Dual Cell HSDPA Application Performance

Siddharth Mohan, Rohit Kapoor and Bibhu Mohanty
Qualcomm Incorporated, San Diego, USA
{mohans,rkapoor,bmohanty}@qualcomm.com

Abstract—**Dual Cell HSDPA (DC-HSDPA), which was introduced in Release 8 of the WCDMA specifications, enables the User Equipment (UE) to receive downlink data on two adjacent carriers simultaneously. Although the user physical layer throughput is expected to double compared to a single carrier HSDPA (SC-HSDPA) system, it is not quite clear how this would translate to user experience for realistic applications in various operating scenarios, i.e. channel conditions and loading. We implemented DC-HSDPA functionality in a prototype and evaluated its performance for various applications in comparison with SC-HSDPA. Our results show that, with DC-HSDPA, realistic applications such as web browsing and video streaming see significant gains in lab as well as OTA environments compared to SC-HSDPA with or without loading due to other users. Our results also highlight the ability of DC-HSDPA UEs to improve application performance by taking advantage of uneven loading across carriers, which may result due to UEs operating on a single carrier.**

I. Introduction

DC-HSDPA was introduced by 3rd Generation Partnership Project (3GPP) in Release 8 of the Wideband CDMA (WCDMA) specifications [1][2]. DC-HSDPA enables doubling the physical channel rate seen by the UE compared to SC-HSDPA at all locations in the cell by aggregating traffic flow at the MAC level across two carriers. In this paper, using a prototype implementation of DC-HSDPA, we evaluate the gain seen by real applications when using DC-HSDPA compared to HSDPA. We focus on a few representative applications that a typical user uses on the Internet today. We consider UEs with single as well as two receive antennas.

The realistic applications we consider are Web Browsing (CNN and Google Maps) and Video Streaming. We consider the following scenarios: no loading and loading due to one background FTP user. We also consider scenarios of uneven loading across carriers. In today's HSDPA networks where operators typically add another carrier to increase capacity (and hence operate with two SC-HSDPA systems), uneven loading across these carriers can occur for short time durations. These time durations are comparable to the time duration of user application activity: how well DC-HSDPA balances load across carriers under such uneven loading is our main motivation in looking at such scenarios.

The lab tests span a range of geometries. The OTA tests evaluate performance using different drive routes which cover a range of radio environments. The results show that using DC-HSDPA leads to *significant gains seen by realistic applications* which translate to much better user experience compared to a SC-HSDPA deployment.

II. Application Description

The following applications are used in this paper:

File Download: A file downloading application causes a sizeable amount of data bytes to be transferred over a TCP connection. File download may happen using the File Transfer Protocol (FTP), or HTTP, or some other protocol, the key characteristic being the availability of back-to-back application data packets. Various file sizes are considered. The key metric is file download time reduction (in %).

Web Browsing (CNN): A web browsing session consisting of downloading the main page of www.cnn.com. To allow repeatability (since server load as well as content at www.cnn.com could vary at different times), we copied a snapshot of www.cnn.com onto a local server. The key metric used for analysis is average page download time.

Web Browsing (Google Maps): A web browsing session consisting of Google Maps sessions of the cities San Diego, Las Vegas and Los Angeles. To allow repeatability, we copied snapshots of Google Maps sessions of the 3 cities onto a local server. The key metric used for analysis is average page download time.

Video Streaming: Video sources at different bitrates (256 kbps, 768 kbps, 2 Mbps) streamed from a local server. The video sources are streamed at 15 frames/sec. The video playout buffer starts buffering if the size of the buffer goes to 0 and then starts playing only when the playout buffer has buffered 2.6 seconds worth of playout, which corresponds to a buffer size of: 665 kbits, 2 Mbits, 5.2 Mbits at bitrates of 256 kbps, 768 kbps, 2 Mbps respectively. The key metrics for video streaming analysis are:

- *Ratio of Buffering to Playing Duration:* The ratio of the time spent in buffering incoming frames to the time taken for playing out the video frames. During the time that the playout buffer is buffering incoming frames, video frames are not played out. This would be perceived as interruption in the video playout.
- *Total time taken to finish playing the video clip:* This is the total time, including playing as well as re-buffering time (interruption time), that the video player takes to finish playing the video clip.

III. DC-HSDPA Prototype Description

A. Key features

Our DC-HSDPA prototype implements all the layers of the protocol stack (physical, MAC, RLC, PDCP) per 3GPP

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Rel 8 specifications. The following are some of the key features:
1. The DC-HSDPA/SC-HSDPA prototype UE uses an LMMSE Equalizer receiver.
2. The CQI reported by the UE is filtered through an IIR filter at the Node B, with a time constant of 30 Transmission Time Intervals (TTIs).
3. A Proportional Fair (PF) scheduler with a throughput time constant of 300 ms is used in the DC-HSDPA prototype.
4. The HS-PDSCH scheduler selects the transport block size based on the filtered CQI value and an outer loop algorithm which targets 10% BLER after the first Hybrid ARQ (HARQ) transmission.
5. The power used on the HS-SCCH channel is fixed at 10% of the total cell power.
6. On the uplink, 10 ms TTI is used for the Enhanced Dedicated Physical Data Channel (E-DPDCH) channel with a maximum of 2 HARQ transmissions. An outer loop power control algorithm, which targets 10% BLER after the first HARQ transmission on the E-DPDCH channel, is implemented at the Node B. Residual BLER is less than 1%.

B. *Description of Downlink User Simulator (DLUS)*

One key goal of the prototype was to study DC-HSDPA system performance under uneven loading of carriers, where load is introduced by multiple users. To avoid logistical testing difficulties in using multiple simultaneously active prototype UEs, a realistic downlink user simulator (DLUS) was used. For DLUS UEs, CQIs and ACK/NAKs are generated based on logs from simulations and input to the scheduler. However, DLUS UEs are treated as real UEs by the HSDPA scheduler: the scheduler transmits packets for the DLUS UEs on the HS channels with appropriate power. Using DLUS UEs, we can load the system with the equivalent of a number of real UEs. Data arrival pattern for the DLUS UEs can also be defined using input files. We use 32 DLUS Ues, each having the Bursty Traffic source (as defined by 3GPP in [3]), to create load. A 1Mbit burst size is chosen and the mean inter arrival time is varied for these 32 DLUS UEs to create system loading corresponding to 25%, 50%, 75% and 100% TTI utilization by these DLUS UEs. CQI and ACK traces were generated for DLUS UEs based on 57 cell simulations with 32 UEs per cell.

IV. LAB RESULTS

In the lab setup, a laptop is connected to the prototype UE, which can be either a DC-HSDPA or a SC-HSDPA UE. The laptop is the client for the applications evaluated. It should be noted that the lab setup uses a single source of interference to create geometry, whereas in the field, there are typically multiple cells that create interference. This will likely lead to slightly optimistic performance for the Dual rx LMMSE Equalizer receiver (for both SC-HSDPA and DC-HSDPA UEs). We show lab results for the vehicular VA30 channel and spanning a range of geometries. It should be noted that DC-HSDPA gains are not sensitive to the type of fading channel since the application duration spans multiple coherence times of the channel.

A. *Performance Comparison under no load*

In this section, we compare the performance of SC-HSDPA and DC-HSDPA UEs when the system is unloaded.

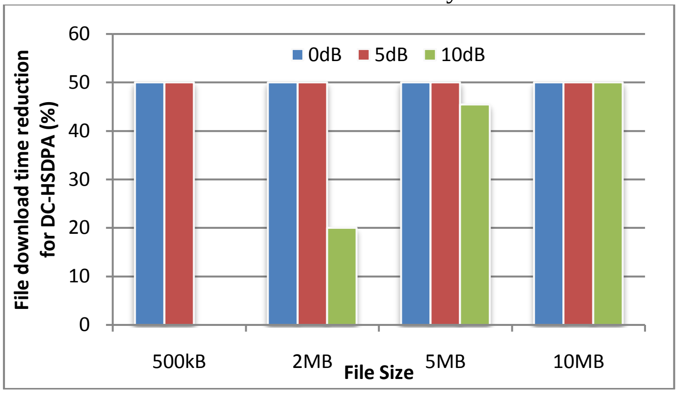

Figure 1*: File download time reduction of DC-HSDPA (%) for single rx*

Figure 1 shows the reduction in file download time for a DC-HSDPA UE over a SC-HSDPA UE for a few file sizes and geometries in VA30 fading channel. We see more impact of TCP Slow Start at smaller file sizes and higher geometries, i.e., when the time to download the file is small. In this case, TCP Slow Start dilutes some of the gains possible. For larger file sizes or lower geometries, the file download time for a SC-HSDPA UE is twice that of a DC-HSDPA UE.

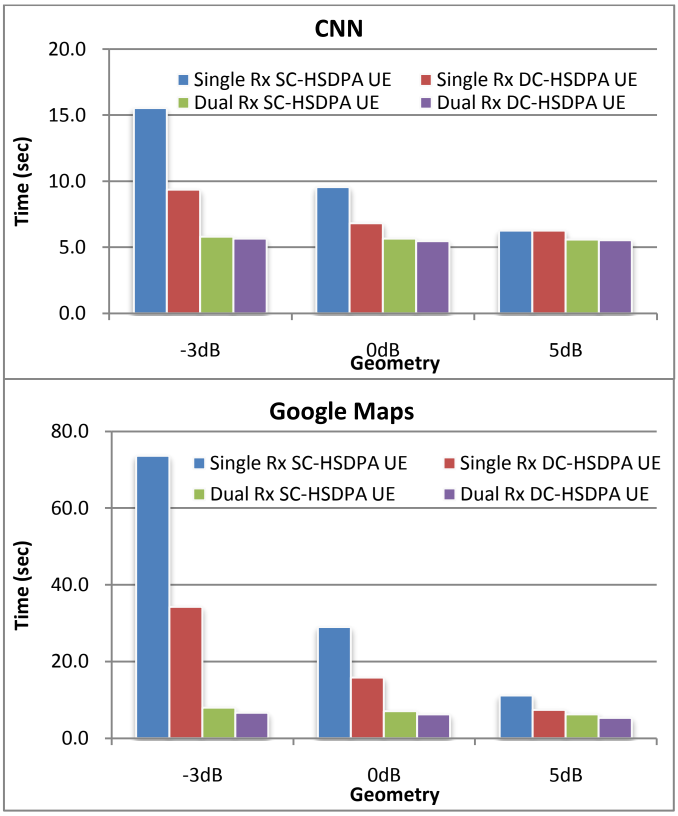

Figure 2*: Page download times for CNN and GoogleMaps in VA30 channel-no loading*

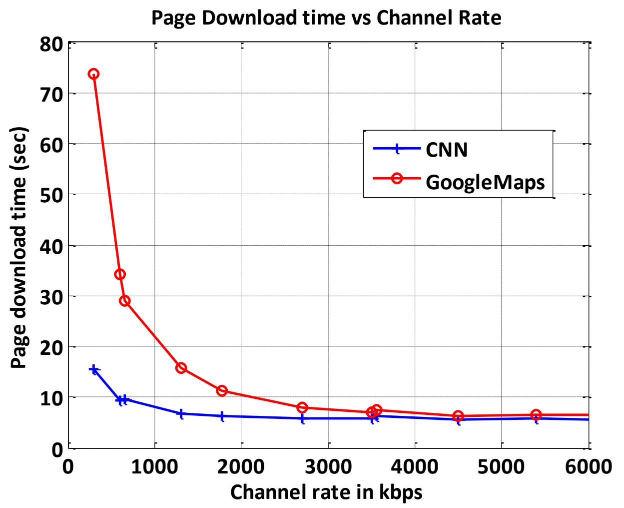

Figure 3: *Page download time as a function of channel rate*

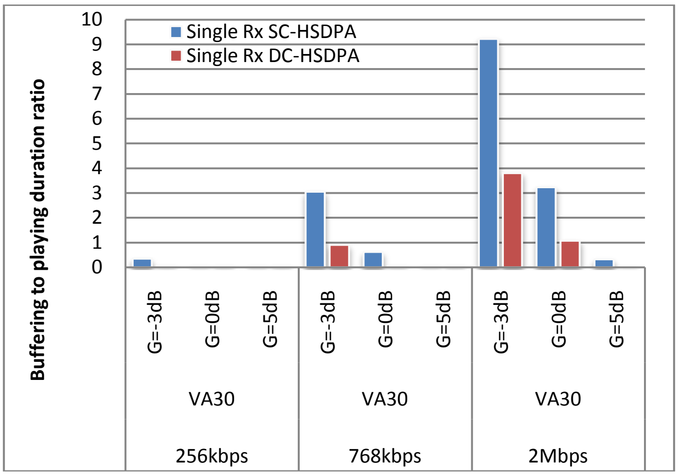

Figure 4: *Ratio of buffering to playing duration for VA30 and different geometries- no loading*

Figure 2 shows that the CNN and Google Maps page download time for a single rx DC-HSDPA UE is 30% to 50% lower than that for a single rx SC-HSDPA UE at low to medium geometries (-3dB and 0dB). At higher geometries (5 dB), the page download times for single rx DC-HSDPA UE and SC-HSDPA UEs are similar. These results indicate that for single rx UEs, the cell edge user experience will be greatly enhanced with a DC-HSDPA UE. For dual rx UEs, some gains are seen for DC-HSDPA UEs for Google Maps at low geometries.

Note that the request-response nature of HTTP leads to multiple round trip times being used for sending HTTP requests, during which the channel may be under-utilized [4]. This, coupled with browser processing delays, leads to web browsing delays saturating once the channel rate is sufficiently high. This effect is shown in Figure 3 where page download times for CNN and Google Maps are plotted as a function of the channel rate. The different channel rates in Figure 3 are varied by changing geometry/reciever type in a VA30 channel. Browsers are being constantly improved to reduce the impact of RTT on the page download time [5]. This would result in higher gains for DC-HSDPA compared to SC-HSDPA.

Figure 4 shows the ratio of buffering to playing duration for video streaming for different video rates for single rx UEs.

- An SC-HSDPA UE can support 256kbps only at geometries 0dB and above with no buffering whereas a DC-HSDPA UE can support 256kbps at all geometries.
- An SC-HSDPA UE can support 768kbps only at geometries 5dB and above with no buffering whereas a DC-HSDPA UE can support 768kbps at 0dB and above.
- An SC-HSDPA UE cannot support 2Mbps whereas a DC-HSDPA UE can support 2Mbps at 5dB and above with no buffering.

B. Performance Comparison under loading due to single user

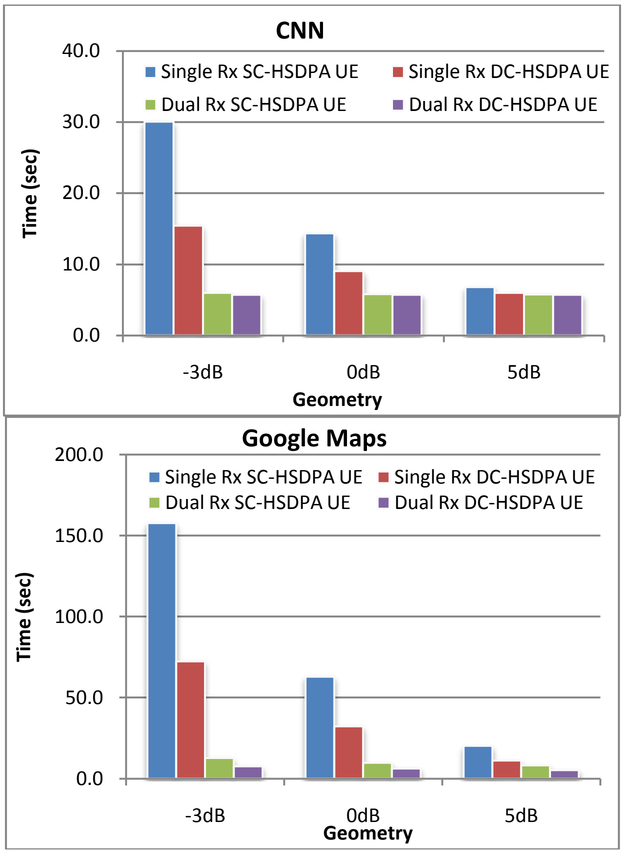

Figure 5: *Page download times for CNN and Google Maps in VA30 channel with 1 user loading*

In this section, we compare the performance of SC-HSDPA and DC-HSDPA UEs when the system is loaded with 1 background FTP user. The background FTP user occupies ~50% of the TTIs when the user under tests is present due to the effect of the proportional fair scheduler. Figure 5 shows the page download times for CNN and Google Maps under loading due to 1 FTP user. DC-HSDPA UE shows 40 to 50% lower page download time than SC-HSDPA UE, at low and medium geometries (-3dB and 0dB) for CNN for single rx receiver. For google maps, DC-HSDPA UE shows 50% to 60% lower at all geometries for single rx receiver. Figure 5 also shows that with loading, the DC-HSDPA gain (in %) over SC-HSDPA has increased compared to the no loading case in

Figure 2. For dual rx UEs, the page download times for CNN are similar. For Google Maps, on the other hand, a dual rx DC-HSDPA UE shows significant gain over a dual rx SC-HSDPA UE for all geometries. Overall, the gain of a dual rx DC UE over a dual rx SC UE is seen only for "heavier" pages such as Google Maps, which typically generate larger bursts of data compared to web pages such as CNN.

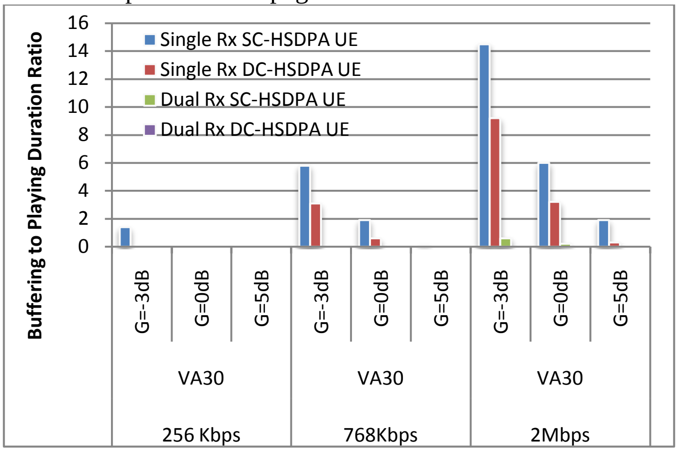

Figure 6: Ratio of buffering to playing duration for VA30 and different geometries- 1 user FTP loading

Figure 6 shows the ratio of buffering to playing duration for video streaming for different video rates for single rx/dual rx DC and SC UEs. We see that:

- A single rx DC-HSDPA UE can support 256 kbps video at all geometries without the client having to pause for buffering during playout. For a single rx SC UE, on the other hand, a significant amount of time is spent in buffering at low geometries (-3 dB).
- For 768 kbps and 2 Mbps video, a single rx DC-HSDPA UE shows less buffering than a SC-HSDPA UE.
- A dual rx DC-HSDPA UE can support all the evaluated video rates across geometries whereas a dual rx SC-HSDPA UE sees buffering for the 2Mbps video source for geometries of -3dB and below.

C. *Performance Comparison under unequally loaded carriers*

In this section, we compare the performance of DC-HSDPA and SC-HSDPA UEs under scenarios where the carriers are unequally loaded. Since traffic generated by data users is unpredictable, short-term periods of load imbalance across carriers are likely to exist as explained earlier. DLUS UEs are used to create background loading on the carriers. We consider 3 loading scenarios created by 32 DLUS UEs in each cell, where the average loading across the carriers is 50%:

- *Scenario 1*: In terms of TTI utilization, carrier 1 is 0% loaded, carrier 2 is 100% loaded. Note that even under 100% load, the proportional fair scheduler allows the SC-HSDPA user under test to be allocated a certain proportion of TTIs.
- *Scenario 2*: In terms of TTI utilization, carrier 1 is 25% loaded, carrier 2 is 75% loaded.
- *Scenario 3*: In terms of TTI utilization, carrier 1 is 50% loaded, carrier 2 is 50% loaded.

We show results for foreground SC-HSDPA or DC-HSDPA UEs with two receive antennas (we also ran tests for foreground UEs with a single receive antenna: these results showed similar trends). Two values of geometry, 10dB and 5dB, are evaluated for the foreground UEs. In the tests, the SC-HSDPA UE can be present with equal probability on either carrier, while the DC-HSDPA UE is connected on both carriers. The results for the SC-HSDPA UE are the average of the user experience of the two carriers.

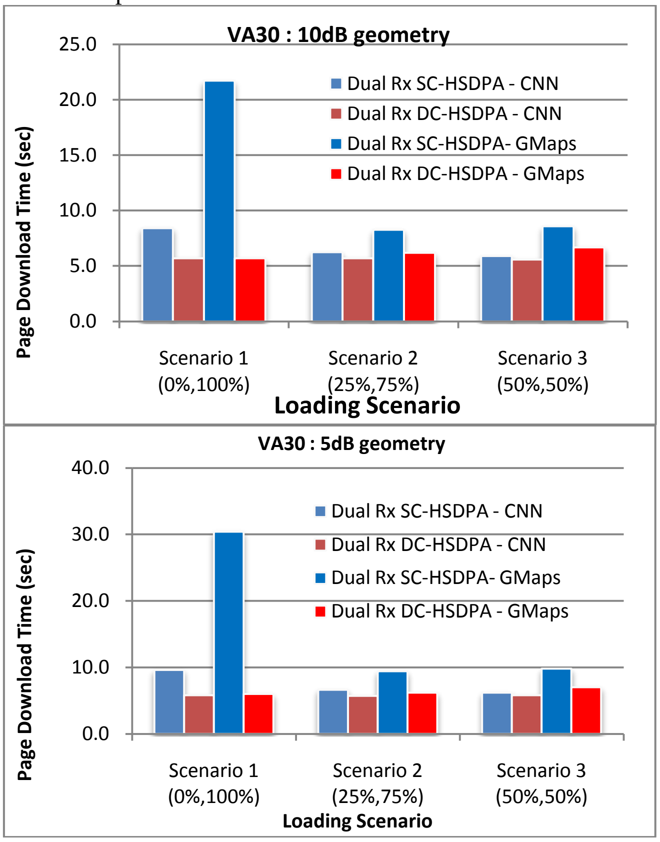

Figure 7: Page download times for CNN and Google Maps for dual rx UEs

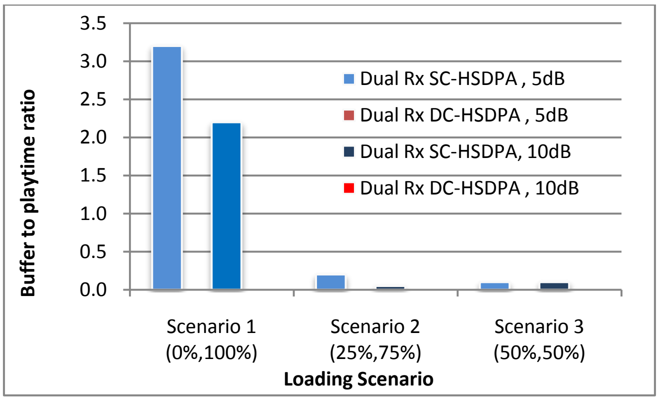

Figure 8: Ratio of buffering to playing duration for dual rx UEs

Figure 7 shows the page download times for CNN and Google Maps. For dual rx, at 10dB geometry, the page download time reduction for a DC-HSDPA UE is 5-30% for CNN and 20-75 % for Google Maps for the two cases of unequal loading. At 5dB geometry, the corresponding gains are 5-40% for CNN and 30-85% for Google Maps. Under unequal loading, a DC-HSDPA UE can receive more service on the less loaded carrier. Figure 8 shows the ratio of buffering to play duration and number of buffering events per minute for the 2 Mbps video streaming source for dual rx UEs. A dual rx DC-HSDPA UE can support a 2Mbps video stream without buffering for all the evaluated loading scenarios. A SC-HSDPA UE sees some buffering, particularly for the scenarios where the carriers are unequally loaded.

V. OVER THE AIR (OTA) SETUP AND RESULTS

Our OTA setup consists of 3 NodeBs. Figure 9 shows the distribution of CQI for drive routes selected from the 3 NodeB OTA configuration for evaluating DC-HSDPA and SC-HSDPA performance. The solid curves indicate the cdf for single rx UEs and the dotted curves indicate the cdf for dual rx UEs. The SCC drive route includes multiple serving cell changes. The Average CQI route was chosen to cover low and high CQI regions that will be seen in a typical deployment.

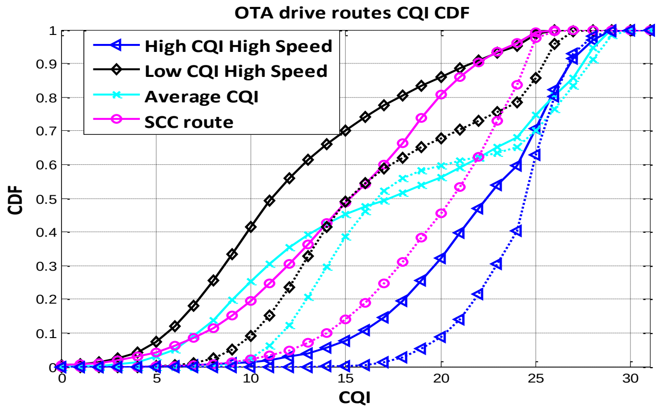

Figure 9: *cdf of CQI for UEs with single and dual receive antennas for the OTA drive routes*

A. *Performance Comparison under loading due to single user*

In this section, we compare the performance of SC-HSDPA and DC-HSDPA UEs when the system is loaded with 1 real background FTP user. The background FTP user occupies ~50% of the TTIs when the user under test is present.

Figure 10 shows page download times for CNN and Google Maps in the presence of loading from 1 FTP user. The following are some of the key observations:

- For UEs with a single receive antenna, (a) the CNN page download times for a DC-HSDPA UE are 20% to 25% lower than for a SC-HSDPA UE, for the low and average CQI routes and (b) for Google Maps, gain is seen for a DC-HSDPA UE for all drive routes, in the range of 15 to 30%.
- For UEs with two receive antennas, (a) for the CNN page, small gain (<15%) is seen for a DC-HSDPA UE for the low and average CQI routes and (b) for Google Maps, significant gain is seen for a DC-HSDPA UE for all but the high CQI drive routes, in the range of 20% to 60%.

One key point that should be noted from Figure 10 is the ability of DC-HSDPA UEs (particularly with two receive antennas) to provide similar performance across the range of CQI drive routes: this is a very attractive property of DC-HSDPA UEs for web browsing applications.

Figure 11 shows that a dual rx DC-HSDPA UE can support 768Kbps in the OTA drive routes without buffering.

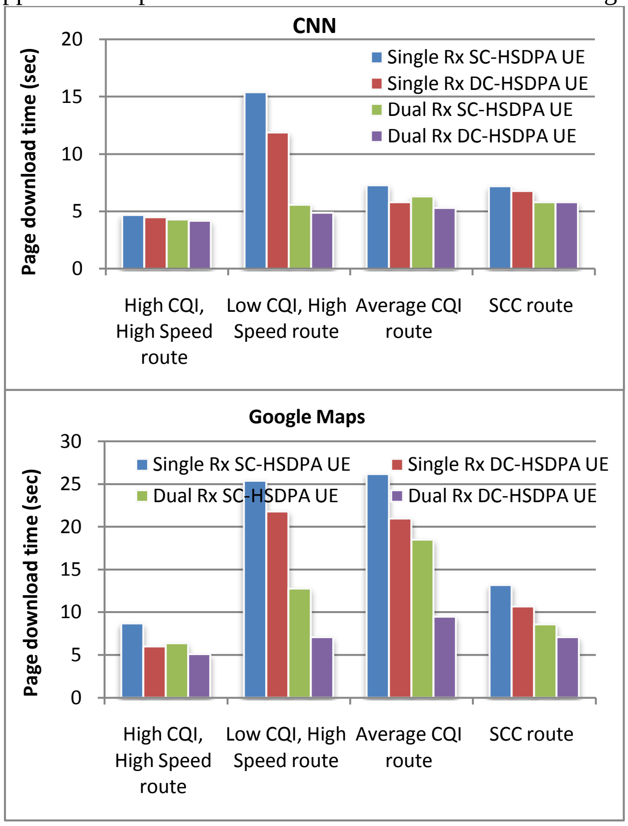

Figure 10: *Page download times of CNN and Google Maps for different OTA drive routes*

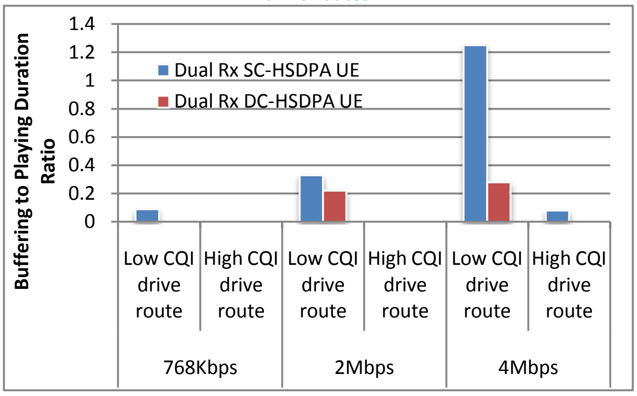

Figure 11: ***Buffering to playing duration ratio for video streaming for different OTA drive routes***

B. *Performance Comparison under unequally loaded carriers*

In this section, we compare the performance of DC-HSDPA and SC-HSDPA UEs under scenarios where the carriers are unequally loaded. We show results for UEs with two receive antennas. We consider the 3 loading scenarios defined in section IV.C. As in section IV.C, the results for the SC-HSDPA UE are the average of the two carriers.

Figure 12 shows the page download times for CNN and Google Maps for the High and Average CQI drive routes. The page download time reduction for DC-HSDPA is 20-70% for CNN and 25-85% for Google Maps. Figure 13 shows the ratio of buffering to playing duration for the average CQI and high CQI drive routes. The results show that a DC-HSDPA UE can support a 2Mbps video with little or no buffering for the carrier loading scenarios considered. A SC-HSDPA UE, on the other hand, incurs significant buffering, particularly for the scenarios where the carriers have unequal loading.

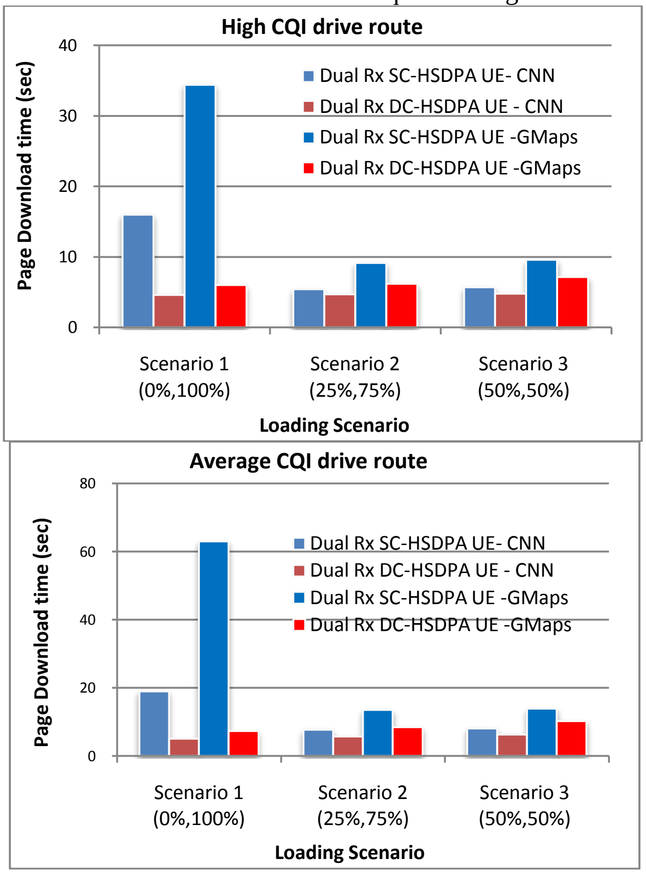

Figure 12*: Page download times of CNN and Google Maps for different OTA drive routes under carrier load imbalance*

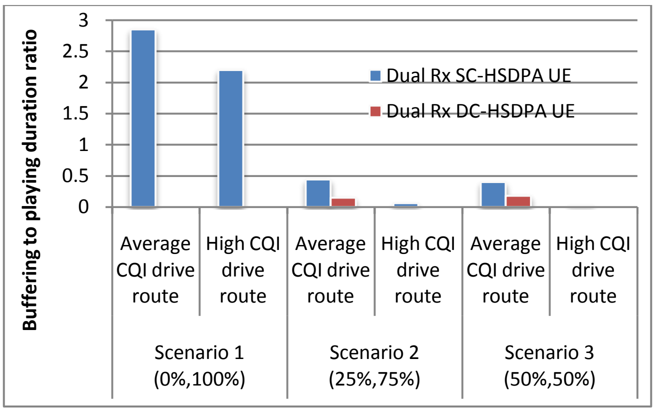

Figure 13*: Results for 2Mbps video Streaming for different OTA drive routes under load imbalance across carriers*

VI. DISCUSSION ON DUAL RX

In some results presented in this paper, a dual rx SC-HSDPA UE either matches or outperforms a single rx DC-HSDPA UE. This is mainly due to the performance of the LMMSE equalizer when interference is significant. At high geometries, when interference is not as significant, we expect a single rx DC-HSDPA UE to outperform a dual rx SC-HSDPA UE. Although dual rx is strongly recommended for all future UE implementations, studying performance benefits of single rx DC-HSDPA UEs is relevant considering that majority of the handsets today are single rx and the low end handsets might remain so in the near future.

VII. CONCLUSIONS

We compared the performance of DC-HSDPA and SC-HSDPA UEs for realistic applications in lab and OTA environments. We evaluated performance under the following loading scenarios: no loading, loading due to one background user and uneven loading across carriers. The realistic applications we considered included web browsing (CNN and Google Maps) and video streaming.

Our results showed that under background loading due to 1 FTP user, single rx DC-HSDPA UEs reduced page download times by 10-50% for CNN and by 40-60% for Google Maps compared to single rx SC-HSDPA UEs. Under the same loading scenario, dual rx DC-HSDPA UEs experienced small gain in download time for CNN and 30-40% gain for Google Maps. For video streaming, DC-HSDPA UEs reduced time spent in buffering significantly for all video streaming rates considered (256 kbps, 768 kbps and 2 Mbps) for single rx UEs. For dual rx UEs, buffering time reduction was seen by DC-HSDPA UEs for the higher video streaming rates (768 kbps and 2 Mbps). When carriers had uneven loading, DC-HSDPA UEs showed reduction in page download time of up to 70% for CNN and up to 90% for Google Maps, depending upon carrier loading and user geometry. Gains were seen for both single rx and dual rx DC-HSDPA UEs compared to corresponding SC-HSDPA UEs. These results highlighted the ability of DC-HSDPA UEs to balance load across carriers, which we believe is a useful property since traffic generated by data users is unpredictable.

Across all the results, one common trend we see is that for the realistic data applications considered, DC-HSDPA shows significant gains over SC-HSDPA for low to medium geometries, and somewhat reduced gains for high geometries. Furthermore, we see that DC-HSDPA provides a nearly uniform user experience across geometries and under various loading conditions: this is a key take-away from these results.

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