

# ***HSPA+ Multiflow***

***Solution for cell edge performance improvement and  
dynamic load balancing***

***February 1, 2014***

**Qualcomm Technologies, Inc.**

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# 1 Introduction

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Rapid wireless subscriber growth coupled with the necessity to provide desired levels of user experience for broadband multimedia applications has led to the continuous evolution of HSPA technology. As an example, features such as downlink Multiple-Input-Multiple-Output (MIMO) and higher level modulation (downlink 64QAM, uplink 16QAM) were introduced in Release 7, focusing on increasing the spectral efficiency. Subsequently, in Release 8 and Release 9, the dual cell HSDPA (DC-HSDPA) and dual band DC-HSDPA features were introduced. Both features allow the NodeB to schedule independent data streams to the same user simultaneously on two different carrier frequencies. Furthermore, in Release 10, the multi-carrier operation concept has been extended to allow the NodeB to serve the same users simultaneously on four different carriers (4C-HSDPA). All these features were enabled by enhancing radio transceiver chain design, both on the network side and in the mobile device (UE).

Even with advanced radio transceivers in place, there is still scope for further improving HSPA system performance. Many current HSPA networks face challenges of capacity saturation and inadequate cell edge user experience due to the strong interference from neighboring cells. Further more, adjacent sectors and carrier frequencies are often unevenly loaded; different topological layers in the network (e.g. macro, pico, femto) are sometimes unevenly loaded as well.

In Release 11, to address some of the aforementioned issues, the Multiflow feature was introduced. Release 11 Multiflow allows simultaneous scheduling/transmission of up to four independent downlink data packets to a user from cells belonging to up to two sectors in the same NodeB or different NodeBs. These cells may be on the same or different carriers. The Multiflow feature offers advantages such as:

- Improved user experience at the cell edge
- Efficient and dynamic load balancing across sectors in single-carrier deployments
- Efficient and dynamic load balancing across sectors / carriers in multi-carrier deployments
- Improve radio resource and backhaul utilization
- Leverage DC-HSDPA / MC-HSDPA capabilities of the network and UEs by means of incremental hardware and software upgrades

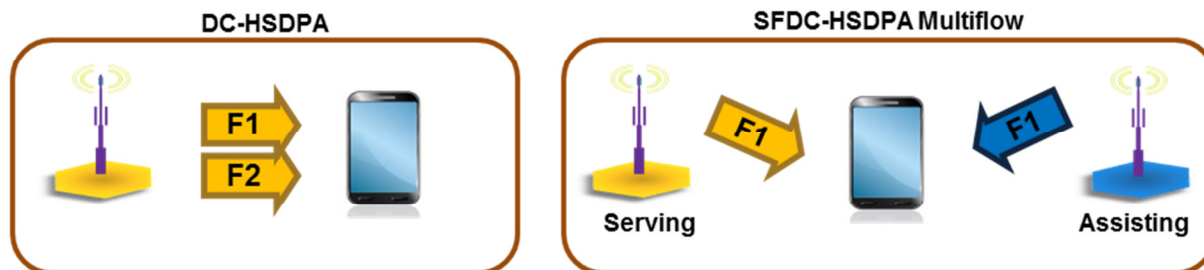
## 2 HSPA+ Multiflow Features

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The Multiflow feature allows the UE in softer or soft handover regions to be served by both the serving and the non-serving cell (assisting serving cell) on the same frequency at the same time. As a result, it improves those UEs' downlink data rate, especially when the assisting serving cell is partially loaded. The Multiflow operation can operate on either one or two frequencies.

The Multiflow feature can be seen as an extension to the existing multi-carrier feature. Using single frequency Multiflow operation as an example, Figure 1 illustrates the concept of Multiflow operation by

comparing the similarity and disparity between Single-Frequency-Dual-Cell HSDPA (SFDC-HSDPA) Multiflow and Dual-Cell HSDPA (DC-HSDPA) operations.



**Figure 1: Single-Frequency-Dual-Cell HSDPA (SFDC-HSDPA) Multiflow, In Comparison with DC-HSDPA**

DC-HSDPA allows scheduling of two independent data streams to the UE from one sector on two carrier frequencies. Similar to DC-HSDPA, SFDC-HSDPA also allows scheduling of two independent data streams to the UE. Both features require the UE to be capable of decoding multiple data stream simultaneously. However, as illustrated in Figure 1, two data streams are scheduled *from two different sectors on the same carrier*. In other words, in a single carrier deployment, SFDC-HSDPA Multiflow operation allows both the serving and assisting serving cell to simultaneously send independent data streams to the UE. Therefore, the major difference between SFDC-HSDPA and DC-HSDPA operation is that the secondary data stream is scheduled to the UE from a different sector on the same frequency as the primary data stream. In addition, as SFDC-HSDPA requires the UE to receive independent data streams from two different cells on the same frequency, UE needs to be equipped with interference cancellation capable receiver.

## 2.1 Different Multiflow Schemes

Release 11 Multiflow feature supports one or two carrier frequencies. On each carrier frequency, the UE can be scheduled with independent data streams from two different sectors. In this section, we list the three Multiflow schemes that are supported by Release 11.

### Single-Frequency-Dual-Cell HSDPA (SFDC-HSDPA) Multiflow

Figure 1 illustrates the Single-Frequency-Dual-Cell HSDPA (SFDC-HSDPA) Multiflow operation. SFDC-HSDPA Multiflow operates on one carrier frequency and allows scheduling of *two independent data streams to the UE from two different sectors on one carrier frequency*.

### Dual-Frequency-Three-Cell HSDPA (DF3C-HSDPA) Multiflow



**Figure 2: Dual-Frequency-Three-Cell HSDPA (DF3C-HSDPA) Multiflow**

Figure 2 illustrates the Dual-Frequency-Three-Cell HSDPA (DF3C-HSDPA) Multiflow operation. DF3C-HSDPA Multiflow operates on two carrier frequencies. On the anchor carrier frequency, DF3C-HSDPA allows *scheduling of two independent data streams to the UE from two different sectors*; on the secondary carrier frequency, only one sector is allowed to schedule data stream to the UE.

### **Dual-Frequency-Four-Cell HSDPA (DF4C-HSDPA) Multiflow**



**Figure 3: Dual-Frequency-Four-Cell HSDPA (DF4C-HSDPA) Multiflow**

Figure 3 illustrates the Dual-Frequency-Four-Cell HSDPA (DF4C-HSDPA) Multiflow operation. DF4C-HSDPA Multiflow operates on two carrier frequencies and *allows scheduling of two independent data streams to the UE from two different sectors on each carrier frequency*.

## **2.2 Intra-NodeB and Inter-NodeB Multiflow**

Multiflow can also be categorized into Intra-NodeB or Inter-NodeB operation, depending upon whether the two sectors involved in the Multiflow operation belong to the same or different NodeB(s).

- Intra-NodeB Multiflow: two sectors participating in Multiflow operation belong to *the same* NodeB
- Inter-NodeB Multiflow: two sectors participating in Multiflow operation belong to *different* NodeBs

To support Intra-NodeB MultiFlow, the queue management and RLC layer operation is essentially the same as multi-carrier HSDPA. Compared to Intra-NodeB Multiflow, Inter-NodeB is more complicated as it requires the DL data to be split at the RLC layer. To allow Inter-NodeB Multiflow operation, Release 11 introduced RLC enhancements to help the UE distinguish genuine RLC packet losses from RLC packet “skew” caused by the scheduling difference between NodeBs. Details on features and enhancement needed for Intra-NodeB and Inter-NodeB Multiflow will be provided in Section 4 .

From system performance perspective, Inter-NodeB operation enables more UEs to benefit from the Multiflow operation, since, in a typical HSPA deployment, far more UEs are in either the softer or soft handover regions (~40%), compared to only the softer handover region (~10%), which requires only Intra-NodeB Multiflow.

Note that, in the inter-NodeB Multiflow operation, the two NodeBs participating in the Multiflow operation are typically controlled by the same RNC. However, inter-NodeB Multiflow could also be supported when two NodeBs are controlled by different RNCs. Considering that Intra-NodeB Multiflow is easier to implement compared to Inter-NodeB Multiflow, in practical Multiflow deployments, the system should support either only Intra-NodeB Multiflow or both intra-NodeB and inter-NodeB Multiflow.

## 3 HSPA+ Multiflow Performance Benefits

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In this section, we present both the system simulation results and the Over-The-Air (OTA) field test results to demonstrate the performance benefit from Multiflow operation.

### 3.1 System Simulation Results

For simulation, we focus on the dual carrier deployment and compare the performance of two systems

1. Baseline (DC-HSDPA): pre-Release 11 dual carrier deployments. All UEs are DC-HSDPA capable, but Multiflow operation is not supported
2. Multiflow (DF4C-HSDPA): Release 11 Dual carrier deployment. DF4C-HSDPA Multiflow operation is enabled at the network and all the UEs.

**Table 1: System Simulation Assumptions**

<b>Simulation framework</b>	3GPP 57 sector wrap around
<b>Inter Site Distance (ISD)</b>	500m
<b>Receiver type</b>	LMMSE, Rx Diversity Receiver implementation loss realistically modelled
<b>Traffic model</b>	3GPP bursty source with 2 Mbit burst, Exponential inter-arrival with 5s mean Average load is 400kbps
<b>Antenna pattern</b>	2D with 70deg 3dB beam width
<b>Power allocation</b>	20% total overhead power (incl. 10% of CPICH)
<b>Channel Model</b>	PA3
<b>UE Distribution</b>	Uniform random dropping
<b>Loading Scenario</b>	1. Even loading, 1UE/sector 2. Uneven network loading (center 3 sectors have 3x load), varying number of users/sector
<b>Event 1a Reporting Range</b>	4.5dB



Table 1 lists the system simulation assumptions. The main performance metric is the burst rate which is computed as the ratio of the data burst size in bits to the total time the burst spent in the system. The total time the burst spent in the system is the time difference between the burst arriving at the Node B and the completion of all the data transmission over the air interface.

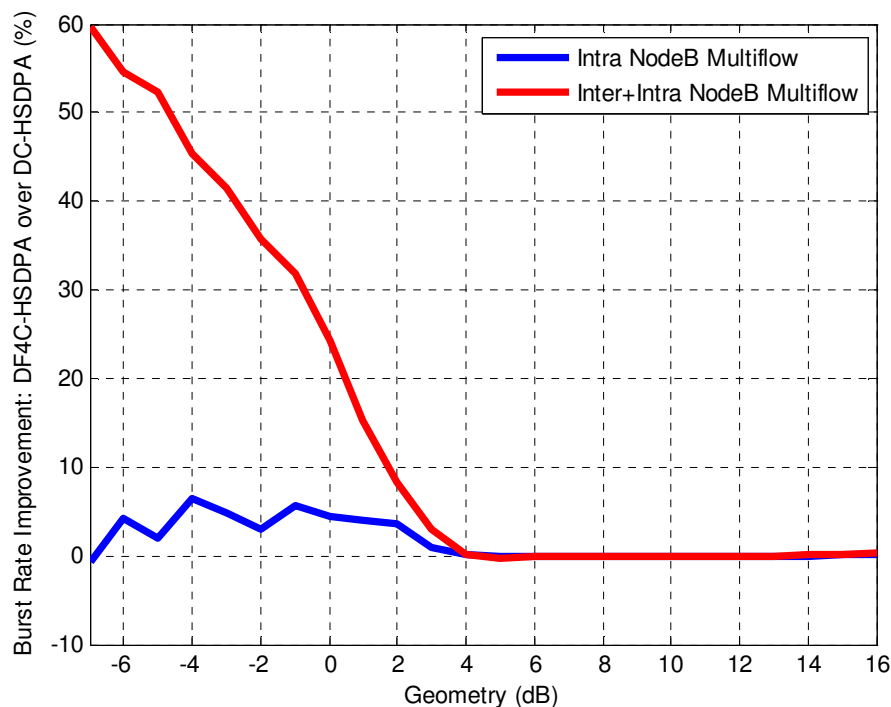
### 3.1.1 Cell Edge Performance Improvement

Network operators have identified user experience at the cell edge as an issue to be addressed. With the advancement of heterogeneous networks, in which multiple topological network layers co-exist, cell edge regions with overlapping coverage from multiple cells may increase. This magnifies the above problem and at the same time provides increased opportunity for improving cell edge user experience using Multiflow operation.

Consider UEs located at the cell edge and in softer/soft handover (SHO), the neighboring cell in the active set could cause significant interference to the cell edge UEs; thereby limiting the user experience in terms of downlink data rate. Furthermore, the neighboring cell may be lightly loaded with available resources for HSDPA scheduling. In pre- Release 11, without support of Multiflow, the UE is only allowed to be served by the serving cell, even though the neighboring cell may have available scheduling resources. Release 11 Multiflow offers performance improvement for cell edge users by taking advantage of the available scheduling resources of the neighboring cells in the active set and allowing users to be served by two different cells on the same carrier frequency simultaneously. This concept is similar to SHO in Release 99, the difference being that in Multiflow HSDPA, two independent data streams are received from the two cells, whereas during SHO in Release 99, both cells transmit identical information.

In the simulation to show cell edge user experience improvement, we drop 1 user per sector with bursty traffic. On average, each user has an offer-load of 400kbps. Figure 4 shows the user burst rate gain as a function of geometry. Geometry is defined as the ratio of the total received power from the serving cell to the sum of total received power from all other cells and the thermal noise. High geometry means the UE is close to the cell center, while low geometry means the UE is close to the cell edge.

Figure 4 clearly shows that cell edge UEs, i.e. users at low geometry, enjoy significant performance improvement in terms of burst rate increase, thanks to the Multiflow operation. For those UEs in softer or soft handover at the cell edge, their average geometry is around -1.5dB. Figure 4 shows that, at -1.5dB geometry, the expected average burst rate improvement reaches 34% when both Inter-NodeB and Intra-NodeB Multiflow is enabled and 5% when only Intra-NodeB Multiflow is enabled. The greater benefits of combining Inter-NodeB with Intra-NodeB Multiflow stem from the significantly larger number of users in either softer or soft handover region as compared to the ones only in the softer handover region. From simulation, 36% of total UE population can enable Multiflow operation, i.e. has more than 1 cell in the active set, when both Intra-NodeB and Inter-NodeB Multiflow are enabled. On the contrary, only 7% of total UE population can enable Multiflow operation, i.e. has at least one cell in the active set that belong to the same NodeB as the serving cell, when only Intra-NodeB Multiflow is enabled. Note that, there is no burst rate improvement at geometries higher than 4dB due to the fact that there is no UE in the system with geometry higher than 4dB in softer or soft handoff.

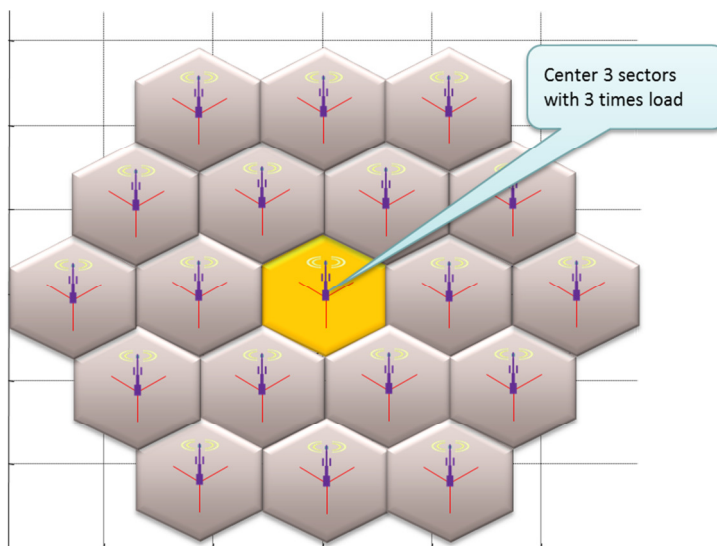


**Figure 4: User Burst Rate Gain vs. Geometry at 1UE/Sector**

### 3.1.2 Load Balancing Across Sectors and Carriers

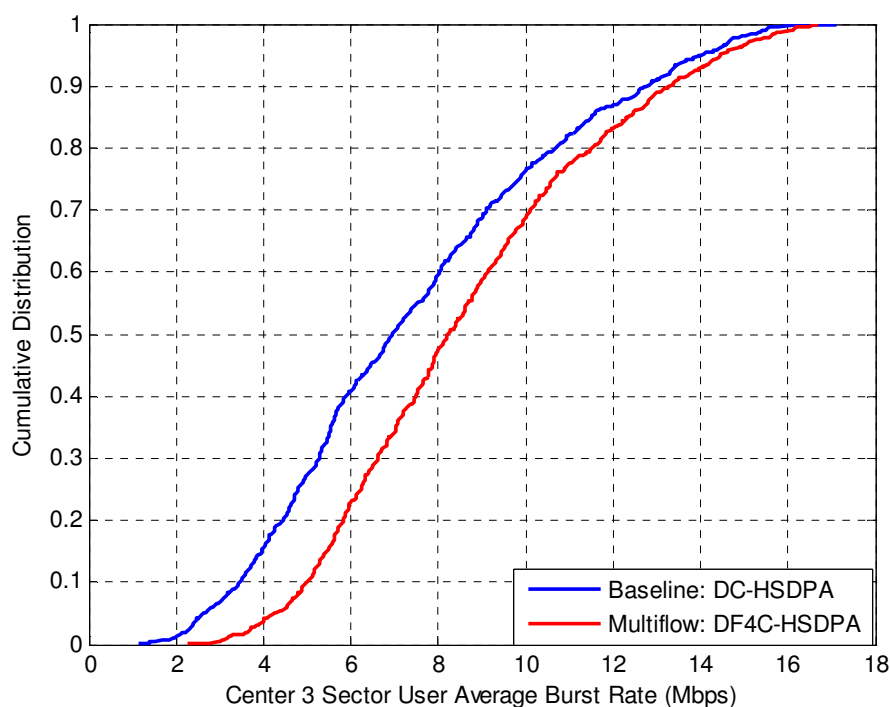
In a real deployment, the system is often non-uniformly loaded as evidenced by data from the field. Consider the case where a user's serving cell is heavily loaded over a given period of time, while a neighboring cell (in user's active set) is lightly loaded during the same period. Multiflow operation allows such a user to be served by both the heavily loaded serving cell and the lightly loaded neighboring cell simultaneously. Such operation improves the user experience and relieves the load on the heavily loaded cell through dynamic load balancing. Without Multiflow operation, such a UE would only get scheduled from the heavily loaded serving cell, thereby experiencing poorer performance while the lightly loaded neighboring cell would not be efficiently utilized.

To demonstrate the Multiflow load balancing gain in an un-evenly loaded system, we consider a simulation in which the 3 center sectors are 3 times loaded compared to the rest of the sectors. More specifically, the 3 sectors in the center of the 57-sector system have  $3 \times N$  UEs/sector, while the other 54 sectors have  $N$  UEs/sector. Figure 5 illustrates the 57 sectors layout used in the system simulation with 3:1 uneven loading. Both the Intra-Node and Inter-NodeB Multiflow are enabled.



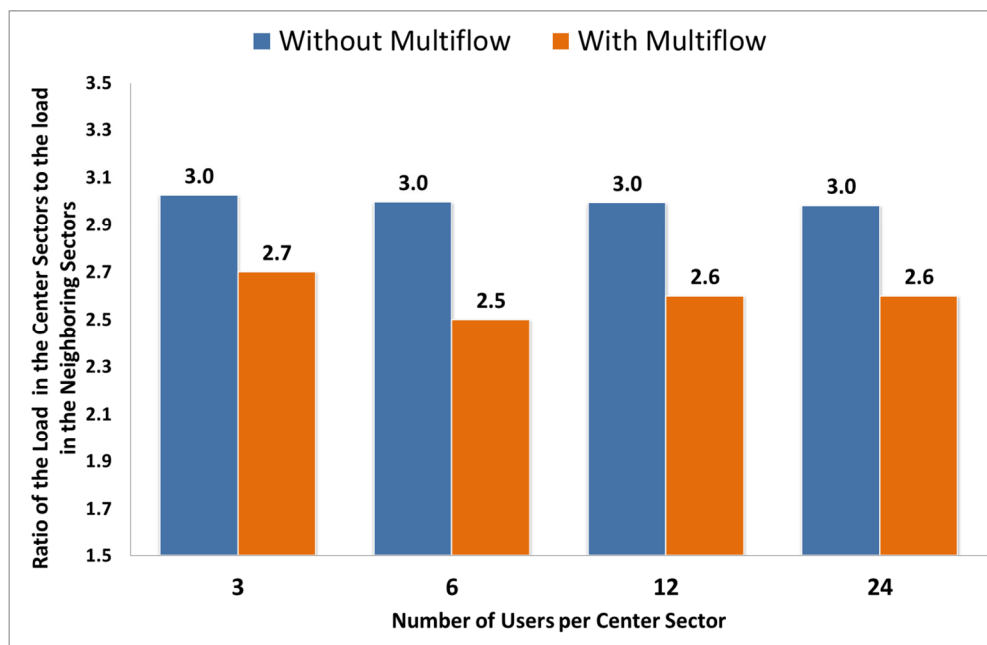
**Figure 5: 57 Sector System Simulation Layout with 3:1 Uneven Loading**

Figure 6 compares the cumulative distribution of user average burst rate in the center three sectors with and without Multiflow. The three center sectors are heavily loaded with 24 active users with a corresponding average TTI utilization, from the simulation, of 74% when Multiflow is not enabled. TTI utilization is computed as the percentage of time that a sector schedules data packet to at least one user in the system. In contrast, the adjacent sectors have eight users whose average TTI utilization is only 27% when Multiflow is not enabled. Consequently, the neighboring sectors have significant spare capacity. Figure 6 illustrates that the majority of users in the loaded sector benefit from traffic offloading created by Multiflow. Moreover, the users that benefit most are those with lower burst rates. For example, less than 4% of users experienced burst rates of less than 4 Mbps with Multiflow HSDPA compared to 15% of users without Multiflow HSDPA.



**Figure 6: Cumulative Distribution of the User Average Burst Rate in the Heavily Loaded Center 3 Sectors**

To demonstrate the load balancing, Figure 7 compares the ratio of the load in the heavily loaded center sectors to the load in the lightly loaded neighboring sectors, before and after DF4C-HSDPA Multiflow is enabled. We use average sector throughput to measure the load in each sector. In the simulation setup, each center sector has 3 times as many users as the neighboring sector. The bursty traffic model generates an average of 400kbps traffic for each user. Without Multiflow, each user is only allowed to be served by its serving and secondary serving cell from the same sector. As a result, the center sector needs to carry 3 times the load (average sector throughput) compared to the neighboring sector as shown in Figure 7. When Multiflow is enabled, the center sector users in the softer or soft handover region between the center sectors and neighboring sectors can help balance the load disparity by offloading traffic to the neighboring sectors. Figure 7 shows that the ratio of load (average sector throughput) between the center sector and the neighboring sector is reduced from 3 to ~2.6 (the variation between 2.5 to 2.7 at different number of users per center sector could be due to the limited simulation length), thanks to the Multiflow operation. This clearly demonstrates the load balancing benefits of Multiflow, as Multiflow reduces the load disparity in the system by offloading traffic from heavily loaded sectors to the lightly loaded neighboring sectors.

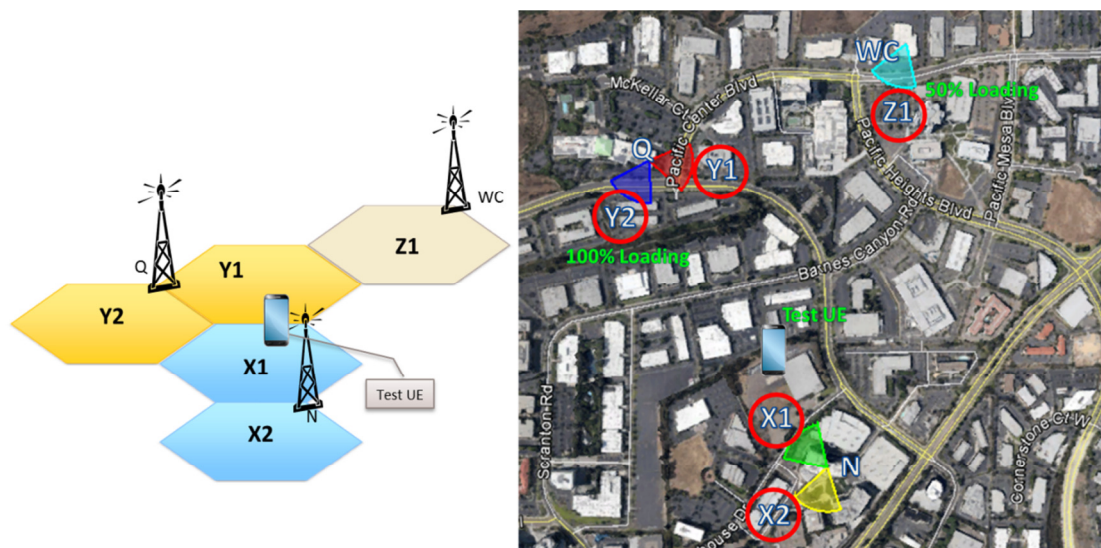


**Figure 7: Ratio of Load (average sector throughput) in Heavily Loaded Center Sectors to that in Lightly Loaded Neighboring Sector, with and without Multiflow**

Note that Multiflow load balancing simulation results presented here assume even loading across carriers, but uneven loading across sectors. In a real deployment, different carriers can also be unevenly loaded due to various reasons, such as mixture of single-carrier and multi-carrier devices, different number of carriers supported for each NodeB, etc. Dual Frequency Multiflow HSDPA (DF3C-HSDPA and DF4C-HSDPA) can improve the system performance by providing load balancing between different carriers as well.

## 3.2 Over-The-Air (OTA) Field Test Result

In this section, we present OTA field test results to show the performance benefit of Multiflow HSDPA, especially in terms of backhaul load balancing. Figure 8 shows the OTA field test setup up. The OTA system is configured as single-carrier HSPA system and consists of 3 NodeBs with 5 cells. The test UE is placed at the cell edge, in the soft handover region between cell X1 and cell Y1. The location of the test UE is chosen to make sure that cell X1 is the serving cell for more than 50% of time when Multiflow is not enabled, and cell Y1 is the assisting serving cell for more than 50% of time when Multiflow is enabled. To mimic the neighboring cell interference that the test UE could observe in a real deployment, we introduce 100% loading in cell Y2 and 50% loading in cell Z1.



**Figure 8: Multiflow Over-The-Air (OTA) Test Setup**

### 3.2.1 Backhaul Load Balancing

One important aspect we consider during the field test is to evaluate the user experience when there is backhaul congestion. Backhaul refers to the Iub link between a NodeB and its RNC. In HSPA, data for each UE is collected at the RNC; a NodeB periodically requests the data from the RNC through the backhaul and schedules the data to a UE over the air. Clearly, when the backhaul is congested and its capacity becomes smaller than the over-the-air link capacity, user experience could suffer since the rate at which data can be delivered to a UE will be limited by the backhaul instead of the over-the-air link. When Multiflow is not enabled, UE data can only be delivered through the single backhaul between the serving NodeB and the RNC. During the Inter-NodeB operation when Multiflow is enabled, both the serving NodeB and assisting serving NodeB can schedule data to a UE. Since each NodeB has its own backhaul to an RNC, backhaul congestion in one of the NodeB's would not impact user experience noticeably, thanks to the backhaul load balancing offered by Multiflow.

For field testing, video streaming was used to show the user experience benefit from Multiflow. The video stream is encoded at 4Mbps. Table 2 lists the different backhaul setups we considered in the field test. The backhaul capacity is set to 6Mbps which is larger than the 4Mbps video streaming rate when there is no backhaul limitation. When there is a backhaul limitation, backhaul capacity is set to 2Mbps.

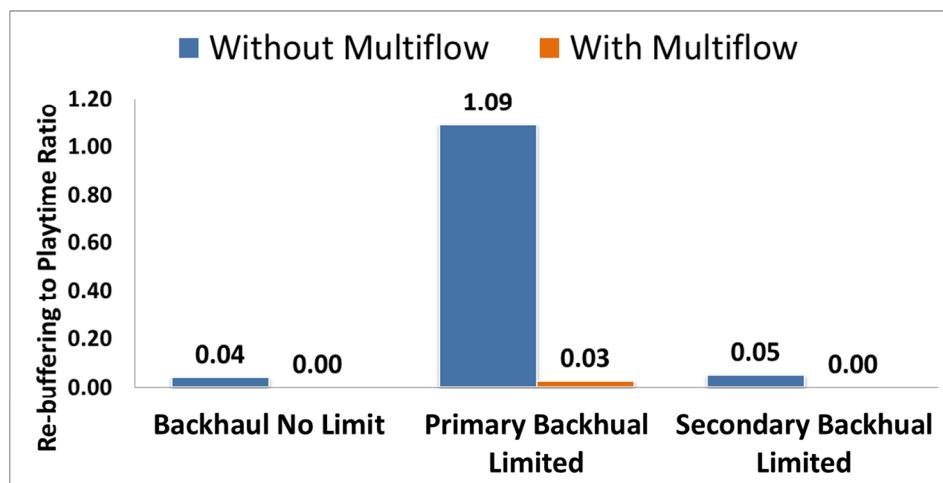
**Table 2: Multiflow OTA Test Backhaul Setup**

	Backhaul (Iub Link) Capacity (Mbps)	
	Primary Cell (X1)	Secondary Cell (Y1)
<b>Backhaul No Limit</b>	6	6
<b>Primary Backhaul Limited</b>	2	6
<b>Secondary Backhaul Limited</b>	6	2

We use video re-buffering to playtime ratio as the performance metric for user experience. The re-buffering to playtime ratio is defined as the ratio of the time spent in re-buffering incoming video frames (video is stalled) to the time taken for playing out the video. Re-buffering happens when the video image

is stalled due to insufficient data in the buffer of the video player. During re-buffering time, the video player needs to re-buffer video frames from the server before it resumes video playing. Clearly, a lower value of this ratio indicates a better user experience.

Figure 9 shows the re-buffering to playtime ratio with and without Multiflow. We observed significant performance improvement when the primary backhaul is limited. Without Multiflow, the test UE spent more time (1.09) in re-buffering video than the time for actual video play. With Multiflow, the ratio was reduced from 1.09 to 0.03 which results in tremendous user experience improvement.



**Figure 9: Re-buffering to Playtime Ratio for 4Mbps video streaming, with and without Multiflow**

Note that, since the OTA system was single carrier, we are showing performance gains of SFDC-HSDPA over a baseline of SC-HSDPA. However, we expect to see similar performance benefit in dual carrier systems, i.e. DF4C-HSDPA vs. DC-HSDPA.

## 4 HSPA+ Multiflow Design Aspects

In this section, we describe the major changes/enhancements that are needed for supporting Multiflow features at different layers, including; Physical Layer, MAC/RLC Layer and RRC Layer.

### 4.1 Physical Layer Multiflow Design

At the physical layer, Multiflow operation has a great deal of commonality with multi-carrier operation. For Multiflow operation, Release 11 requires the device to receive up to four independent data streams over up to two different carriers. To achieve this, the device needs to be able to decode up to four data streams at the same time. This requirement is the same as multi-carrier HSDPA. However, unlike multi-carrier HSDPA in which different data streams are transmitted on different carrier frequencies, and thereby do not interfere with each other; a Multiflow device needs to decode two data streams being transmitted on the same carrier frequency. To spatially separate the two data streams on the same frequency, the modem device needs to have at least two receive antennas and be equipped with an advance receiver (type 3i) capable of suppressing the interference from the other cell.



To support Hybrid ARQ (HARQ) operation and Adaptive Coding and Modulation, independent (per carrier) ACK/NAK/CQI has to be generated and fed back from the UE on the uplink HS-DPCCH for Multiflow operation. The same requirement also exists for multi-carrier operation. In fact, HS-DPCCH format and coding design for Multiflow reuses the HS-DPCCH design introduced in Release 8 and 10 for multi-carrier operation.

At the physical layer, another difference between Multiflow and multi-carrier lies in the HS-DPCCH timing. For multi-carrier operation, only one sector participates in the data transmission. All cells in the same sector have the same data channel (HS-PDSCH) timing; thereby HS-DPCCH timing is the same for multi-carrier as the pre-Release 8 HSPA system, HS-DPCCH timing becomes more complicated for Multiflow operation as more than one NodeB/Sector could participate in the data transmission. In HSDPA, downlink HS-PDSCH transmissions are not synchronized between different NodeBs as illustrated in Figure 10. For the time reference cell, a UE has around 5ms (7.5 slots) processing time after receiving the complete HS-PDSCH subframe to generate and transmit the ACK/NAK on HS-DPCCH. In Multiflow, the non-time reference cell could reside in a different NodeB/Sector hence have different HS-PDSCH timing compared to the time reference cell. The maximum timing difference is 2ms (3 slots) without any enhancement. This significantly reduces the ACK/NAK processing time for non-time reference cell data being aggregated at the UE. To mitigate the problem, an enhancement was introduced in Release 11 to allow the network to configure the time reference cell to be either the serving cell or the assisting serving cell. This enhancement reduces the maximum allowed processing time difference between the time reference and non-time reference cells to 1ms (1.5 slots). With this enhancement, the UE processing time of ACK/NAK generation for the non-time reference cell is reduced by up to 1ms compared to multi-carrier operation. It is also important to note that, in a practical deployment, the timing difference between two NodeBs could change over time due to various reasons such as time drifting. The RNC is required to constantly monitor the timing difference between the two NodeBs in Multiflow operation and reconfigure/change the time reference cell when needed.

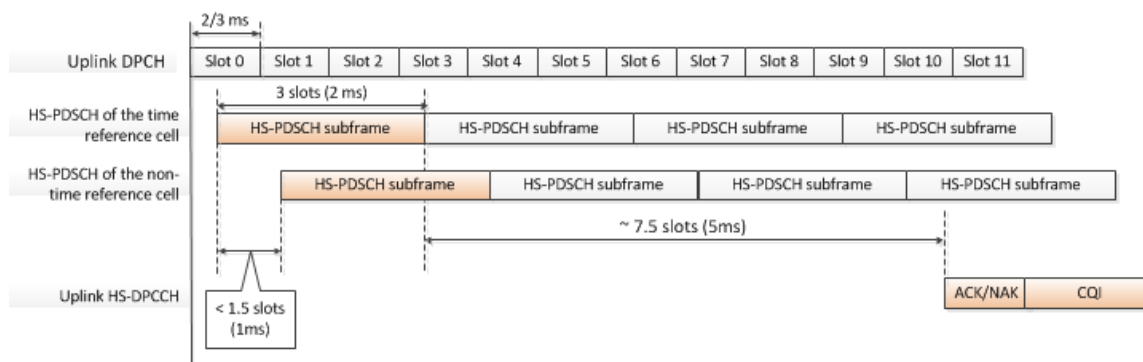


Figure 10: HS-DPCCH Timing for Multiflow HSDPA

## 4.2 MAC/RLC Layer Multiflow Design

Figure 11 illustrates the high level MAC and RLC structure of Intra-NodeB Multiflow and Inter-NodeB Multiflow. For Intra-NodeB Multiflow, all downlink transmissions are controlled by one NodeB. Therefore, there needs to be only one transmission queue in the NodeB as well as only one MAC-ehs entity in NodeB and UE, respectively. In summary, the MAC and RLC design for Intra-NodeB Multiflow is the same as multi-carrier. A new requirement on the NodeB is the capability of scheduling data to the UE across two sectors.

For Inter-NodeB Multiflow, some additional enhancements are needed. First, there is a separate transmission queue and a MAC-ehs entity in each NodeB. This requires the RNC to split the downlink data stream at the RLC layer into two separate MAC-ehs flows as shown in the right part of Figure 11.



Since the packets sent by the RNC across separate flows may experience different amounts of delay, there is a possibility that the UE receives packets out of sequence and therefore sends RLC acknowledgements out of sequence. Therefore, to support Inter-NodeB Multiflow, an RLC enhancement was needed in order to differentiate genuine RLC packet loss from those that are due to out-of-sequence RLC packet delivery. A new RLC reordering timer has been introduced in Release 11 to handle the issue. The reordering timer starts when an out-of-sequence RLC packet is detected at the UE. However, the receiver is not allowed to transmit an RLC status report until the reordering timer expires. This gives time for those missing RLC packets due to skew between multiple flows to arrive before a retransmission is requested. In addition to the reordering timer, enhanced flow control over the Iub interface along with enhanced NodeB buffer management may be needed as well. The purpose of enhanced flow control and NodeB buffer management is to minimize the differential RLC packet delay between flows while avoiding NodeB buffer under-runs. These enhancements are limited to upper layer software upgrades in the NodeB and RNC.

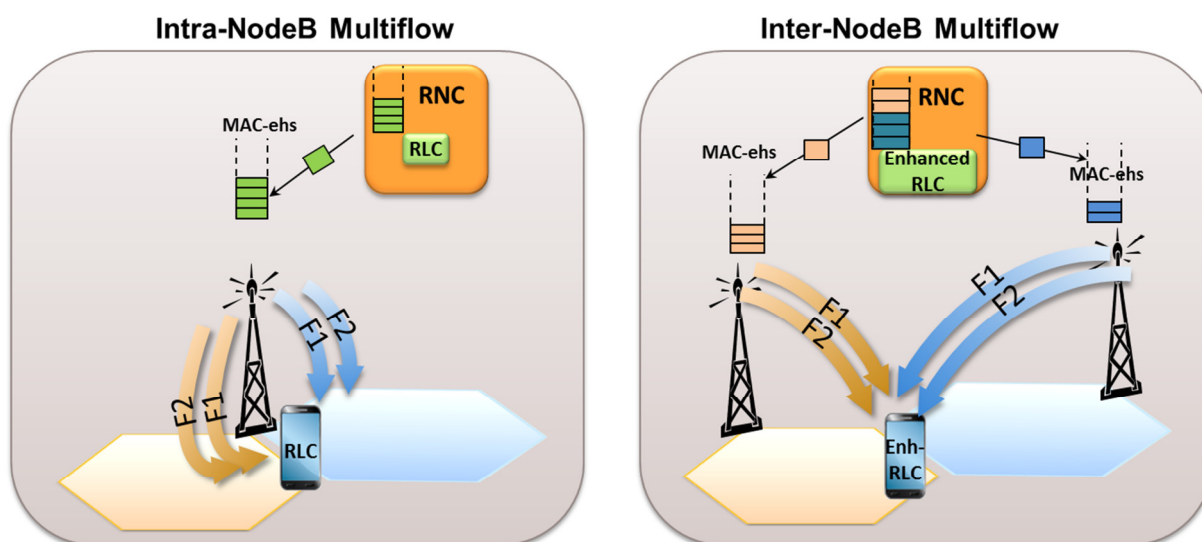


Figure 11: Intra-NodeB and Inter-NodeB Multiflow

### 4.3 RRC Layer Multiflow Design

New RRC signaling is defined in Release 11 to configure Multiflow operation. In general, the legacy RRC messages are re-used to setup/ (re)configure HSDPA with new Information Elements (IE) added to configure Multiflow operation and/or parameters needed at Physical, MAC and RLC layers. On the UE capabilities side, Multiflow (SFDC, DF3C and DF4C) HSDPA re-uses categories of multi-carrier (DC, 3C and 4C) HSPDA. Several new RRC signaling messages have been introduced for the UE to inform the RNC of its Multiflow capabilities.

## 5 Multiflow Deployment Consideration

As we discussed in the previous sections, both the multi-carrier and Multiflow features introduced as part of HSPA evolution allow users to be served by more than one cell at the same time. From the individual user experience perspective, both features improve the downlink data rate as the user can be scheduled

with multiple data streams simultaneously. From the system performance perspective, multi-carrier and Multiflow features also provide promising gains by allowing load balancing across different links.

Considering an HSPA deployment that supports both multi-carrier and Multiflow features, the network now has greater flexibility in terms of configuring the best links to serve users to optimize the user experience. For a user located in the SHO region, the network has multiple options; it could configure the user to be served by the same sector on different carriers using the multi-carrier feature, or be served by different sectors on the same carrier(s) using the Multiflow feature. In order to make the optimized decision, the network should take multiple factors into consideration, including:

- The number of links that can be configured to the UE
- The quality of each link
- The loading on each link
- The backhaul condition of each link, etc.

In general, the network should configure the user to use the links that can provide the most efficient utilization of resources, in other words, the links that have higher link quality, less loading and/or better backhaul conditions.

For example, consider an HSPA deployment with 3 carriers supporting both multi-carrier and Multiflow. For a user located in a SHO region, the network could configure the user as 3C-HSDPA (multi-carrier) or DF4C-HSDPA (Multiflow). If the neighboring sector in the active set is lightly loaded compared to the serving sector and has good backhaul condition, the network should configure the user to use DF4C-HSDPA, since it allows the user to be served by 4 cells simultaneously while 3C-HSDPA only allows 3 cells. On the contrary, if the neighboring sector becomes heavily loaded or experiences backhaul congestion, the network should configure the user to use 3C-HSDPA instead of DF4C-HSDPA. Clearly, multi-carrier and Multiflow features, combined together, provide the network with greater power to adapt to the dynamic load/ link/backhaul conditions seen in real deployments.

Another example to consider is the dual carrier deployment supporting both DC-HSDPA and SFDC-HSDPA features. For users in the SHO region, static configuration of either DC-HSDPA or SFDC-HSDPA is not the optimal solution. Instead, a user should be configured as DC-HSDPA if the serving sector is lightly loaded and has good backhaul condition, considering the fact that other links in SHO typically have worse quality compared to the serving link. However, if the serving sector becomes heavily loaded or experiences backhaul congestion while the other SHO link has abundant available resources, SFDC-HSDPA should be configured to take full advantage of the load balancing.

In Summary, when the network makes smart decisions about multi-carrier and Multiflow configurations by jointly considering the number of links, link quality, loading and backhaul conditions, it offers a great potential for both user experience and system performance improvement.

## 6 Conclusion

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Multiflow is introduced in Release 11 to allow two sectors to simultaneously schedule independent data streams to the user on the same frequency. Release 11 Multiflow supports one or two carriers, and thereby enables users to receive up to 4 data streams in a dual carrier deployment without MIMO operation. The impact of Multiflow HSDPA on the network side is primarily limited to software upgrades affecting the upper layers (RLC and RRC). On the UE side, a Multiflow capable UE needs to be able to decode multiple

data streams simultaneously, have at least two receive antennas and be equipped with advanced receiver capable of interference cancellation.

The Multiflow feature provides promising gain for cell edge users. For typical cell edge users at -1.5dB geometry, the Multiflow feature could improve their user experience, i.e. burst rate, by over 30%. In addition to the user experience improvement, Multiflow also provides system load balancing. In our simulation when loading of center sector is three times that of neighboring sector, we observe significant system performance improvement. In the heavily loaded center sector, less than 4% of users experience burst rates of less than 4 Mbps with Multiflow compared to 15% of users without Multiflow. Furthermore, Multiflow also improves the system performance by offering dynamic backhaul load balancing. In our field test when the primary cell backhaul is congested, significant user experience improvement could be observed for a video streaming application when Multiflow is enabled.