3GPP channel profiles in the IMT2000 band. Monsoon power monitors are employed to measure the energy consumption of respective UEs. Both UEs are assumed to be put at locations with around 100dB EPL from the corresponding NodeB. To investigate the effect of TCP slow start, we have considered different file sizes, ranging from 1MB to 5MB.

Figure 5 summarizes the FTP performance results. It can be observed from Fig. 5(a) and Fig. 5 (b) that DC-HSUPA offers up to 45% gain in FTP upload time. The gain is slightly reduced for smaller file sizes where TCP may suffer slow start in comparison with the PHY throughput (not keeping the pipe full). As for the energy consumption comparison, Fig. 5(c) indicates that DC-HSUPA offers up to 33% gain in a PA3 channel and up to 34% gain in a VA30 channel. In addition, due to the TCP slow start, the energy consumption gain is reduced for smaller file sizes.

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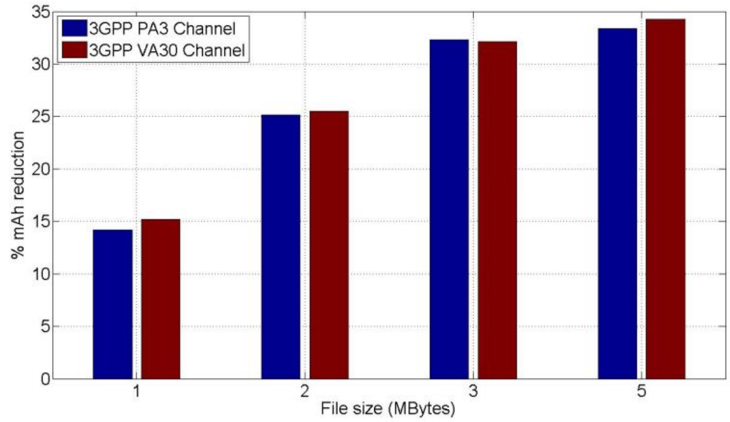
(a)

(b)



(c)

Figure 5: Lab measured FTP performance improvement. (a) Reduction in upload time over 3GPP PA3 channel, (b) Reduction in upload time over 3GPP VA30 channel, (c) Reduction in energy consumption.

System Performance Benefits

In this section we first investigate the user experience gain and then the system capacity gain by running multi-cell system-level simulations to compare the performance without and with the feature of DC-HSUPA. Table 1 contains the basic system simulation assumptions made to facilitate the performance evaluation for a practical network in busy hours (i.e., with a relatively large number of users resulting in medium to high loading levels). In these loaded scenarios, each UE has to compete with others for the limited radio resources and, hence, is rarely able to transmit very high data rates. To complete the picture of DC-HSUPA's system performance benefits, we conclude this section with the power efficiency gain of DC-HSUPA in serving high data rate users as observed from OTA trials.

Table 1: Multi-cell System-level Simulation Assumptions

Parameter	Value
Layout	Wrap-around 19 Node-Bs with 3 cells/NodeB
Inter-site Distance	1.1km
Path Loss (dB)	128. + 1 37.6 Log10 (Dkm), where Dkm is the distance in km
Shadowing	Log normal distributed with standard deviation of 8dB
Penetration Loss	80% are indoor UEs suffering 20dB building penetration loss,
	20% are outdoor-UEs suffering 10dB vehicular penetration loss
Channel Type	3GPP PA3
Traffic Type	FTP with 2MB burst arrives every "T1" sec, where T1 is exponentially distributed with the mean of 60 sec

	Web-browsing with a packet of length "L" arrives every "T2" sec, where L is log normal distributed with the mean of 53kB, and T2 is exponentially distributed with the mean of 30 sec
NodeB Receiver Type	2 Rx Rake Receiver
NodeB Scheduler	Proportional fair, targeting 10dB RoT. Independently running on respective carriers

User Experience Gain

We investigate the user experience gain in scenarios as further specified in Table 2, where several different DC-HSUPA device penetration ratios are studied —0% DC-HSUPA device penetration serves as the *baseline*. Without loss of generality, for any other ratio it is assumed that the FTP UEs and the Web-browsing UEs have the same DC-HSUPA device penetration ratio. Since balanced load is just a special case, we consider load imbalance in the *baseline* by assuming different dominating traffic on respective carriers — a traffic type is said to be dominating if it has the largest number of active UEs on that carrier. Per our simulations, the Carrier F1 is dominated by the Web-browsing traffic because it has, on average, around 2.4 Web-browsing UEs among the total 3.8 active ones per cell, while Carrier F2 is dominated by the FTP traffic because it has about 3.6 FTP UEs among the total 4.8 active ones. Due to the significantly different traffic volume between a FTP UE and a Web-browsing UE, Carrier F2 has about 3dB larger RoT over Carrier F1 as shown in Figure 6 (b).

Table 2 : Scenarios for Demonstration User Experience Gain

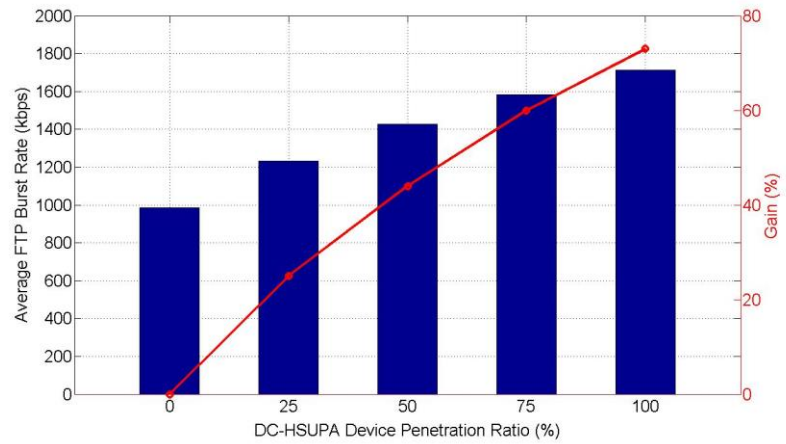
DC-HSUPA Device Penetration Ratio	Carrier	Number of HSUPA FTP UEs per cell	Number of HSUPA Web-browsing UEs per cell	Number of DC-HSUPA FTP UEs per cell	Number of DC-HSUPA Web-browsing UEs per cell
0% (baseline)	F1	4	24	0	0
	F2	8	12		
25%	F1	3	18	3	9
	F2	6	9		
50%	F1	2	12	6	18
	F2	4	6		
75%	F1	1	6	9	27
	F2	2	3		
100%	F1	0	0	12	36
	F2	0	0		

To better understand the user experience in a wide range of deployment scenarios, we consider the 1.1km ISD, which is relatively large for present day HSPA networks. Assuming that all UEs are uniformly distributed within the coverage area, a considerable number of UEs are dropped at locations with relatively large EPL and, hence, do not have adequate power for DC operation. We address this issue by assuming that a DC-capable UE will fall back to HSUPA operation when its EPL is larger than 123.5dB. This is seen in Figure 2 where the maximum data rate of DC-HSUPA begins to overlap that of HSUPA when the RoT is around 8dB.

Throughout this study we have assumed a reasonable gap between the actually achieved RoT and the 10dB RoT target, which is necessary to reasonably exploit the trunking gain of DC-HSUPA. It has been well understood since the early standardization efforts that there is no gain for DC-HSUPA when the system is fully loaded due to the extra DPCCH and E-DPCCH over the Secondary carrier. With1.1km ISD about 25%of the UEs have an EPL greater than or equal to 123.5dB in the simulation.

For a given FTP UE, we measure its user experience as the average data rate at which its traffic bursts are uploaded (a.k.a. burst rate). Throughout this sub-section, we are concerned with the average FTP burst rate obtained as the mean of the burst rate of all FTP UEs in the simulated 57 cells. For each fractional device penetration ratio in Table 2, we calculate the mean burst rate from all FTP UEs including both the DC-HSUPA based ones and the HSUPA based ones.

Figure 6 summarizes the simulation results. In particular, Fig. 6(a) shows the average FTP burst rate as a function of the DC-HSUPA device penetration ratio. Not surprisingly, it is observed that the user experience gain increases with the DC-HSUPA device penetration ratio. Specifically, with 50% DC-HSUPA device penetration the gain is about 44%, and with 100% penetration the gain is up to 73%. Fig. 6(b) shows that the penetration of DC-HUSPA devices also helps to balance the RoTs across two carriers. For example, with 50% DC-HSUPA device penetration the RoT imbalance can be reduced about 65%, and with 100% penetration the RoT imbalance is totally eliminated. The more balanced RoTs lead to balanced uplink coverage across the two carriers. We also show the average FTP burst rate as a function of the EPL in Fig. 6(c), which indicates that DC-HSUPA offers significantly improved experience for users within the DC-coverage (i.e., with EPL < 123.5dB). Specifically, the gain in average FTP burst rate within DC coverage is at least 14%. Due to the slightly increased RoT contributed by DC-HSUPA UEs —A DC UE transmits extra DPCCH and E-DPCCH on its Secondary carrier—the cell-edge users (i.e., with EPL≥123.5dB and all are HSUPA based under the aforementioned assumption of fall back) are suffering slightly degraded user experience. Specifically, the loss in average FTP burst rate at cell edge is at most 14%. Since the number of users within DC-coverage is about two times larger than that at cell-edge, DC-HSUPA leads to significantly improved overall user experience as reported in Fig. 6(a).



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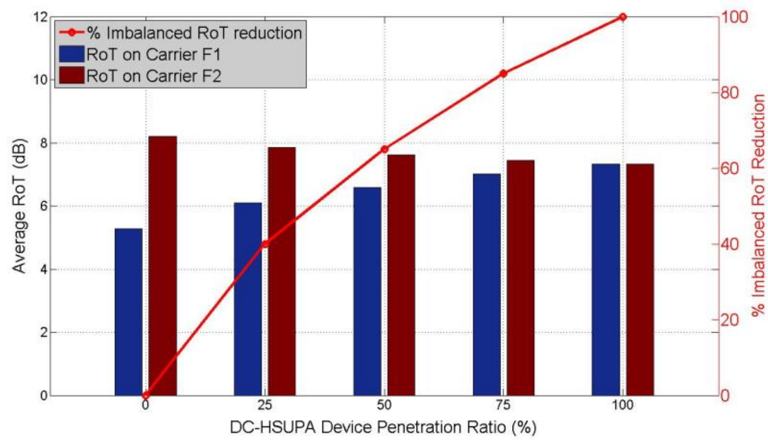

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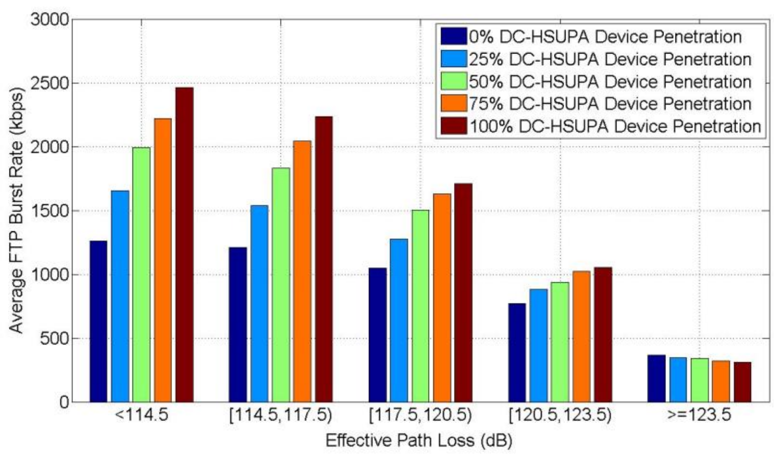

(c)

Figure 6 : User Experience Gain and Load Balancing Gain. (a) Gains in average FTP burst rate, (b) Gains in RoT imbalance reduction, (c) Average FTP burst rate throughout the coverage area.

System Capacity Gain

We investigate the system capacity gain in scenarios as further specified in Table 3. For this scenario, we are concerned with not only the average FTP burst rate but also the corresponding number of Web-browsing UEs per cell in SC and DC configurations (the number 'A' and the number 'B' introduced in Table 3). In particular, the system capacity gain is the difference in the number of Web-browsing UEs when the average throughput for the FTP UEs is similar for the DC-HSUPA configuration as the baseline for two standalone carriers. For the sake of simplicity, we have assumed balanced loading across two carries. In addition, we consider 25% DC-HSUPA device penetration in the DC-HSUPA system configuration and assume, without loss of generality, this penetration ratio applies to both the FTP UEs and the Web-browsing UEs as shown in the table — In particular, two of the total eight FTP UEs and one-fourth of the total 'B' Web-browsing UEs are assumed to be DC-HSUPA capable.

Table 3 : Scenarios for Demonstrating System Capacity Gain

System Configuration	Carrier	Number of HSUPA FTP UEs per cell	Number of HSUPA Web-browsing UEs per cell	Number of DC-HSUPA FTP UEs per cell	Number of DC-HSUPA Web-browsing UEs per cell
Two Standalone Carriers (baseline)	F1	4	'1/2 A'	0	0
	F2	4	'1/2 A'		
DC-HSUPA	F1	3	'3/8 B'	2	'1/4 B'
	F2	3	'3/8 B'		

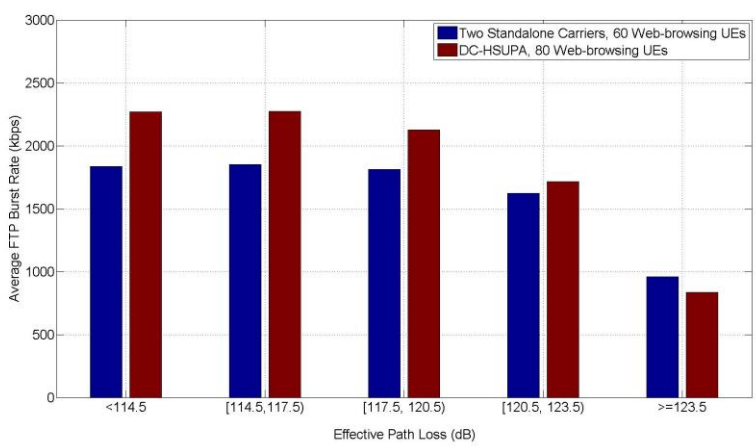

Figure 7: System Capacity Gain assuming 25% DC-HSUPA device penetration

The simulation results are reported in Figure 7, where we compare the average FTP burst rates achieved in the system configuration of two standalone carriers with 'A'=60, and that of DC-HSUPA configuration with 'B'=80. It can be observed that DC-HSUPA outperforms (up to 23% burst rate gain) two standalone carriers for UEs at locations with less than 123.5dB EPL. Due to the higher RoT contributed by the extra 20 UEs in the DC-HSUPA configuration, the cell-edge UEs with ≥123.5dB EPL suffer ≈13% loss in burst rate. As aforementioned, there are 25% cell-edge UEs and, hence, the DC-HSUPA configuration is providing better, not just comparable, average user experience while at the same time supporting 29% more users per 10MHz per sector. In other words, the 25% penetration of DC-HSUPA devices leads to 29% system capacity gain.

Power Efficiency Gain

OTA trials were conducted to demonstrate the higher power efficiency of DC-HSUPA in serving high-data rate users. In particular, a HSUPA UE is configured to transmit a fixed transport block of 10681 bits, while a DC-HSUPA UE is configured to transmit a fixed transport block of 5369 bits on each of both carriers. As expected, the two UEs achieve comparable throughputs, which are 5141 kbps and 5085 kbps respectively. However, due to the different effective coding rate of these two transport blocks (see Figure 4), the HSUPA UE transmits ≈6.7dB more power for comparable throughput. In other words, the DC-operation provides a more power efficient approach to serve the high-data-rate users in HSPA uplink.

Conclusion

In this paper, we presented an overview and the benefits of DC-HSUPA feature in HSPA networks. Several benefits were measured on a prototype in our lab and demonstrated via OTA trials. From a user experience standpoint, there is significant reduction in the uploading time due to the DC operation in typical networks. The users also enjoy longer battery life due to reduced energy consumption as measured in our lab. From a network standpoint, this feature enables the system to perform TTI-by-TTI load balancing and to support more smartphone users while keeping the same level of user experience.