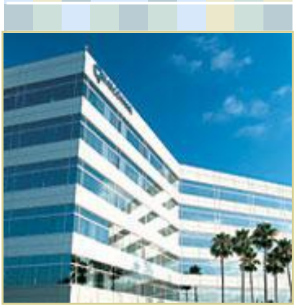
Performance and Implementation of SF-DC Aggregation



February 2011

Contents

1. Introduction .... - 3 -

2. Performance of SF-DC Aggregation.. - 5 -

2.1. Simulation assumptions .... - 5 -
2.2. Performance with all UEs capable of SF-DC Aggregation .... - 7 -
2.2.1. Performance under uniform loading .... - 7 -
2.2.2. Performance under non-uniform loading .... - 11 -
2.3. Performance with mixed legacy and SF-DC Aggregation capable UEs .... - 13 -
2.3.1. Performance under uniform loading .... - 13 -
2.3.2. Performance under non-uniform loading .... - 17 -
2.4. Performance with 3D antennas .... - 19 -

3. Impacts to Upper Layers .... - 22 -

3.1. MAC layer changes .... - 22 -
3.2. RLC enhancements .... - 22 -
3.3. Iub flow control .... - 25 -

4. Conclusions.. - 27 -

5. References... - 28 -

1. Introduction

The proliferation of 3G services has fuelled continuous enhancements to the WCDMA-HSPA system, such as 64QAM, MIMO, DC-HSDPA and Multi-Carrier HSDPA. The introduction of Multi-Carrier HSDPA networks along with Multi-Carrier HSDPA capable UEs opens the possibility of MultiPoint HSDPA, where a UE in soft or softer handover can receive HS packets from multiple cells. The main motivations include improving the cell edge user experience and balancing the uneven loading across different cells. In December 2010, MultiPoint HSDPA became a study item for Release 11 of WCDMA/HSPA standardization [1].

In the meetings of the 3rd Generation Partnership Project (3GPP) where WCDMA standards are specified, a number of candidate schemes for MultiPoint HSDPA have been proposed. They include:

- Single-Frequency DC-HSDPA Aggregation (SF-DC Aggregation): two sectors schedule independent transport blocks to the UE in the same frequency;
- Single-Frequency DC-HSDPA Switching (SF-DC Switching): as a variant to SF-DC Aggregation, among the two sectors in the same frequency, only the stronger sector in any given TTI transmits to the UE during that TTI;
- Dual-Frequency DC-HSDPA Aggregation (DF-DC Aggregation): the two sectors scheduling independent transport blocks to the UE are on two different frequencies;
- Dual-Frequency 4C-HSDPA Aggregation (DF-4C Aggregation): up to two sectors schedule up to four independent transport blocks on the two frequencies;
- Dual-Frequency 4C-HSDPA Switching (DF-4C Switching): as a variant to DF-4C Aggregation, among the two sectors on each of the two frequencies, only the strongest sector on each frequency transmits to the UE in any TTI.

A nomenclature is used for the various schemes:

- ‘SF’ or ‘DF’ refers to the number of frequencies required for the network;
- ‘DC’ or ‘4C’ refers to the UE receiver capability in terms of number of CQI streams;
- ‘Aggregation’ or ‘Switching’ refers to whether the number of simultaneous packets is equal to the number of CQI streams.

The references of [2] through [7] are contributions to the 3GPP meetings discussing MultiPoint HSDPA schemes. These contributions can all be found at the 3GPP website (http://www.3gpp.com/). The white paper of [8] provides an overview of these schemes and their performance benefit.

These MultiPoint HSDPA schemes have different requirements on the network, UE and system bandwidth. The following table provides a comparison of these schemes.

Table 1: Complexity comparison of MultiPoint HSDPA schemes

Scheme	# carriers in network	UE RxD requirement	# simultaneous packets per TTI	#CQI feedback stream	Intra-NodeB and Inter-NodeB Applicability
SF-DC Aggregation	1	RxD	2	2	Both
SF-DC Switching	1	Single Rx	1	2	Intra-NodeB only
DF-DC Aggregation	2	Single Rx	2	2	Both
DF-4C Aggregation	2	RxD	3 or 4	3 or 4	Both
DF-4C Switching	2	Single Rx	2	3 or 4	Intra-NodeB only

Among these schemes, SF-DC Aggregation might be adopted the earliest. Therefore, in this paper, we focus on the performance of SF-DC Aggregation. The performance results for the other schemes can be found in the 3GPP contributions ([2] through [6]).

In Section 2, SF-DC Aggregation is studied under a variety of network deployment and loading conditions. In Section 3, the implementation issues on the upper layer are discussed and simple enhancements are presented. This paper concludes with Section 4.

2. Performance of SF-DC Aggregation

In this scheme, two sectors schedule independent transport blocks to the UE in the same frequency. Up to two transport blocks can be scheduled during a TTI. This scheme is applicable to a single carrier network. It requires the UE to be dual-carrier (DC) capable and have a receiver with an interference aware chip equalizer and receive diversity, for example, the type 3i equalizer specified by 3GPP in [9].

There are two flavors of SF-DC Aggregation: Intra-NodeB Aggregation where the two serving cells must reside in the same Node B and Inter-NodeB SF-DC Aggregation where the two serving cells reside in different Node Bs. The key advantage of Inter-NodeB SF-DC Aggregation is that many more UEs can benefit from Inter-NodeB Aggregation. This is because the percentage of UEs in soft handover is much higher than that of softer handover. Intra-NodeB SF-DC Aggregation is most attractive for deployments with remote radio heads where non-colocated sectors are controlled by the same Node B baseband unit (BBU) and therefore the percentage of softer handover UEs is higher.

2.1. Simulation assumptions

The main simulation assumptions are listed in Table 2. We have followed the simulation assumptions widely used in WCDMA/HSPA standardization.

Table 2: System Simulation Assumptions for SF-DC Aggregation

Parameters	**Comments**
Cell Layout	Hexagonal grid, 19 Node B, 3 sectors per Node B with wrap-around
Inter-site distance	1000 m
Carrier Frequency	2000 MHz
Path Loss	L=128.1 + 37.6log10(R), R in kilometers
Log Normal Fading	Standard Deviation : 8dB Inter-Node B Correlation:0.5 Intra-Node B Correlation :1.0
Max BS Antenna Gain	14 dBi
Antenna pattern	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ θ_{3dB} = 70 degrees, A_m = 20 dB
Channel Model	PA3
CPICH Ec/Io	-10 dB
Total Overhead power	30%
UE Antenna Gain	0 dBi
UE noise figure	9 dB
UE Receiver Type	Type 3i
Maximum Sector Transmit Power	43 dBm
Traffic	Bursty Traffic Source Model File Size: Truncated Lognormal, $\mu = 11.736$ $\sigma = 0.0$, Mean = 0.125 Mbytes Maximum = 1.25 Mbytes Inter-arrival time: Exponential, Mean = 5 seconds
Flow control on Iub	Ideal and instantaneous
HS-DPCCH Decoding	Ideal on both sectors

With SF-DC Aggregation, the UEs served by a cell can be classified into two kinds:

- Primary UEs: including the legacy UEs and those SF-DC UEs who have this cell as their primary serving cell;
- Secondary UEs: including those SF-DC UEs who have this cell as their secondary serving cell.

In our studies, the scheduling algorithm is chosen to be the following:

- The scheduling algorithm at the two serving cells is independent. This is motivated by the desire to simplify implementation.
- Among all UEs in a particular cell, the traffic for the primary UEs is given absolute priority over the traffic for the secondary UEs. This means that a SF-DC UE will not be scheduled in its secondary serving cell if there is any traffic for the primary UEs in that cell. This scheduling policy can protect the legacy users from being adversely affected by the new SF-DC Aggregation schemes.

The above scheduling algorithm serves as a reference design. Other choices are possible. For example, the prioritization between the primary and secondary UEs can be configured differently to trade-off the SF-DC gain and impact from SF-DC Aggregation on the legacy UEs.

The main performance metric for comparison purposes is the average burst rate. For each file, the burst rate is defined as the ratio between the file size and the total download time measured at RNC from the moment the file arrives to the moment the reception of the entire file is acknowledged by the UE. The average burst rate per UE is defined as the mean burst rate of all the files downloaded by the UE during the simulation time.

In this layout, if a UE is in both softer and soft handover, its secondary serving cell is the next strongest cell to the primary serving cell, based on the CPICH Ec/Io. Overall, there are about 10% of UEs in softer handover and 38% of UEs in soft handover. Hence, the Inter-NodeB schemes are expected to provide more significant gains than Intra-NodeB schemes.

2.2. Performance with all UEs capable of SF-DC Aggregation

2.2.1. Performance under uniform loading

Uniform loading refers to the assumption that the number of users is same in all sectors and each user is engaged in the same bursty file download as described in Table 2. Uniform loading is a simplified assumption used in many studies. Although unrealistic, results under uniform loading serve as a useful reference point. As seen later, the performance gain from SF-DC Aggregation is higher under non-uniform loading.

There are three scenarios in our simulation: a baseline system without any aggregation schemes, a system with only Intra-NodeB SF-DC Aggregation and a system with both Intra-NodeB and Inter-NodeB SF-DC Aggregation.

To provide insight on the SF-DC gain, Figure 1 shows the cumulative distribution function (CDF) of the average burst rate for all the users in the system when there is 1 user per cell. As seen in Figure 1, there is a noticeable but small improvement of user experience due to Intra-NodeB Aggregation and a much larger gain due to Intra + Inter-NodeB Aggregation. Since the softer and soft handover users are typically located near the cell edge, the gain from SF-DC Aggregation is concentrated on users with low to medium burst rate. The larger gain with Intra + Inter-NodeB Aggregation is due to the much larger percentage of UEs capable of benefiting from the aggregation.

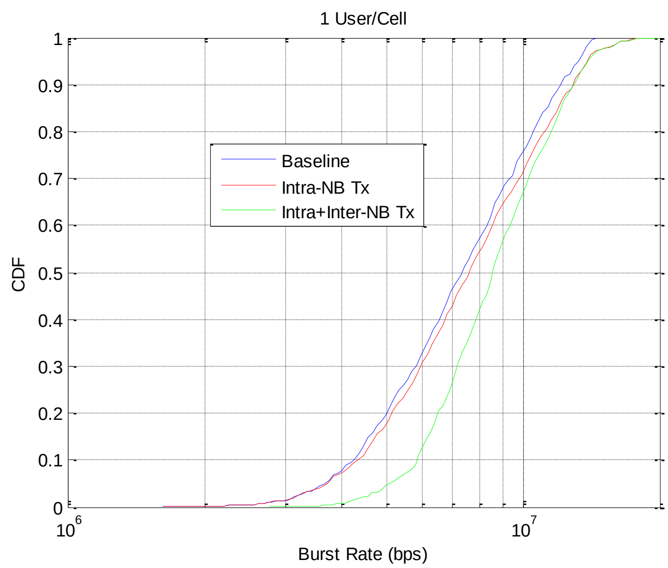


Figure 1: CDF of average burst rates for all the UEs

As seen in Figure 1, there is no degradation of user experience due to SF-DC Aggregation. In particular, users that do not avail of this feature (users not in softer or soft handover) do not experience performance degradation due to this feature in the handover regions of the system. This is a consequence of prioritizing the traffic for the primary UEs over secondary UEs in a cell, as discussed in Section 2.1. A SF-DC UE will not be served in its secondary serving cell if any primary UE in that cell has data to receive. The impact from SF-DC Aggregation on the legacy UEs will be studied further in Section 2.3 where a mixture of SF-DC capable and legacy UEs is considered.

The performance with multiple users per cell is studied in Figure 2 to Figure 5. Figure 2 shows the average user burst rate for softer handover users in the baseline system, a system with only Intra-NodeB SF-DC Aggregation and a system with both Intra-NodeB and Inter NodeB SF-DC Aggregation. It is seen in Figure 2 that a softer handover user experiences similar benefit in both aggregation scenarios. Figure 3 shows the same performance for the soft handover users. It is seen in Figure 3 that a soft handover user only benefits when the Inter-NodeB Aggregation is allowed.

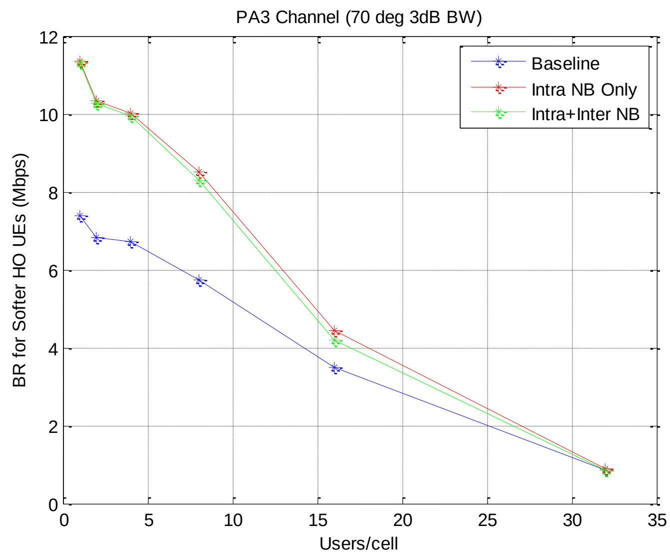


Figure 2: Average burst rate for softer handover UEs versus the number of UEs/cell

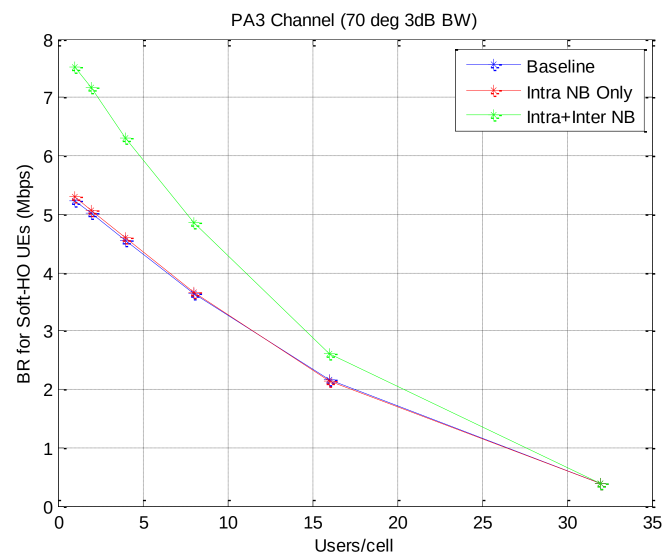


Figure 3: Average burst rate for soft handover UEs versus the number of UEs/cell

The burst rate gains for the softer and soft handover UEs, when both aggregation schemes are allowed, are plotted in Figure 4 and Figure 5 respectively. If the gains shown in Figure 4 and Figure 5 are compared, at the same loading level, the gain seen by a softer handover UE is comparable to the gain seen by a soft handover UE; however, there are only 10% UEs in softer handover versus 38% of UEs in soft handover. Therefore, the system benefit from SF-DC Aggregation is much more significant if Inter-NodeB Aggregation is allowed in addition to Intra-NodeB Aggregation.

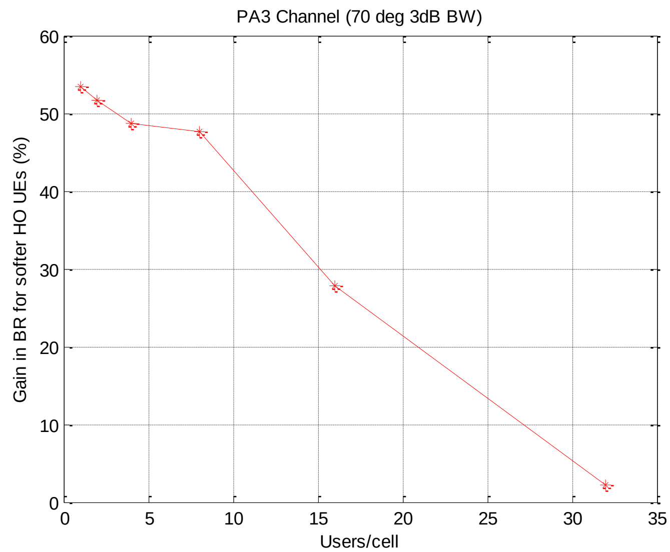


Figure 4: Gain in average burst rates for softer handover UEs with both Intra-NodeB and Inter-NodeB Aggregation

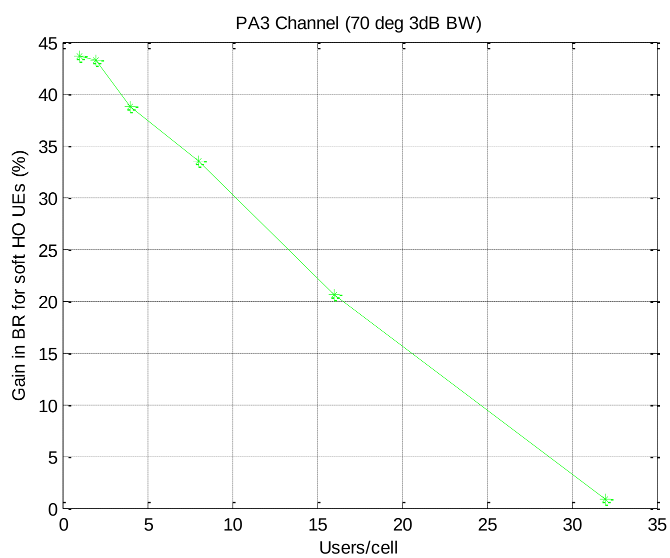


Figure 5: Gain in average burst rates for soft handover UEs with both Intra-NodeB and Inter-NodeB Aggregation

With multiple users per cell, the effect of loading can be clearly seen. In Figure 4 and Figure 5, the gain from SF-DC Aggregation decreases with loading because the SF-DC UEs have less opportunity to get service from their secondary serving cells as load increases.

In summary, under uniform loading, SF-DC Aggregation shows sizeable improvements to the data rate achievable by the softer and soft handover UEs. This gain can be seen as a lower bound since SF-DC can provide higher gain with non-uniform loading through cross-cell load balancing, which is discussed next. Furthermore, the trend of decreasing gain with increasing load will be reversed with non-uniform loading.

2.2.2. Performance under non-uniform loading

In a real deployment, the system is typically non-uniformly loaded as evidenced by data from the field. Consider the case where a UE’s serving cell experiences heavy load over a given period of time, while a neighboring cell (in UE’s active set) is more lightly loaded during the same period. If Intra-NodeB and/or Inter-NodeB Aggregation were allowed, such a UE would get scheduled from both the cells thereby resulting in dynamic load-balancing in the network. If aggregation were not allowed, such a UE would only get scheduled from the serving cell and thereby experiences poorer performance while at the same time the cells would not be efficiently utilized.

To analyze gains in this scenario, we have assumed that the 3 cells in the center Node B (of the 57 cell/19 NodeB layout) have 3*N users/cell, while cells in the other 18 Node Bs have N users/cell, where N = 1, 2, 4, 8 and 16. The following figures (Figure 6 and Figure 7) focus on the performance of UEs in the heavily loaded center Node B.

Figure 6 shows the average burst rate performance of soft-handover UEs in the heavily loaded center Node B with and without aggregation. Figure 7 shows the average burst rate gain for these UEs with aggregation.

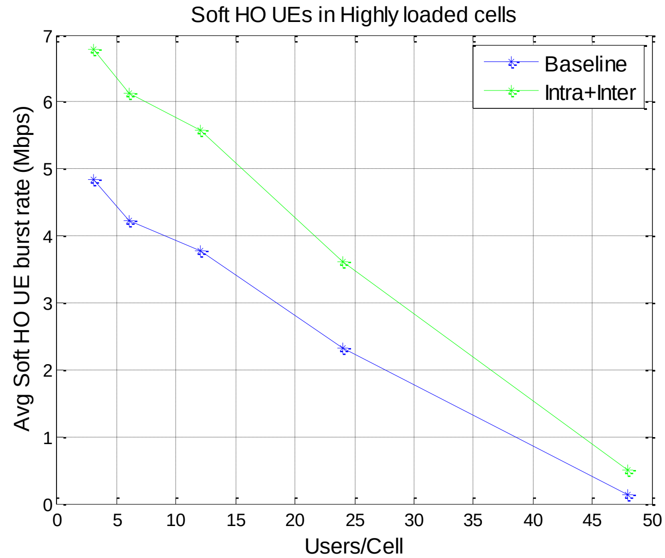


Figure 6: Average burst rate for soft handover UEs versus the number of UEs/cell in the highly loaded center Node B

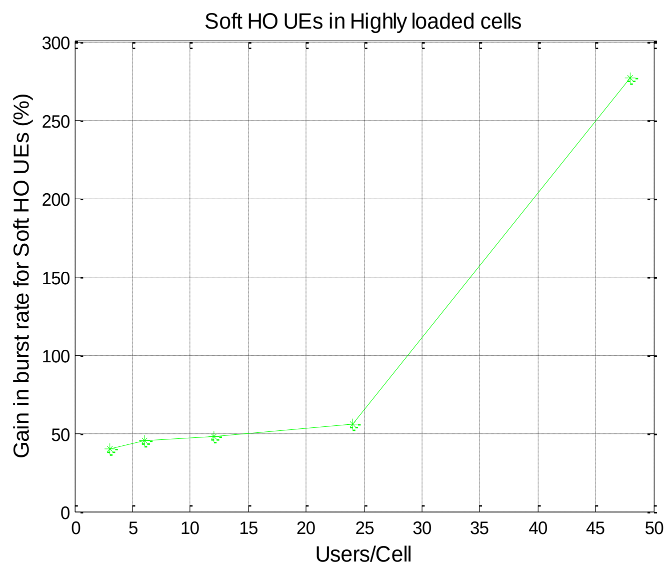


Figure 7: Average burst rate gain for soft handover UEs versus the number of UEs/cell in the highly loaded center Node B

From Figure 6 and Figure 7, two important trends can be identified:

1. The gain from SF-DC Aggregation is higher in the highly loaded cells than in a cell in a uniformly loaded system. This is seen by comparing the gain in Figure 7 and Figure 5 in Section 2.2.1 for the same number of users per cell. This is due to the fact that the soft handover UEs in the highly loaded Node B can get more service from the lightly loaded neighboring cells.

2. The gain from SF-DC Aggregation for UEs in the heavily loaded cells is increasing with load. This is unlike the observation in Section 2.2.1 with uniform loading. The reason is, with non-uniform loading, the service from the secondary serving cell decreases much more slowly with increasing load since the neighboring cells are much less loaded. Thus, as load increases, a SF-DC UE in the heavily loaded cell receives an increasing portion of its total service from its lightly loaded secondary serving cell. Here is a simple example. When a center cell is 30% loaded, its non-center neighboring cell is only 10% loaded, the ratio of time slots a SF-DC UE can be scheduled in the center cell to those in the neighboring cell is (100%-30%)/(100%-10%)=7/9. When the center cell is 90% loaded, the neighboring cell is only 30% loaded, the same ratio becomes (100%-90%)/(100%-30%)=1/7. To keep the analysis simple, we have ignored the role of other factors including the CQI and scheduling algorithm.

NOTE: The loading across the 3 sectors of the same Node B is assumed to be the same in our simulation and hence Intra-NodeB Aggregation does not provide higher gain when compared to the scenario with uniform loading as in Section 2.2.1 . Therefore, those results are not shown here. However, in practice, the loading across sectors in the same Node B can also be very different.

2.3. Performance with mixed legacy and SF-DC Aggregation capable UEs

In Section 2.2, SF-DC Aggregation is shown to provide substantial benefit to users in handover, especially when the system is non-uniformly loaded. The impact of SF-DC Aggregation to the legacy UEs is studied in this subsection.

We assume a 50/50 mixture of the legacy and SF-DC Aggregation capable UEs. The legacy UEs have single receive antenna only. The SF-DC Aggregation capable UEs have Rx diversity, even for their baseline simulations.

For the case where the legacy UEs have receive diversity, our simulation shows very similar results as those presented here.

2.3.1. Performance under uniform loading

Figure 8 and Figure 9 show the CDF of user burst rates for 2 users and 16 users per cell respectively. Here the baseline performance is the case where SF-DC is not enabled, i.e., all the UEs, including both the legacy UEs and the SF-DC capable UEs receive data only from the serving cell. In the baseline system, the SF-DC capable UEs achieve higher burst rate than the legacy UEs because of the receive diversity. When SF-DC is enabled, the users that are SF-DC capable receive data from two cells if they are in soft or softer handover regions. In Figure 8 and Figure 9, the performance of the legacy UEs are represented by dashed lines when both Intra-NodeB and Inter-NodeB Aggregation are enabled. It can be seen that there is no performance degradation experienced by these UE’s when SF-DC is enabled. At the same time, the burst rates of the SF-DC capable UEs increase with aggregation.

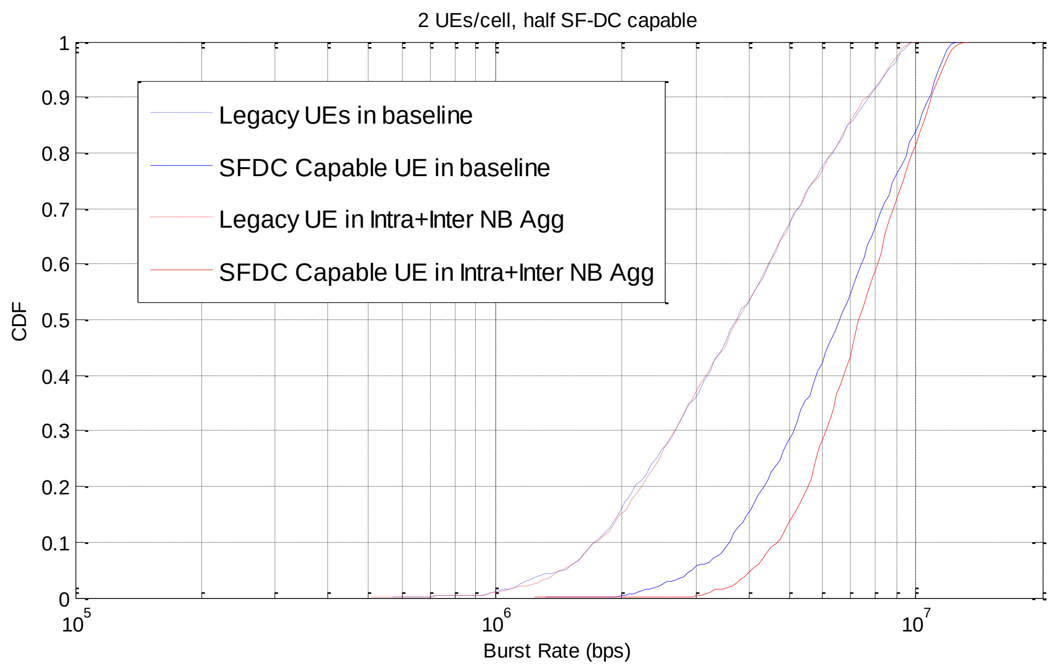


Figure 8: CDF of UE burst rate (2 users/cell: 1 legacy, 1 SF-DC capable UE per cell)

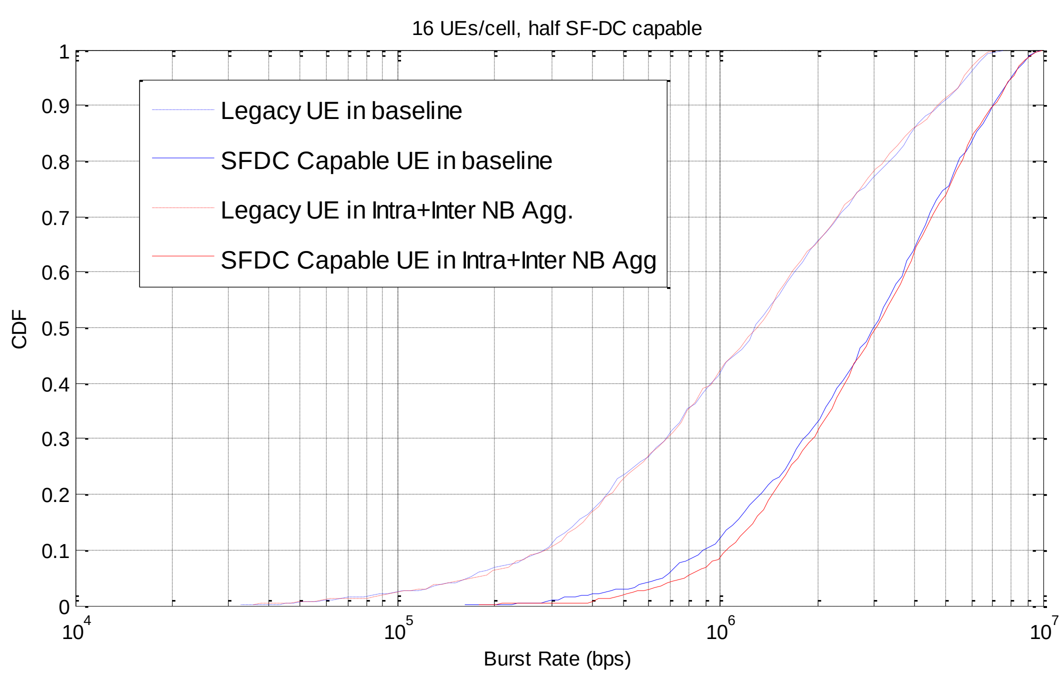


Figure 9: CDF of UE burst rate (16 users/cell: 8 legacy, 8 SF-DC capable UEs per cell)

Figure 10 and Figure 11 below show the average gain in burst rate for the UE's that are SF-DC capable and are in softer and soft handover regions.

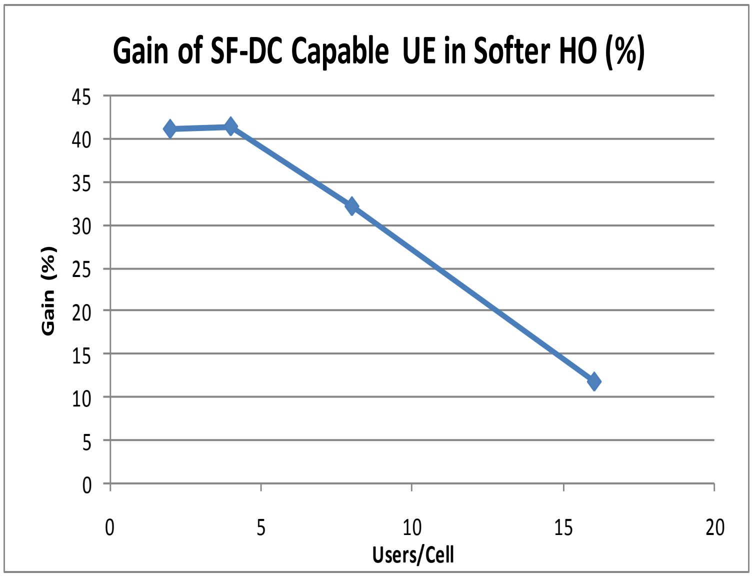


Figure 10: Burst rate gain for SF-DC capable UEs in softer handover versus number of UEs/cell

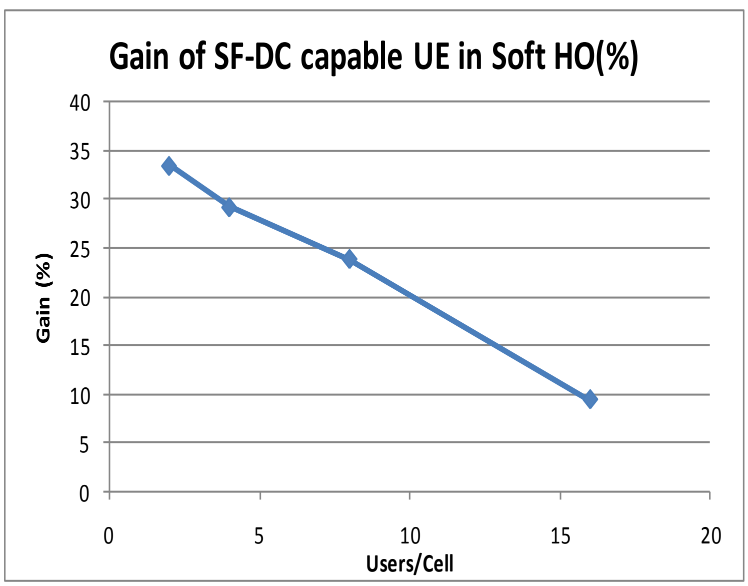


Figure 11: Burst rate gain for SF-DC capable UEs in soft handover versus number of UEs/cell

In Figure 10 and Figure 11, it can be seen that there are significant gains in average user burst rate for users that are SF-DC capable and are in softer and soft handover regions. Note however that the gains seen by SF-DC capable users are somewhat smaller than the gain seen in the cases with all UEs SF-DC capable for the same number of users per cell (Section 2.2.1). This is because the number of slots used to serve a legacy UE in handover is higher than it would be to serve the same UE were it SF-DC capable, resulting higher slot utilization at the same offered load and less service to the SF-DC UEs from the secondary serving cells.

Like in the previous case in Section 2.2.1, at the same loading level, the gain seen by a softer handover UE is comparable to the gain seen by a soft handover UE; however, there are only 10% UEs in softer handover versus 38% of UEs in soft handover. Therefore, the system benefit from SF-DC Aggregation is much more significant if Inter-NodeB Aggregation is allowed in addition to Intra-NodeB Aggregation.

2.3.2. Performance under non-uniform loading

Like in Section 2.2.2, it is assumed that the 3 cells in the center Node B (of the 57 cell/19 NodeB layout) have 3*N users/cell, whereas cells in the other 18 Node Bs have N users/cell, where N = 2, 4, 6 and 8. Results are shown for the performance of the UEs located in the center Node B, i.e., the one that is comparatively heavily loaded.

Figure 12 and Figure 13 show the CDF of UE burst rates for 6 and 24 users/cell in the center Node B respectively. The simulations were conducted in the same fashion as described in the previous section.

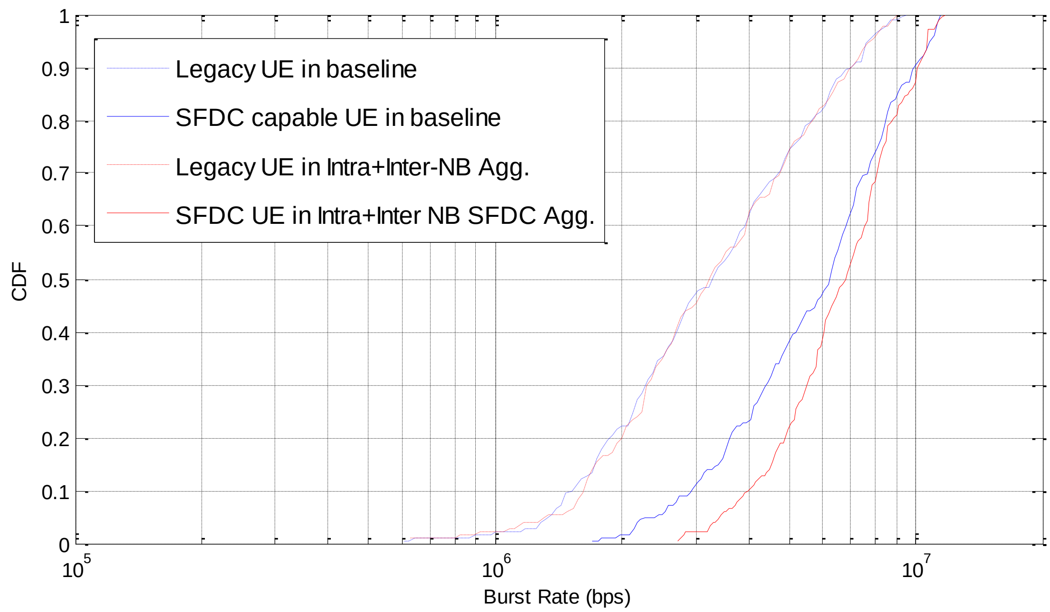


Figure 12: CDF of UE burst rates (6 users per cell) in highly loaded center Node B

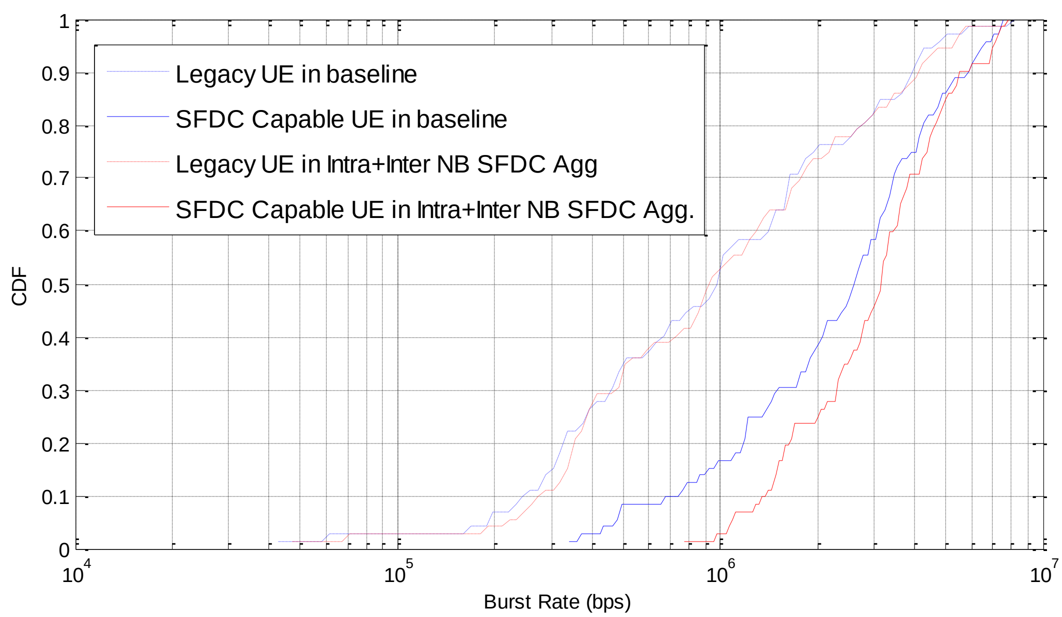


Figure 13: CDF of UE burst rates (24 users per cell) in highly loaded center Node B

Like in the previous section, the impact of SF-DC on legacy UE’s can be ascertained by comparing the performance of the legacy UEs in the baseline case and the case when SF-DC is enabled. This can be seen in Figure 12 and Figure 13 by comparing the dashed lines. It is observed that the legacy UEs do not suffer any performance degradation due to the enabling of SF-DC. On the other hand, the SF-DC capable UEs in soft handover have a significant performance gain which is seen by comparing the solid lines in both figures.

Figure 14 shows the gain in average burst rates for SF-DC capable UEs located in the center Node B and in soft handover with cells in neighboring Node-Bs.

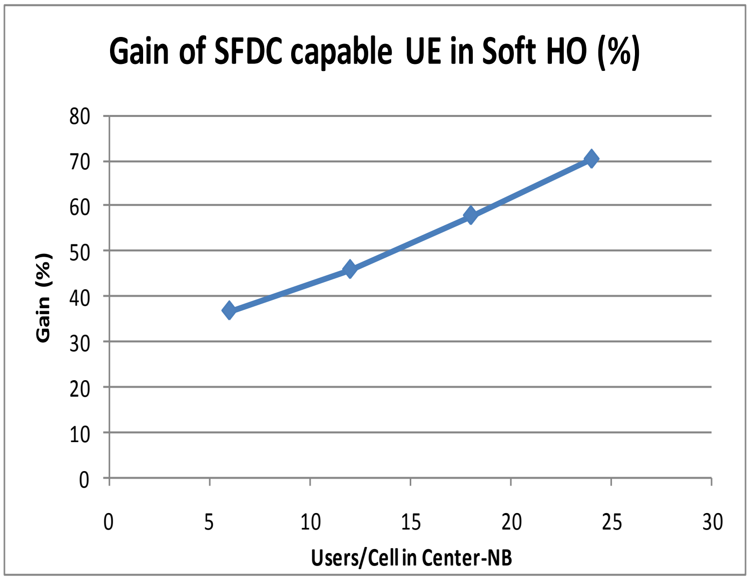


Figure 14: Burst rate gain for SF-DC capable UEs in soft handover vs Users/Cell in center Node B

In Figure 14, as observed in Section 2.2.2, the benefit of off-loading is most pronounced at high loads since the gain from SF-DC increases with load.

2.4. Performance with 3D antennas

To show the robustness of MultiPoint HSDPA gain with real antenna patterns, a 3D antenna (Kathrein Antenna Pattern with 7 degree downtilt) is also studied. Earlier, a 2D antenna pattern was used, as defined in the table in Section 2.1. With this 3D antenna pattern, due to the antenna downtilt, the percentage of soft handover UEs decreases to 28% while the percentage of softer handover UEs remains at 10%. Under uniform loading, the average user burst rate of softer and soft handover UEs is shown in Figure 15 and Figure 16. Both Intra and Inter-NodeB Aggregation are allowed.

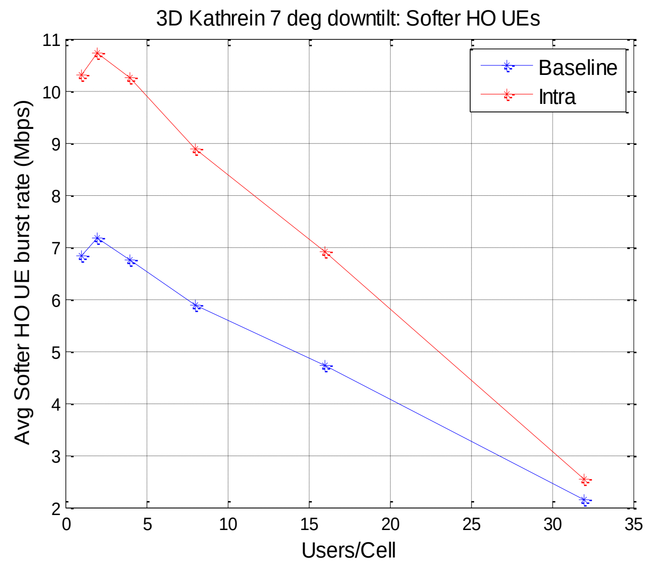


Figure 15: Average burst rate of softer handover UEs versus number of UEs/cell

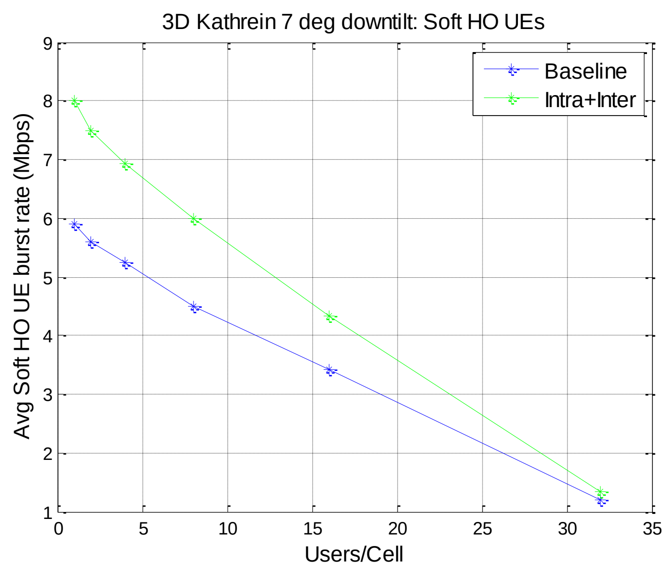


Figure 16: Average burst rate of soft handover UEs versus number of UEs/cell

Figure 17 and Figure 18 show how significant user experience gains can be obtained for softer and soft handover UEs over the baseline.

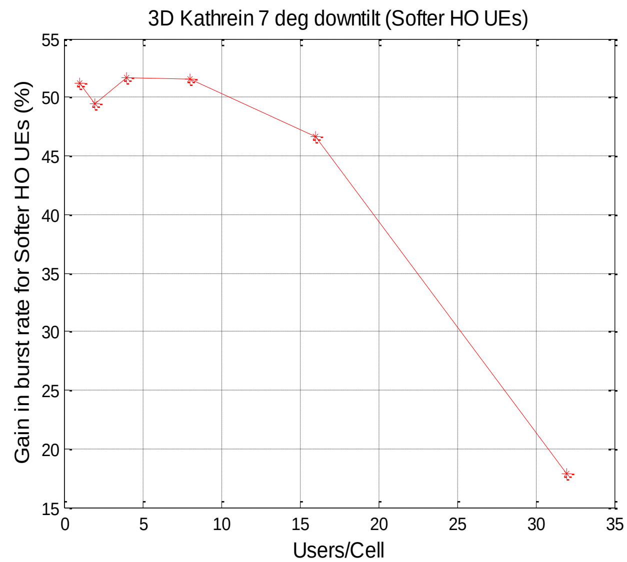


Figure 17: Burst rate gain for softer handover UEs versus number of UEs/cell

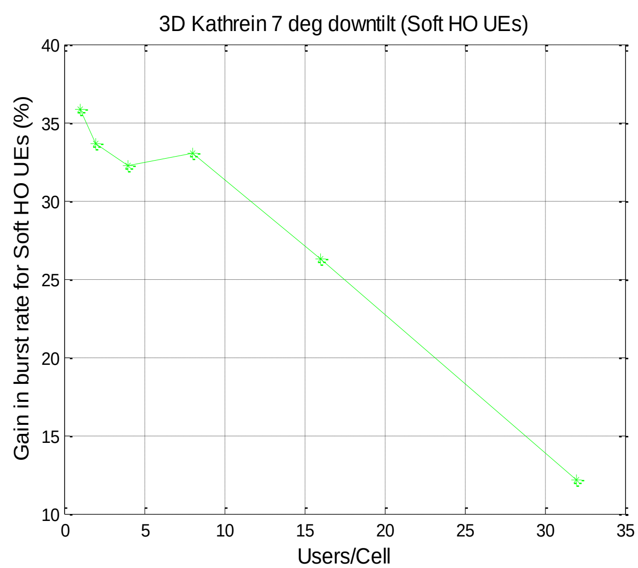


Figure 18: Burst rate gain for soft handover UEs versus number of UEs/cell

If Figure 17 and Figure 18 here are compared with Figure 4 and Figure 5 in Section 2.2.1, the gain from SF-DC Aggregation with the 3D antenna is similar to the gain obtained with the 2D antenna. The downtilt only slightly dampens the gain from SF-DC Aggregation. This is because the downtilt also reduces the overall size of the active set, which in turns boosts the interference cancellation performance of the type 3i receiver. Consequently, since there are still many more UEs in soft handover than in softer handover with the 3D antenna, the system benefit from SF-DC Aggregation is much more significant if Inter-NodeB Aggregation is allowed in addition to Intra-NodeB Aggregation.

3. Impacts to Upper Layers

In this section, we study the issues in implementing HSDPA on the MAC and RLC layers and in Iub flow control.

3.1. MAC layer changes

The MultiPoint HSDPA feature is only applied to HS channels. Therefore, only MAC-hs and MAC-ehs are affected.

If MultiPoint HSDPA is applied to two cells at the same Node B, a single MAC-hs/ehs entity with a shared TSN is used by the single Node B.

If MultiPoint HSDPA is applied to two cells at two different Node Bs, each cell must have a separate MAC-hs/ehs entity. Consequently, there will be two MAC-hs/ehs entities at the UE, one for the primary serving cell and the other for the secondary serving cell. The MAC reordering at the UE is done per serving cell. Therefore, out-of-order delivery of RLC PDUs might happen at the UE RLC receiver.

3.2. RLC enhancements

If MultiPoint HSDPA is applied to two cells at the same Node B, no RLC changes are necessary.

If MultiPoint is applied to two cells at two different Node Bs, minor enhancements to the RLC-AM protocol and implementation are needed to handle out-of-order delivery, or skew, more efficiently.

The following example shows the issues caused by out-of-order delivery, or skew. In Figure 19, the RLC PDUs are formed and queued at the RLC at the RNC.

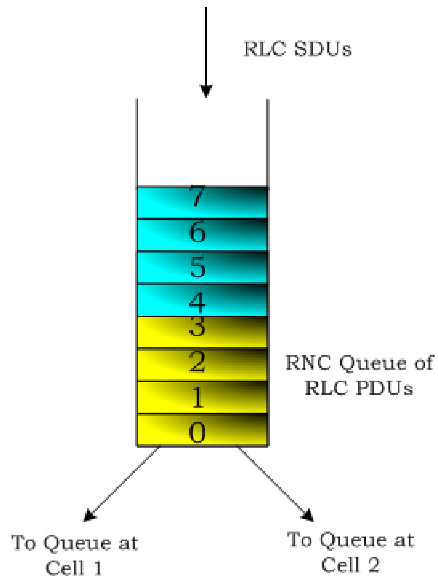


Figure 19:RLC packets queued at RNC

The RLC PDUs are forwarded to either cell in response to flow control. These packets are sent over the air and arrive at the UE in an interleaved fashion, as shown in Figure 20. Even without any packet loss over the air, sequence number gaps will be seen at the RLC receiver at the UE. For instance, at t_0, a gap of sequence number 1 to 3 is seen by RLC receiver. This gap is gradually reduced and filled at time t_3. However, if a Status PDU is generated between t_0 and t_3, it will report a gap to the RLC at the RNC. Without any changes to RLC, such a reported gap will trigger unnecessary RLC retransmissions.

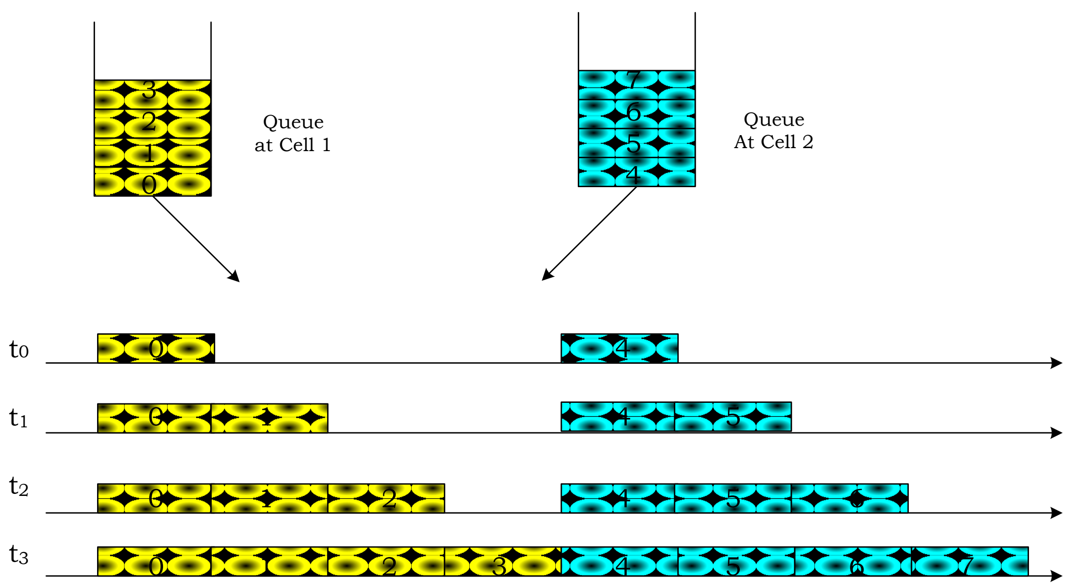


Figure 20: RLC packets arriving at UE at different time instants without packet loss over the air

Therefore, enhancements are necessary on the RLC layer. As shown below, the changes for such enhancements are incremental and straightforward.

On the UE side, existing Super Fields (SUFIs) for the Status PDU can be re-used. The same periodic or event driven feedback mechanisms remain.

For each reported sequence number gap, if the packets have never been retransmitted, the RLC at the RNC has to distinguish whether the gap is due to genuine loss on the physical layer, or out-of-order delivery between the two cells. Since in-order transmission is still maintained for packets which are transmitted for the first time in each cell, a sequence number gap is identified as genuine loss if a packet with a higher sequence number in the same cell is ACKed.

Therefore, the RLC at the RNC must associate each sequence number to the cell it is sent to. It also has to remember which packets have been retransmitted. There is no need to associate a retransmission packet to any cell because the retransmissions are given higher priority by the MAC-ehs scheduler and the in-order delivery is not maintained between packets first transmitted and packets retransmitted.

In case a sequence number gap is considered by the RLC at the RNC as caused by skew, the retransmission should be delayed to allow the gap to be filled by subsequent transmissions. For each sequence number gap first identified as caused by skew, a timer called RetransmissionDelayTimer is started. In the subsequent Status PDU, part of the gap may be ACKed. When the timer expires, if there are still missing data, they will be retransmitted.

For the same example as above, Figure 21 shows the sequence of packet arrival at the RLC receiver when packet 5 is lost over the air.

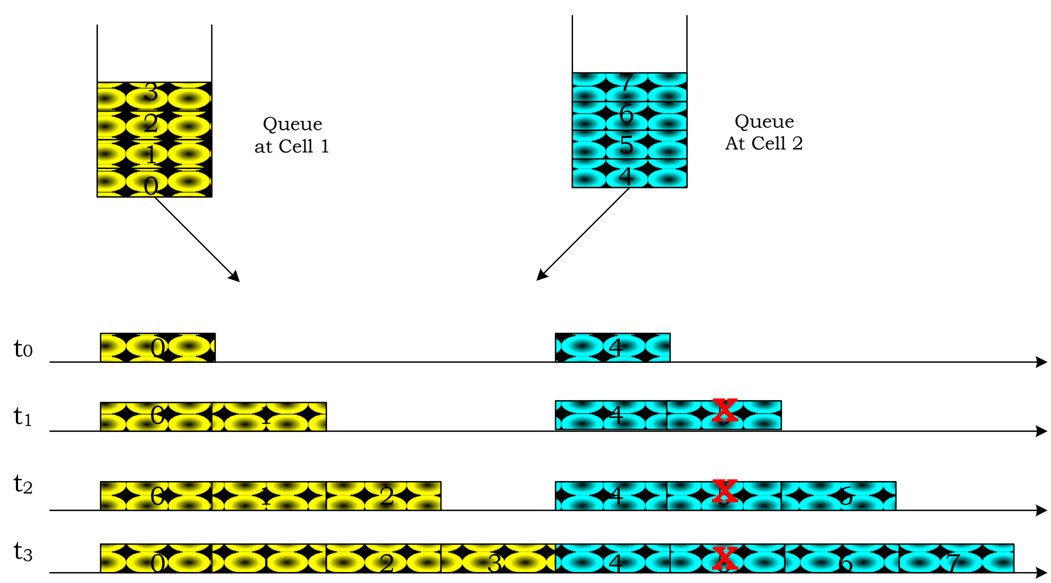


Figure 21: RLC packets arriving at UE at different time instants with packet loss over the air

At t_0, if a Status PDU is generated, it will report a gap of Packet 1 to 3, and ACK Packet 4 and all packets up to 0. The RLC at the RNC will not retransmit the gap since no packet with higher sequence number is ACKed in Cell 1.

At t_1, if a Status PDU is generated, it will report a gap of Packet 2 to 3 and ACK Packet 4 and all packets up to 1. The RLC at the RNC will not retransmit the gap. The loss of packet 5 is not reported yet since no subsequent packet has arrived.

At t_2, if a Status PDU is generated, it will report gaps of Packet 3 and Packet 5, ACK Packet 4, Packet 6 and all packets up to 2. The RLC at the RNC will not retransmit Packet 3 but will retransmit Packet 5 since Packet 6 is successfully received in the same cell as Packet 5.

As seen in this example, the proposed enhancements ensure no unnecessary retransmissions due to the skew.

In summary, the following enhancements are needed for RLC AM mode for MultiPoint HSDPA with two cells belonging to two different Node Bs:

- The RLC at the RNC must keep a record of which cell a RLC PDU is sent for the first time. It also has to keep a record of which RLC PDU has been retransmitted.
- For each reported sequence number gap, if the packets have never been retransmitted, the RLC at the RNC has to distinguish whether the gap is due to genuine loss on the physical layer, or out-of-order delivery (skew) between the two cells. The sequence number gap is identified as genuine loss if a packet with a higher sequence number in the same cell is ACKed.
- For each sequence number gap first identified as caused by skew, a timer called RetransmissionDelayTimer is started. When this timer expires, the remaining missing data will be retransmitted.
- The value of RetransmissionDelayTimer must be chosen carefully. If the value is too small, unnecessary RLC retransmissions will happen frequently; if the value is too large, TCP Retransmission Timeout (RTO) may happen, causing physical layer resource under-utilized due to TCP congestion control [10].

3.3. Iub flow control

The RLC enhancements discussed above can eliminate unnecessary RLC retransmissions if the sequence number gap caused by skew can be filled before the expiry of the RetransmissionDelayTimer. However, a large skew can still result in unnecessary RLC retransmissions.

The amount of skew can be controlled by the flow control on the Iub between the Node B and the RNC. To limit the skew, a short queue at each Node B is desired. However, frequent buffer under-run has to be avoided to fully utilize the physical layer resource. Therefore, the amount of data each Node B requests from the RNC in each flow control request has to match the UE throughput. The Iub flow control implementation needs to be adaptive to the actual throughput in each cell.

On the other hand, we find no need to change the information structure of the NBAP messages for flow control.

Our simulations have shown that the combination of the RLC enhancements discussed in Section 3.2 and Iub flow control adaptive to UE throughput can not only eliminate unnecessary RLC retransmissions cause by skew but also avoid TCP RTO events for Inter-NodeB schemes.

4. Conclusions

MultiPoint HSDPA has recently attracted considerable interest from the cellular industry. Currently, it is being evaluated as a Study Item for WCDMA Release 11 standardization by 3GPP.

In this paper, we presented the performance results of one MultiPoint HSDPA scheme, namely the SF-DC Aggregation. As seen in this paper, SF-DC Aggregation provides promising gains in both user experience and system load balancing. Although Inter-NodeB SF-DC Aggregation requires certain enhancements to the RLC layer and Iub flow control, it provides a much larger gain than Intra-NodeB SF-DC Aggregation alone, since many more users can benefit. Moreover, due to dynamic load balancing, the SF-DC Aggregation gain is much more significant for UEs in the heavily loaded cells with lightly loaded neighboring cells. In our simulation, a user burst rate gain in excess of 250% is seen for UEs in the cells where the loading is three times that of some of its neighbors. Furthermore, all the gains from SF-DC Aggregation can be obtained without causing degradation to legacy UEs.

5. References

[1] RP-101439 (http://www.3gpp.com/ftp/tsg_ran/TSG_RAN/TSGR_50/Docs/RP-101439.zip), Proposed study item on HSDPA multipoint transmission, 3GPP Work Item description, 3GPP RAN Plenary #50.

[2] R1-104157, “On deploying DC-HSDPA UEs in Single Frequency Networks”, Qualcomm Incorporated, 3GPP RAN1#61-bis.

[3] R1-104738. “Further benefits of deploying DC-HSDPA UEs in Single Frequency Networks”, Qualcomm Incorporated, 3GPP RAN1#62.

[4] R1-105640. “Further System Performance Evaluation of SF-DC”, Qualcomm Incorporated, 3GPP RAN1#62bis.

[5] R1-106334, “Summary of candidate schemes for cell aggregation/switching in HSDPA”, Qualcomm Incorporated, 3GPP RAN1#63.

[6] R1-106335, “System Performance Evaluation of DF-DC”, Qualcomm Incorporated, 3GPP RAN1#63.

[7] R1-104913, “Multi-cell transmission techniques for HSDPA”, NSN, Nokia, 3GPP RAN1#62.

[8] “MultiPoint HSPA”(http://www.qualcomm.com/umts) , white paper, Qualcomm Inc., February, 2011.

[9] 3GPP Specifications, “Feasibility study on interference cancellation for UTRA FDD: User Equipment (UE), v 9.0.0.

[10] W. Richard Stevens, “TCP/IP Illustrated, vol 1: The Protocols”, Addison-Wesley Professional Series, 1994.