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Contents

Foreword

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1 Scope

The present document is intended to capture findings produced in the context of the Feasibility Study on Dual-Cell HSDPA operation [1].

The work under this study item aims at assessing the feasibility, benefits and complexity of combining network radio resources (i.e. cells) to achieve enhanced user experience and enhanced user experience consistency. The assessment focuses on scenarios with the following constraints:

- The dual cell operation only applies to downlink HS-DSCH.
- The two cells belong to the same Node-B and are on different carriers.
- The two cells do not use MIMO to serve UEs configured for dual cell operation.
- Primary priority: The two cells operate on adjacent carrier frequencies in the same frequency band. Other allocations can be considered with lower priority

In order to characterize benefits of Dual-Cell HSDPA operation, possible enhancements of performance throughout the cell and in particular in the outer area of the cell coverage are evaluated considering:

- UE receiver impairments caused by the implementation of dual-cell operation,
- Node B scheduler architecture (per carrier or joint scheduler),
- Load balancing when coupled with joint scheduling vs. per carrier scheduling.

Furthermore, impacts on implementation and complexity within the UTRA and UE, impacts systems operation (e.g. UL controlchannel coverage and operation of legacy UE), and impacts on the core specifications due to introducing Dual-Cell HSDPA operation are identified.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TD RP-080228: "Feasibility Study on Dual-Cell HSDPA operation".

[2] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[3] R1-081706 "Simulation Assumptions for DC HSDPA Performance Evaluations"

[4] R1-081546, "Initial multi-carrier HSPA performance evaluation", Ericsson, 3GPP TSG-RAN WG1 #52bis, April, 2008.

[5] R1-081361, "System Benefits of Dual Carrier HSDPA", Qualcomm Europe, 3GPP TSG-RAN WG1 #52bis, April, 2008.

[6] R1-081706, "Simulation Assumptions for DC HSDPA Performance Evaluations", Qualcomm Europe, Ericsson, Nokia, NSN, 3GPP TSG-RAN WG1 #53bis, May 2008.

[7] R1-082094, “Text proposal for TR on simulation results” (initial submission), Qualcomm Europe, 3GPP TSG-RAN WG1 #53bis, May 2008.

[8] R1-082135, “System simulation results for DC-HSDPA operation”, Ericsson, 3GPP TSG-RAN WG1 #53bis, May 2008.

[9] R1-081903, “Initial simulation results for dual cell HSDPA operation”, Nokia, 3GPP TSG-RAN WG1 #53bis, May 2008.

[10] “Data Networks”, Dimitri P. Bersekas and Gallager, 2nd edition, Prentice Hall, 1992.

[11] 3GPP TR 25.876 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Multiple Input Multiple Output in UTRA; (Release 7) V7.0.0 (2007-03)

[12] 3GPP TS25.101 “User Equipment (UE) radio transmission and reception (FDD)”.

3 Definitions, symbols and abbreviations

Delete from the above heading those words which are not applicable.

Subclause numbering depends on applicability and should be renumbered accordingly.

3.1 Definitions

For the purposes of the present document, the terms and definitions given in [2] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in [2].

Definition format

***<defined term>**: <definition>.*

example: text used to clarify abstract rules by applying them literally.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

Symbol format

<symbol>	<Explanation>

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in [2] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in [2].

Abbreviation format

DC-HSDPA	Dual-Cell HSDPA

4 Considerations related to Dual-Cell HS-DSCH operation

4.1 Co-existence with legacy UEs

Legacy UE operation will not be impacted by the introduction of the DC-HSDPA in the system. In particular, it should still be possible to operate a UE in MIMO mode or Tx diversity mode on either of the two carriers, while another UE could be in DC-HSDPA mode using these two carriers.

4.2 Carrier allocation

A UE in DC-HSDPA operation is able to simultaneously receive HSDPA traffic over two downlink carrier frequencies transmitted in the same frequency band from a single serving sector and to transmit on one uplink carrier frequency. The uplink carrier for a DC-HSDPA UE is not strictly tied to one of the two downlink carriers.

4.2.1 Anchor carrier and supplementary carrier

Anchor carrier: A UE's anchor carrier has all the physical channels including DPCH/F-DPCH, E-HICH, E-AGCH, and E-RGCH.

Supplementary carrier: During dual carrier operation in CELL_DCH, the UE's supplementary carrier is the downlink carrier which is not the UE's anchor carrier.

4.2.2 Cell definition

[2] defines a Cell as a "*Radio network object that can be uniquely identified by a User Equipment from a (cell) identification that is broadcasted over a geographical area from one UTRAN Access Point*". In DC-HSDPA, a cell means a radio network object representing a combination of a carrier and a geographical area.

4.2.3 Sector definition

[2] defines a sector as "*a sub area of a cell. All sectors within one cell are served by the same base station. A radio link within a sector can be identified by a single logical identification belonging to that sector*".

[2] implies that a sector refers to a geographical area of coverage. The sector nomenclature was introduced early in the WCDMA development. Since, it does not coexist with the way 3GPP specifications have evolved; this TR alters the sector definition to be associated with one or more cells on different carriers covering the same geographical area.

(Note: If the redefinition of a sector is not agreeable, we need a new term to carry this definition.)

4.2.4 Time reference

As stated in [1], the two cells in a multi cell sector belong to the same Node B.

As stated in [1], the two cells in a multi cell sector are transmitted using the same antenna(s).

The two carriers can have the same time reference and their downlinks can be time aligned in the sense that they share the same T_{cell} value. This simplifies the design and the downlink/uplink timing relationships. As a result there is only one τ_{DPCH} per UE.

4.2.5 Active set

The active set definition might have to be updated for DC-HSDPA operation. Two possible options have been identified:

1. The active set is the aggregate of the legacy single carrier active set on the anchor carrier and the serving cell on the supplementary carrier.

2. The presence of a supplementary carrier can be disregarded in the active set definition, i.e. the active set size is not affected by the presence or absence of a supplementary carrier.

4.3 Physical channel considerations

There are no restrictions of channel operation on the anchor carrier. On the supplementary carrier, the UE can only monitor DL HSDPA related channels.

4.3.1 Allocation of common channels

A carrier which is an anchor carrier for one or more UEs must transmit all the common control channels. It may be useful to allow a mode of operation where a carrier which is not the anchor carrier for any UE does not need to transmit common control channels except for the pilot and maybe the synchronization channels.

4.3.2 Control channel structures

4.3.2.1 Uplink

4.3.2.1.1 HS-DPCCH

A few design options exist to modify HS-DPCCH for the purpose of carrying ACK/NACK and CQI for both carriers. Other options might be considered as well.

A second HS-DPCCH channel similar to the existing one can be transmitted in parallel to the usual HS-DPCCH. It is assumed that a maximum of 1 DPDCH is supported on the uplink.

In the case when no DPDCH is configured in uplink, the two HS-DPCCHs can be I/Q multiplexed on the same channelization code that is used today for HS-DPCCH.

In the case when one DPDCH is configured in uplink, the two HS-DPCCHs can also be I/Q multiplexed on a single channelization code if a channelization code is chosen where both branches are available, i.e. a different channelization code than the one that is used today for HS-DPCCH. As an alternative, the two HS-DPCCHs can be allocated to two different channelization codes, either on the same branch or on different branches.

These design options can be summarized as follows:

- Option A:
    - N_max_dpdch = 0, where N_max_dpdch is the maximum number of configured uplink DPDCHs
    - The UE sends the 1st HS-DPCCH and 2nd HS-DPCCH on the same channelization code.
    - The channelization code is the same code as that is currently used for the legacy HS-DPCCH.
    - The 1st HS-DPCCH is sent on the Q branch and the 2nd HS-DPCCH is sent on the I branch.
- Option B:
    - N_max_dpdch = 1
    - The channelization code for the 1st HS-DPCCH is the same code as that is currently used for the legacy HS-DPCCH.
    - The channelization code for the 2nd HS-DPCCH is a different code from that is currently used for the legacy HS-DPCCH.
    - The 1st HS-DPCCH is sent on the Q branch and the 2nd HS-DPCCH is sent on the I or Q branch.

  - When the UE is configured back to SC-HSDPA mode, it switches to the channelization code/branch that is currently used for the legacy HS-DPCCH.

- Option C:
  - N_max_dpdch = 1
  - The UE sends the 1st HS-DPCCH and 2nd HS-DPCCH on the same channelization code.
  - The channelization code is not the same code as that is currently used for the legacy HS-DPCCH.
  - The 1st HS-DPCCH is sent on the Q branch and the 2nd HS-DPCCH is sent on the I branch.
  - When the UE is configured back to SC-HSDPA mode, it switches to the channelization code/branch that is currently used for the legacy HS-DPCCH.

- Option D:
  - N_max_dpdch = 1
  - The UE sends the 1st HS-DPCCH and 2nd HS-DPCCH on the same channelization code.
  - The channelization code is not the same code as that is currently used for the legacy HS-DPCCH.
  - The 1st HS-DPCCH is sent on the Q branch and the 2nd HS-DPCCH is sent on the I branch.
  - When the UE is configured back to SC-HSDPA mode, it continues to use the new channelization code/branch that was assigned to 1st HS-DPCCH.

4.3.2.2 Downlink

4.3.2.2.1 HS-SCCH

Both the anchor and supplementary carriers can have disjoint HS-SCCH channels. In this case the coding of HS-SCCH does not need to be changed. In order to not restrict the scheduler, the UE should preferably monitor up to 4 HS-SCCH codes on each carrier, as in the single carrier case, assuming HS-SCCH is transmitted in both carriers.

4.4 Impact on system operation and procedures

4.4.1 L1/L2/L3 procedures

4.4.1.1 Dynamic supplementary carrier enabling/disabling at the Node B

From e.g. the UE battery point of view, it might be beneficial for the Node B to be able to enable and disable the supplementary carrier based on the downlink traffic and channel conditions.

4.4.1.2 Mobility issues

4.4.1.2.1 Active set change, Serving cell change and Measurement reporting

Although the decision will still reside in the network, there are many possible ways the UE can assist the management of the active set and the serving cell:

- Option 1:
  - The UE monitors and reports events based on the anchor carrier only.
  - This is the simplest scheme as it takes the existing mechanism and ignores the supplementary carrier.

- Option 2:

  - The UE monitors both carriers and reports when the events are triggered on the anchor carrier.
  - This is an enhancement to the current scheme where the UE reports the measurement from both carriers when the triggers are triggered on the anchor carrier. Even though this is an enhancement, it still does not catch all the possible trigger points as the triggers are not based on the supplementary carrier.
- Option 3:
  - The UE monitors both carriers and reports when the events are triggered on either carrier.
  - This mechanism allows the network to receive all the information. The problem is that it can go too far as it could be triggering double the numbers of events needlessly. The reported measurements could be for the anchor carrier only or for both carriers, whenever any of the events is triggered.
- Option 4:
  - The UE monitors both carriers and reports throttled events from both carriers.
  - This proposal tries to get most of the gains without burdening the network with superfluous reports. The simplest way of achieving this is to throttle the events from both carriers, in order to avoid sending duplicate messages for similar triggers happening within a short time frame from each other. The event can still be triggered by one carrier changing conditions, however when the other carrier changes as well, it would probably change in a short amount of time that would be caught by the throttling mechanism.
- Option 5:
  - The UE monitors both carriers and reports events based on the combination of both carriers.
  - This option can be effective, efficient and flexible. It maximizes the inherent value of reports (triggers) rather than only measurements (contents) so that UE can report from a performance standpoint and UTRAN can decide on handover-off or serving cell change from a resource standpoint (i.e., do not dilute the inherent value of reports by over-reporting). It can consider the aggregate merit of cells across carriers for HS-DSCH serving cell changes rather than the individual carrier merit (e.g. total effective throughput achievable for expected CQIs per carrier). It also can minimize reporting (signalling) overhead but do not under-report. Finally, it removes relieves the network from guessing when to perform mobility procedures.

4.4.1.3 Fast power control

Uplink power control can operate in such a way that the UE uplink transmit power is controlled by the network through an F-DPCH transmitted on the anchor carrier. Similarly, downlink power control can operate such that the power of the F-DPCH on the anchor carrier is controlled by the UE sending TPC commands on the UL DPCCH.

4.4.1.4 CPC

HS-SCCH-less operation can be restricted to the anchor carrier, while UE DTX/DRX can be carried out taking both carriers into account (details are FFS).

4.4.2 UE capabilities

Support for DC-HSDPA operation would be a UE capability.

4.5 Scheduling considerations

The serving cells on both carriers belong to the same sector.

4.5.1 Joint vs. Disjoint Queues

The downlink queues at the Node B could be operated in a joint or disjoint manner for the two carriers.

The simulations assumption of [3] is that the queues are joint.

4.5.2 Joint vs. Disjoint Scheduling

Whether the scheduling over the two DL carriers is joint or disjoint, does not impact the specifications.

The simulations assumption of [3] is that the scheduling is joint and using a proportional fair algorithm .

4.5.3 Joint vs. Disjoint HARQ retransmissions

The simulations assumption of [3] is that HARQ retransmissions are assumed to go on the same carrier as the first transmission.

5 Performance evaluation

5.1 Outline of performance evaluation methodology

5.1.1 Simulation procedure

5.1.2 Performance evaluation scenarios

5.1.3 Simulation assumptions

In general, the parameters listed below are the same as those in TR 25.848 and TR 25.896.

Some parameters or algorithms will be left open for each company to pick its favourite. These are marked with an asterisk (*).

Parameters	Values and 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 Correlation Distance: 50m
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, VA3 Fading across carriers is independent for non adjacent carriers. (*) Two fading models for adjacent carriers: - Fading across carriers is completely uncorrelated. - Fading correlation across carriers is modeled using some practical approach (optional) - Fading across carriers is completely correlated
Penetration loss	10 dB
CPICH Ec/Ior	-10 dB
HS-DSCH	Up to 15 SF 16 codes per carrier for HS-PDSCH (*) Power allocation: - Total available power for HS-PDSCH and HS-SCCH is 70% of Node B Tx power, with HS-SCCH transmit power being driven by 1% HS-SCCH BLER, or - Total available power for HS-PDSCH is 75% of Node B Tx power, with a fixed HS-SCCH transmit power and an ideal decoding, or (*) HS-PDSCH HARQ: Both chase combining and IR based can be used. Maximum of 4 transmissions with 10% target BLER after the first transmission. Retransmissions are of highest priority.
HS-DPCCH	9 slot CQI delay CQI bias is 0 and CQI estimation noise is Gaussian with 1 dB std (*) CQI quantization may or may not be modeled Error-free CQI and ACK decoding
UE Antenna Gain	0 dBi
UE noise figure	9 dB
Thermal noise density	-174 dBm/Hz
UE capabilities	15 SF 16 codes capable per carrier
UE Receiver Type	Type 2 and Type 3 for both single carrier and DC-HSDPA (*) Realistic C/I estimation
Maximum Sector Transmit Power	43 dBm per carrier
Other Sector Transmit Power	(*) If OCNS=1, all other sectors always transmit at full power; (*) If OCNS=0, other sectors transmit at full power only when they have data.

Timing	The two carriers have the same time reference and their downlinks are synchronized.
Serving cell	The serving cells on both carriers belong to the same sector.
Traffic model	Full buffer and Bursty Traffic Model (as specified in Section 5.1.2)
Queuing and Scheduling	Joint-queue (**) and Proportional Fair (e.g. as specified in Annex A)
Traffic distribution	Uniform over the area
Number of UEs per sector	1, 2, 4, 8, 16, 32, 64 In addition, other number of UEs per sector can also be considered.

(*) Parameters or algorithms possibly different between companies.

(**) The data on both carriers in DC HSDPA share the same queue at the Node B.

5.1.2 Traffic Models

There are two types of traffic: full buffer and bursty traffic.

Full buffer traffic assumes that each user always has data.

The following simple model is used for bursty traffic: the burst size is log-normally distributed as in FTP traffic model described in TR 25.876 but with the parameters described in the following table. There is no underlying transport protocol modeled. The inter-burst time is the time between the arrival of two consecutive bursts.

Component	**Distribution**	**Parameters**	**PDF**
File size (S)	Truncated Lognormal	Mean = 0.5 Mbytes Std. Dev. = 0.1805 Mbytes Maximum = 1.25 Mbytes	$f_x = \frac{1}{\sqrt{2\pi}\sigma x}\exp\left[\frac{-(\ln x-\mu)^2}{2\sigma^2}\right], x \geq 0$ $\sigma = 0.35, \mu = 13.061$
Inter-burst time	Exponential	Mean = 5 sec, 20 sec	$f_x = \lambda e^{-\lambda x}, x \geq 0$ $\lambda = 0.2$

5.1.3 Simulation scenarios and performance metrics

5.1.3.1 Bursty traffic

Assuming there are two carriers and altogether 2*N users per sector. In the single carrier system, there are N users in each carrier. In DC HSDPA, all 2*N users use dual carriers.

The following performance metrics should be compared between the single-carrier system and DC HSDPA:

- Average burst rates at different number of users (N)
  - The burst rate is defined as the ratio between the data burst size in bits and the total time the burst spent in the system

  - The total time the burst spent in the system is the time difference measured between the instant the data burst arrives at the Node B and the instant when the transfer of the burst over the air interface is completed.
  - The total time the burst spent in the system is equal to the sum of the transmission time over the air and the queuing delay.

- Total system throughput
- Normalized and un-normalized user throughput distribution (CDF)

5.1.3.2 Full buffer traffic and balanced load between two carriers

Assuming there are two carriers and altogether 2*N users per sector. In the single carrier system, there are N users in each carrier. In DC HSDPA, all 2*N users use dual carriers.

The following performance metrics should be compared between the single-carrier system and DC HSDPA:

- Sector throughput at different number of users (N)
- Normalized and un-normalized user data rate distribution (CDF)
- User data rate gain at different user data rate percentiles: This would be the user throughput improvements as a function of the user-quantile (relative improvement of average per-user throughput over user-quantile, e.g. by how much did the throughput of the worst 10% of users improve). This is metric can demonstrate any cell edge user performance enhancement
- Average user throughput as a function of average sector throughput.

5.1.3.3 Full buffer traffic and imbalanced load between two carriers

This is an optional scenario.

Without multicarrier operation, moving users across carriers is a slow procedure. Even if the network equalizes the number of users across carriers, in real life, there is no sustained full buffer traffic. The traffic for a particular user is bursty and the number of users simultaneously receiving packets in each carrier at any given time can be different. The gains in these situations can be shown by studying full buffer traffic with imbalanced number of users across carriers.

Assuming there are two carriers and altogether 2*N users per sector, let M be the number of users in the first carrier and K the number of users in the second carrier, where M+K=2*N and M≠K. In DC HSDPA, all 2*N users use dual carriers.

The following performance metrics should be compared between the single-carrier system and DC HSDPA:

- Sector throughput at different total number of users (2*N) and at different user-carrier association (M,K) with the same total number of users,
- Normalized and un-normalized user data rate distribution (CDF)
- User data rate gain at different user data rate percentiles
- Average user throughput as a function of average sector throughput

5.1.4 Evaluation metrics

5.2 Performance evaluation results

The following example explains this terminology. Consider the case when we have "8 users per sector". By this, we mean that there are 8 users in 10 MHz. When we consider balanced load between carriers, we will compare performance when 4 of the users are on each cell (5 MHz) with the performance when all 8 users are capable of receiving data on both cells (10 MHz). We refer to the former as "2x-single cell" (2x-SC HSDPA) case and the latter as the "dual cell" (DC-HSDPA) case. Note that in the 2x-SC HSDPA case, the load is balanced across carriers.

5.2.1 Simulation results and analysis provided by Source 1 [7]

5.2.1.1 Choice of parameter values

In this subsection, the choice of optional parameter values in Section 5.1.3 is listed in the table below.

Parameters	**Comments**
Channel Model	PA3
UE Receiver Type	Type 3 (LMMSE with RxD)
HS-DSCH Power	Maximum Power = 70% of Node B transmit power HS-SCCH power decided by a 1% HS-SCCH BLER HS-DSCH power margin driven by an outer loop (10% BLER after 1st Tx, Max 4 HARQ Transmissions)
Other Sector Transmit Power	OCNS = 1 (all other sectors always transmit at full power)
Fading Across Carriers	Uncorrelated
Channel Estimation	Realistic

5.2.1.2 Gains with full buffer traffic under balanced load

Figure 1 shows the improvement of average user throughput due to dual cell HSDPA as a function of sector throughput. For both 2xSC and DC-HSDPA, we compare the average user throughputs at the same number of users per sector. As we can see, the dual cell gain is more pronounced at low loads. This is because multi-user diversity gain is larger in DC-HSDPA as there are more users to choose from at each scheduling instance. As the load increases, the gains from multi-user diversity and joint scheduling decrease. At 2 users per sector, the gain is around 25%. At 32 users per sector, it is around 7%.

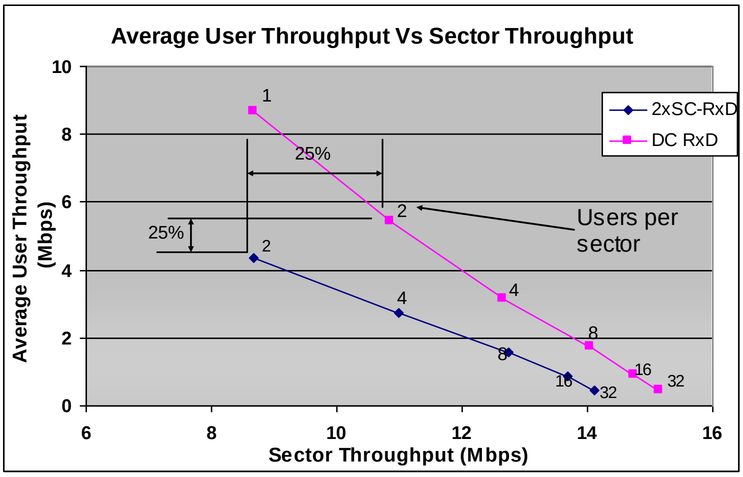


Figure 1 Average user throughput as a function of sector throughput.

Figure 2 shows the CDF of user throughputs for 16 users per sector. We see that the percentage gain for low geometry users is higher than that for high geometry users. Figure 3 shows the CDF of normalized user throughput (fairness curves). We can see that DC HSDPA is fairer than 2xSC-HSDPA.

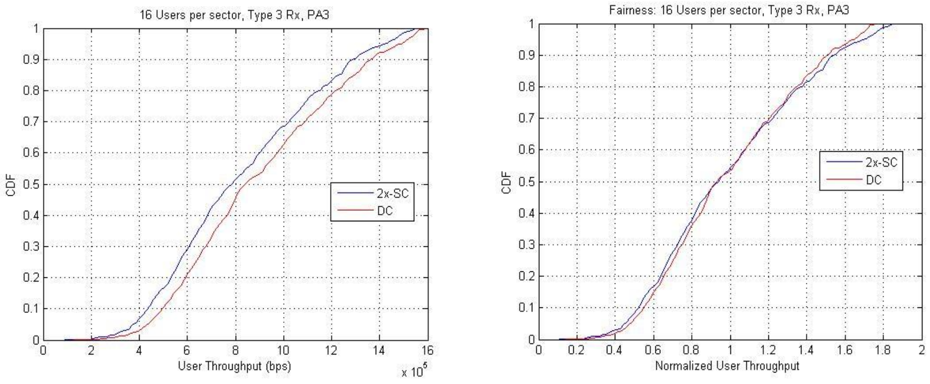


Figure 2, 3: User throughput CDF and fairness curve (16 users per sector)

This behaviour can be seen more clearly when we plot user throughput gains as a function of "user percentile". Essentially, from the CDF of user throughput, we identify the 10%, 20%, …, 90%-ile throughputs from both the 2x-SC and DC-HSDPA curves and compare them.

Figure 4 shows us the user throughput gains as a function of user percentile. At low percentiles (analogous to low geometries), the gains are higher than at high percentiles (high geometries). This is because low geometry users see a higher variation in their proportional fair metric (see Appendix of **Error! Reference source not found.**). Higher geometry users will see a lower variation of this metric, given that they are in more likely to be in the non-linear region of the Shannon curve.

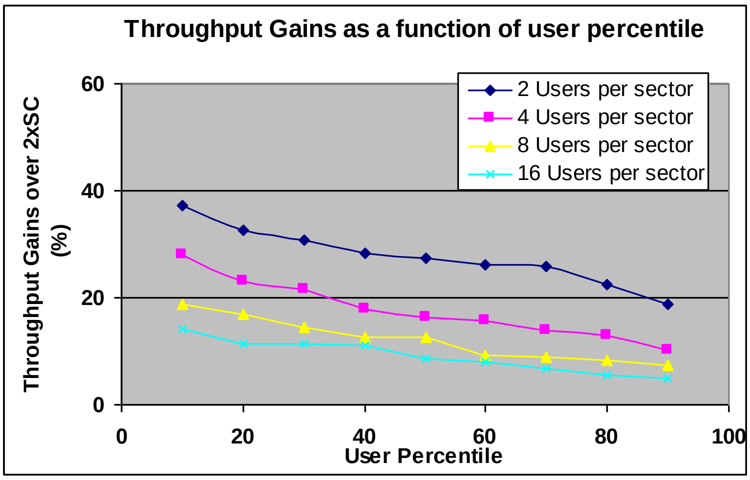


Figure 4. **User throughput gains of DC-HSDPA over 2xSC-HSDPA as a function of user percentile**

Figure 5 shows the gain in sector throughput as a function of number of users per sector. Again, as we can see, DC-HSDPA gain is more pronounced at low loads. At 2 users per sector, the gain in sector throughput is 25%. At 32 users per sector, it is 7%.

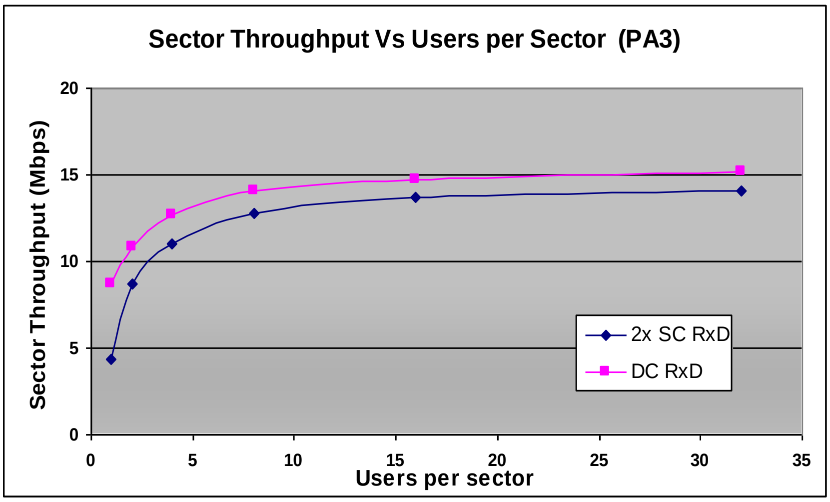


Figure 5 Capacity gain from DC HSDPA over 2xSC-HSDPA

5.2.1.3 DC HSDPA gains with bursty traffic

As seen above, compared with two single carriers each with N users, DC HSDPA with 2*N users results in a small gain in terms of sector capacity with full buffer traffic data. However, with bursty traffic, DC HSDPA provides a significant gain in terms of latency reduction. A more intuitive performance metric is the ‘burst rate’ [6] defined as the ratio between burst size and the time taken to transfer the burst over the air interface from the time it arrives at Node B. The gain can be seen from queuing analysis and system simulations.

5.2.1.4 Queuing analysis of DC HSDPA latency reduction and burst rate increase

The following analysis was presented in [5].

Let's assume a M/G/1 queuing system. The service rate can be random with any distribution. The arrival process is assumed to be memoryless[6], namely, the inter-arrival times are exponentially distributed. This model captures many features in the bursty traffic services in the HSDPA systems.

For one single carrier, let's denote the arrival rate is λ and departure rate is μ. When we have two carriers and twice the number of users, namely, i.e., the same number of users per cell (per sector per carrier), we have another M/G/1 system with arrival rate 2λ and service rate 2μ. It is obvious that the actual service time of each burst is reduced by half in the alternative system. Therefore, to quantify the gain in the burst rate, we need to find the waiting time, which in turn depends on the queue length. If we compress the time resolution to half in the new M/G/1 system with 2λ and 2μ, the queue length dynamic is exactly the same as in the original M/G/1 system with λ and μ. Therefore, the average queue length remains the same but the average waiting time is cut in half.

The same conclusion can be seen from the Kleinrock-Khinchin formula for M/G/1 queue[10]. The total time for a data burst in the system is

$$T_{total} = T_{service} + T_{waiting} = \frac{1}{\mu} + \frac{\lambda m_2}{2(1-\frac{\lambda}{\mu})},$$

where m_2 is the second moment of the service time. As we can see, when both λ and μ doubled, m_2 is reduced to a quarter of its value and the total time in system is reduced by half.

5.2.1.5 Simulation results with bursty traffic

In [5], we had provided analysis and simulation results for burst rates for 2x-SC and DC HSDPA assuming a fixed burst size. In this document, we provide burst rate curves for the traffic model where the burst size follows a truncated log-normal distribution. Figure 6 shows the distribution of burst sizes.

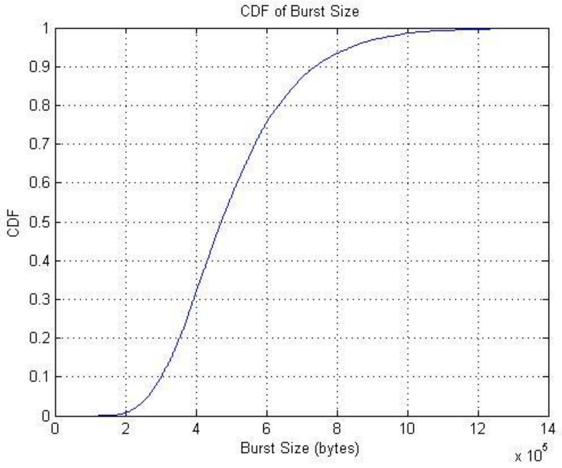


Figure 6 Burst Size CDF

Figure 7 shows the CDF of burst rates for the 8 users per sector. Note that there are 8 users in 10 MHz for both 2xSC and DC-HSDPA. We see that there is a ~2x improvement in the burst rates with dual cell HSDPA compared to 2xSC-HSDPA.

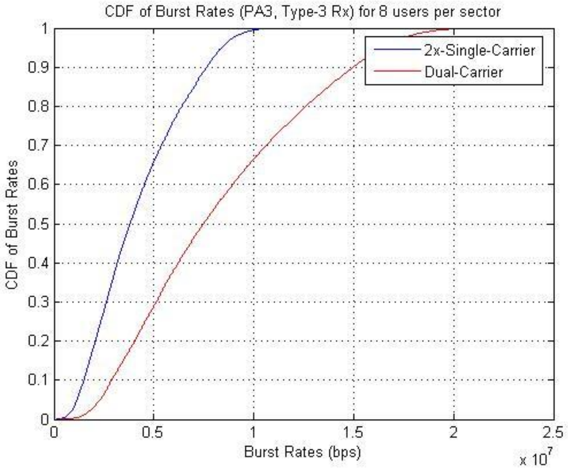


Figure 7 Burst Rate CDF for 8 users per sector. The blue curve refers to the case when 4 of the users are on each cell (2xSC-HSDPA) while the red curve refers to the case when all 8 users are dual cell capable (DC HSDPA).

Figure 8 shows the number of users that can be supported as a function of the average burst rate per user. As the load increases, we see that the gains from DC HSDPA start to fall, as the queue length begins to increase and begins to resemble full-buffer. Note that the number of users per sector is proportional to the load seen by the scheduler. Please note that other cell powers are set to maximum, so partial loading effects are not seen in **Figure 8**. If partial loading is explicitly simulated, the burst rates will be much higher.

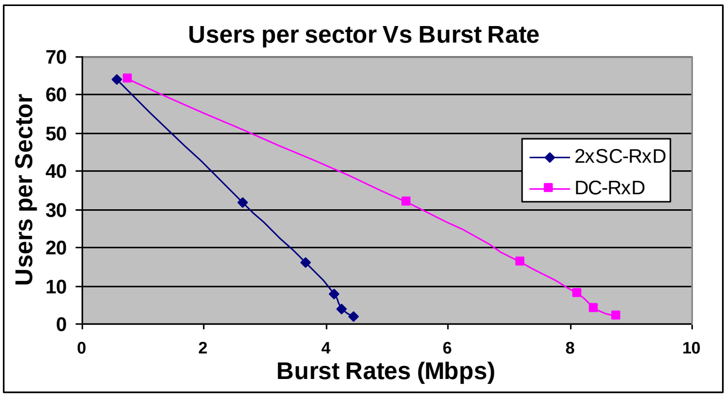


Figure 8 Burst rate performance with OCNS=1.

Figure 9 compares the sector throughput at the application layer for DC HSDPA with 2xSC-HSDPA. The application layer throughput is smaller than the physical layer throughput. Since we do not model TCP, the difference between the physical and application layer throughputs is only the header overhead. Relative Comparison between 2xSC-HSDPA and DC-HSDPA is independent of the overhead.

Read in conjunction with **Figure 8**, we see that while the burst rates have doubled, the sector throughput is the same for both. In other words, the burst is served faster in DC-HSDPA and therefore, there is more idle time in DC-HSDPA than in the 2x-SC HSDPA. As the number of users per sector increases beyond 64, the sector throughput curves will saturate.

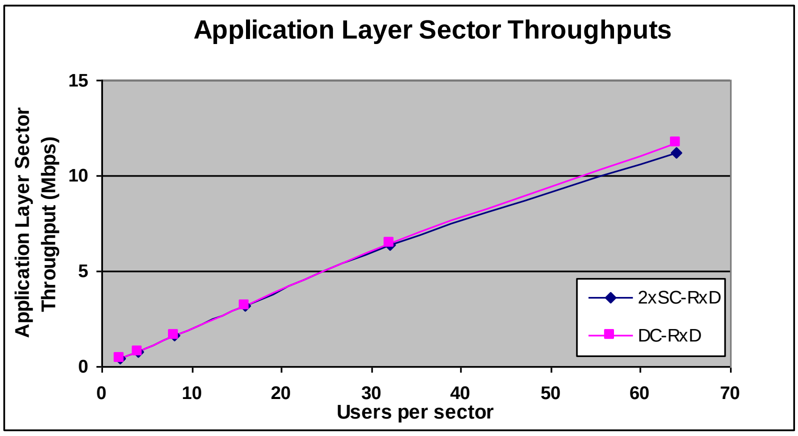


Figure 9 Sector throughput as a function of users per sector

In summary, the simulations show:

- For a given burst rate, DC HSDPA can support more than twice the number of users compared to 2x-single cell HSDPA at low loads. For instance, at a burst rate of 3.5 Mbps, the number of users supportable with DC HSDPA is more than twice the number that can be supported through 2xSC HSDPA.
- At low to medium loads, for a given number of users, DC HSDPA can provide a doubling of the burst rate compared to 2xSC-HSDPA.

5.2.2 Simulation results provided by Source 2 [8]

5.2.2.1 Choice of parameter values

In this subsection, the choice of optional parameter values in Section 5.1.3 is listed in the table below.

Parameters	**Comments**
Channel Model	PA3
UE Receiver Type	Type 2 (LMMSE without RxD), Type 3 (LMMSE with RxD)
HS-DSCH Power	Maximum Power = 70% of Node B transmit power HS-SCCH power decided by a 1% HS-SCCH BLER HS-DSCH power margin driven by an outer loop (10% BLER after 1st Tx, Max 4 HARQ Transmissions)
Other Sector Transmit Power	OCNS = 0 (multicell simulation with active users in each cell where the interference level is a consequence of the current situation in the other sectors)
Fading Across Carriers	Correlated
Channel Estimation	CQI estimation error of 1 dB

5.2.2.2 Simulation results for "Bursty traffic"

If a user is downloading traffic burst 1 and burst 2 arrives before burst 1 is finished there are several ways of dealing with this situation. In this investigation we start the download of burst 2 as soon as it arrives. Burst 1 and 2 will share the available resource until burst 1 (or 2) is finished.

As a consequence of the traffic model there is a straightforward mapping between the number of users in a sector and the offered load in bits/s/sector. Each user contributes with 200kbit/s to the offered load. We use the offered load on the axes instead of number of users since it makes the result a bit more general. Note that in some cases results will depend on the simulation time, e.g. for an unstable system. In these results a 57 sector system was simulated for 5 minutes.

The recommended load of 64 users per cell can not be handled by the system in any of the investigated scenarios. Where a really high load was interesting a load of 50 users (10 Mbit/s/sector) was used instead.

The results are shown in **Figure 10** through **Figure 13**.

Figure 10 shows that for all load levels, DC-HSDPA gives roughly twice as high average user throughput as two single carriers with the corresponding receiver structure. This is a consequence of the better low load properties of DC-HSDPA compared to two single carriers. It is much more unlikely that there is a build-up of files in a sector when DC-HSDPA is used, which leads to higher performance also for the higher loads.

When we study the 10 and 90 percentiles in **Figure 11** and **Figure 12** we realize that this performance increase is valid for all users in the system.

A system can be said to be stable when the output of the system is equal to the input. If we plot the transmitted bits and the bits that arrived to the system as a function of the average number of users as in **Figure 13**, we get a clue whether a certain scenario results in stable operation. From this graph we can guess that a load of 32 users per sector (6.4 Mbit/s in offered load) is too much for systems without Rx diversity to handle.

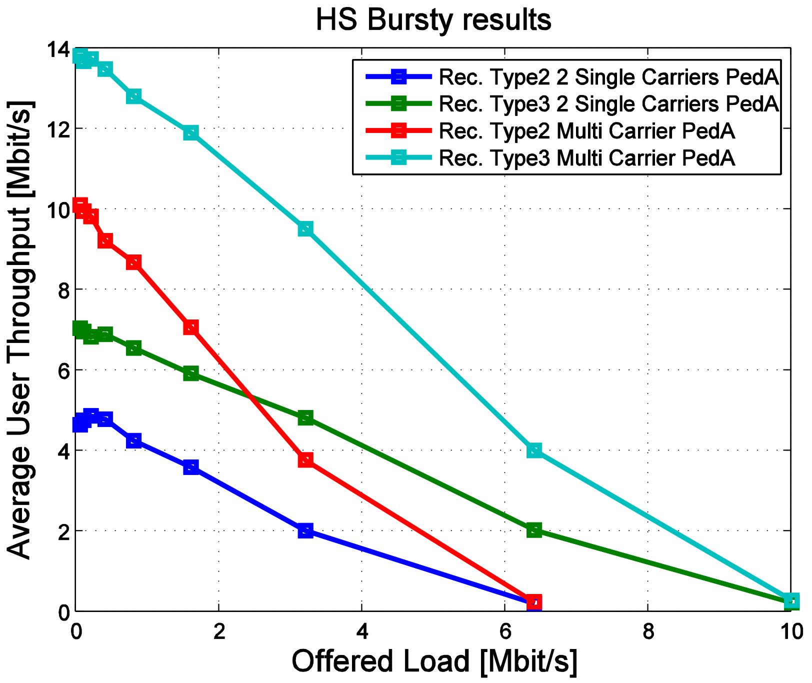


Figure 10: User throughput vs sector throughput for Bursty traffic

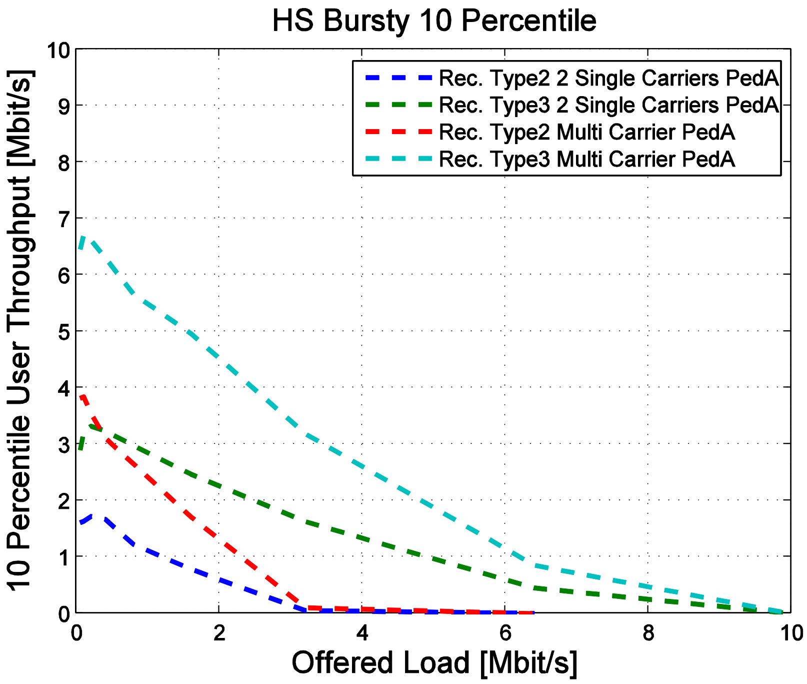


Figure 11: 10 percentile user throughput vs sector throughput for Bursty traffic

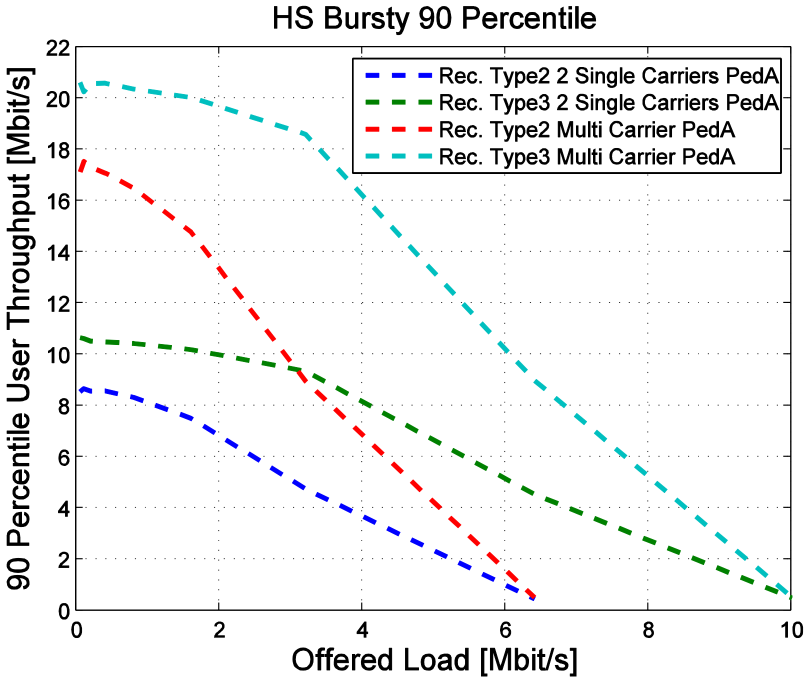


Figure 12: 90 percentile user throughput vs sector throughput for Bursty traffic

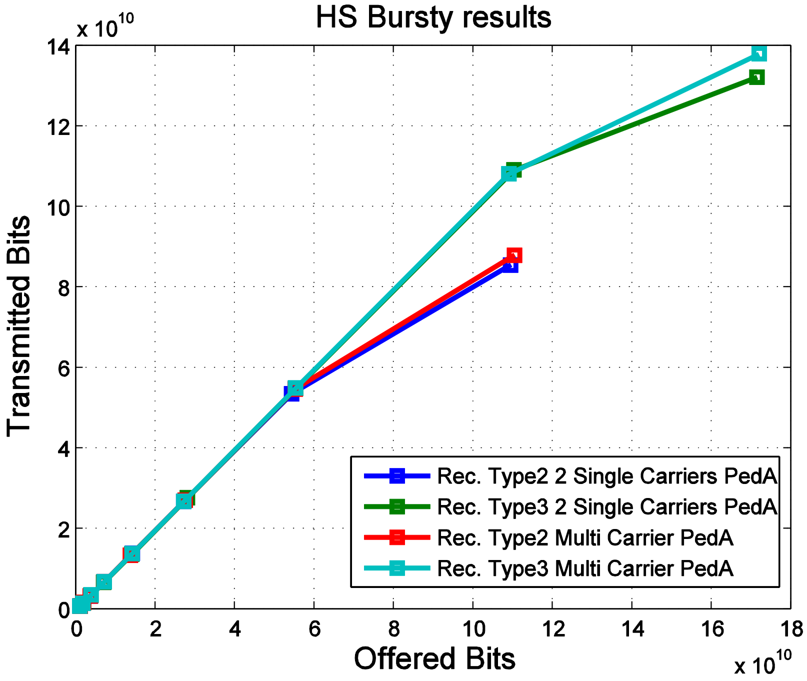


Figure 13: Transmitted bit vs offered bits for Bursty traffic

5.2.2.3 Simulation results for “Full buffer traffic and balanced load between two carriers”

If there is an even number of users in a sector, 2*n where n = 0, 1, 2, 3 …., each carrier will have exactly n users. In a situation where the number of users in the sector is odd, 2*n +1 where n = 0, 1, 2, 3 …., one randomly selected carrier will have n+1 users and the other one will have n users.

The following average numbers of users have been simulated: 0.25, 0.5, 1, 2, 4, 8, 16, 32.

The results are shown in **Figure 14** through **Figure 19**.

We see that there is large difference in both average user and sector throughput depending on the receiver type. Receiver type 3 gives ~30% higher system capacity than type 2. At low number of users the DC-HSDPA solution clearly outperforms the corresponding double single carrier solution.

In **Figure 17**, **Figure 18** and **Figure 19**, the 10/50/90 percentile user throughput for the different scenarios is normalized with the 10/50/90 percentile user throughput of double single carriers with receiver type 2.

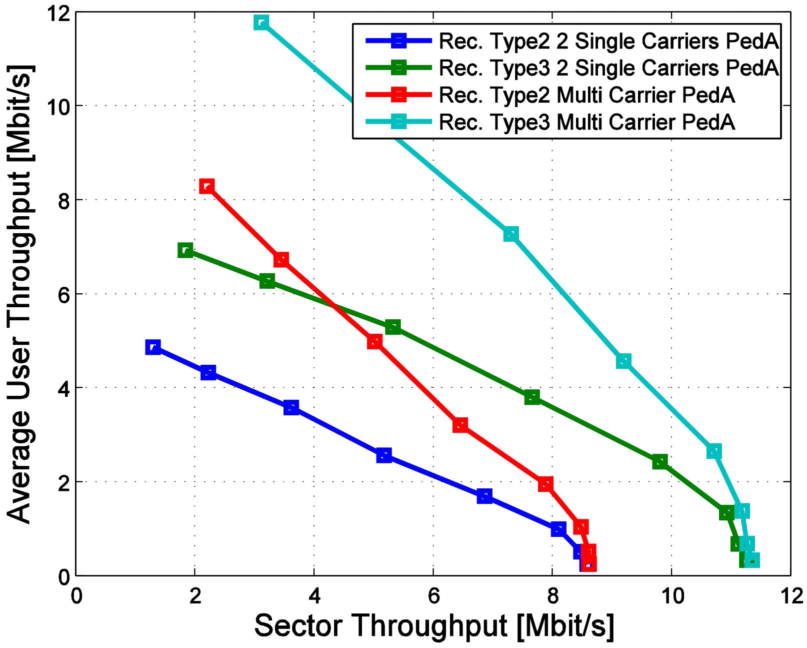


Figure 14: User throughput vs sector throughput for Full buffer traffic

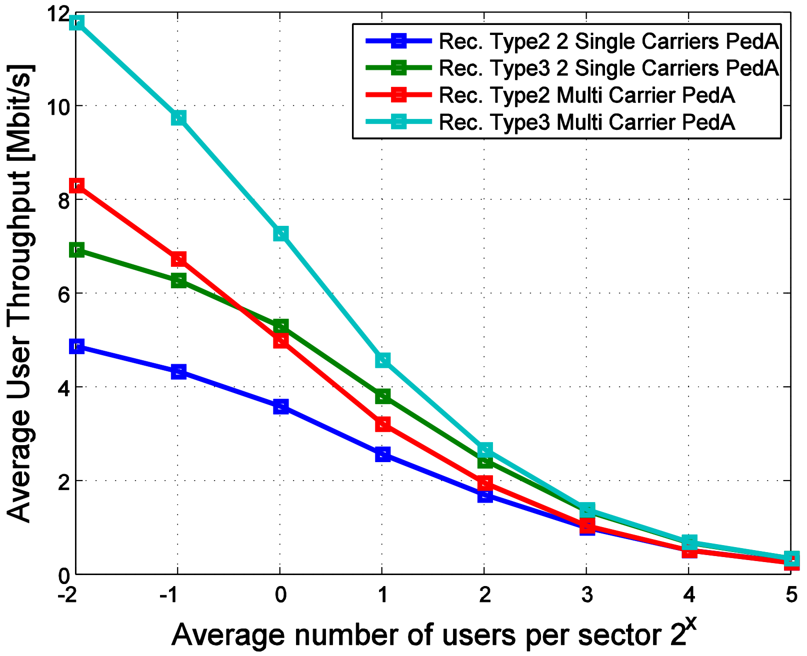


Figure 15: Average user throughput vs average number of users per sector for Full buffer traffic

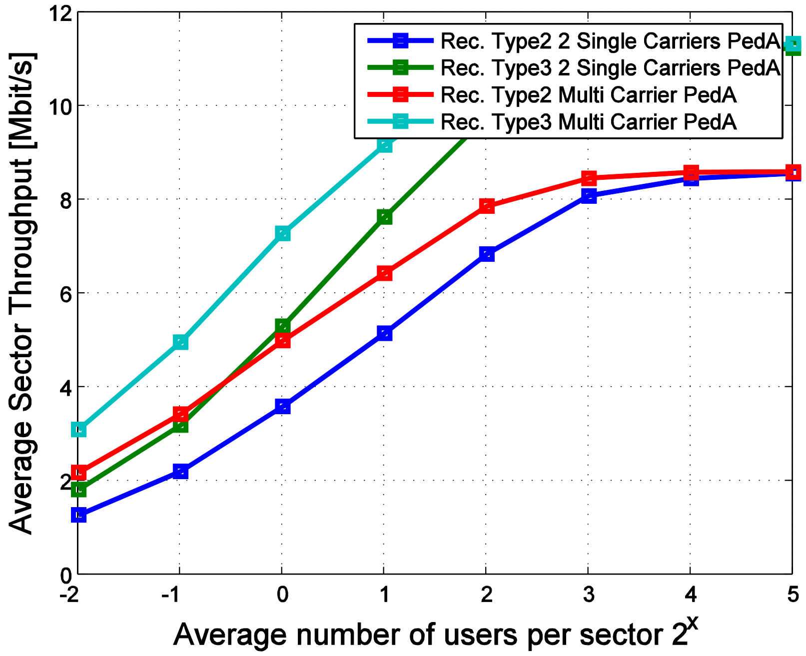


Figure 16: Average sector throughput vs average number of users per sector for Full buffer traffic

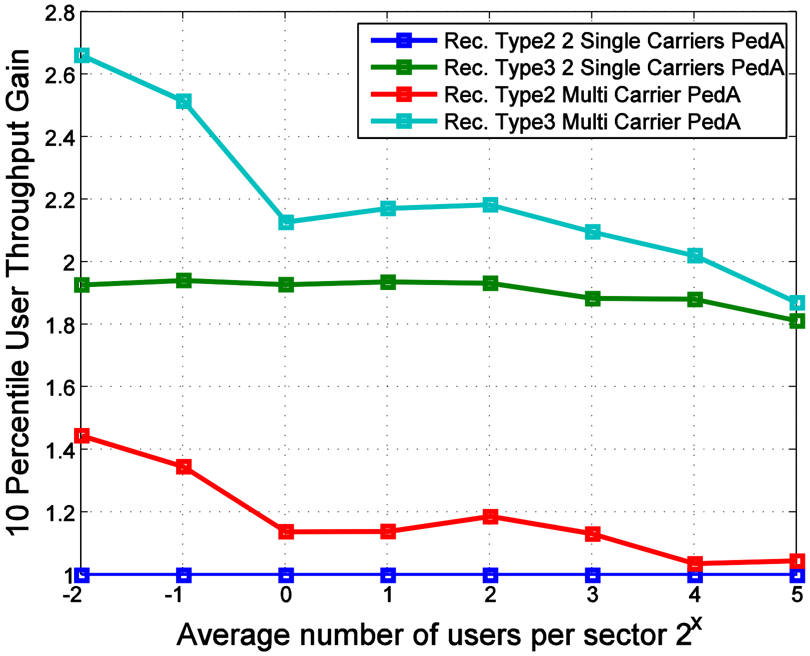


Figure 17: 10 percentile throughput gain vs average number of users per sector for Full buffer traffic

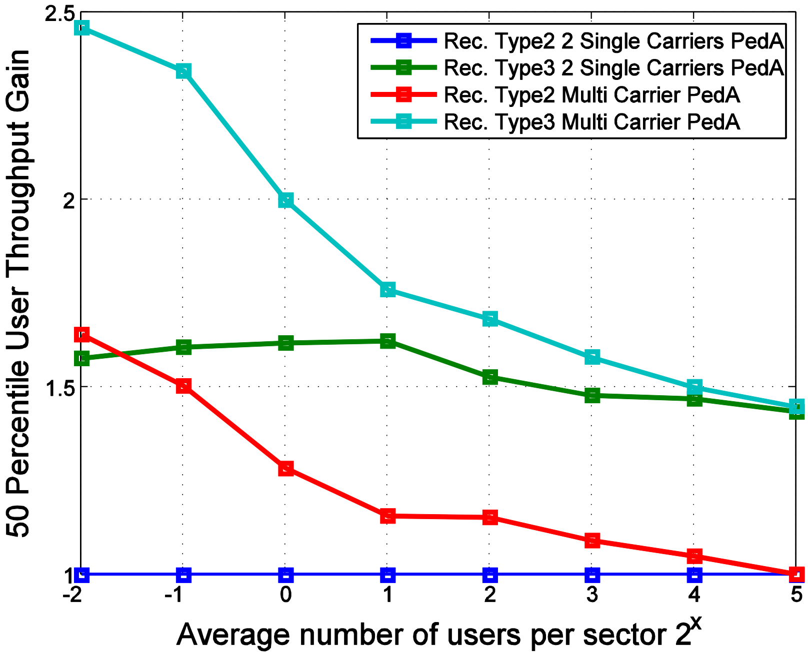


Figure 18: 50 percentile throughput gain vs average number of users per sector for Full buffer traffic

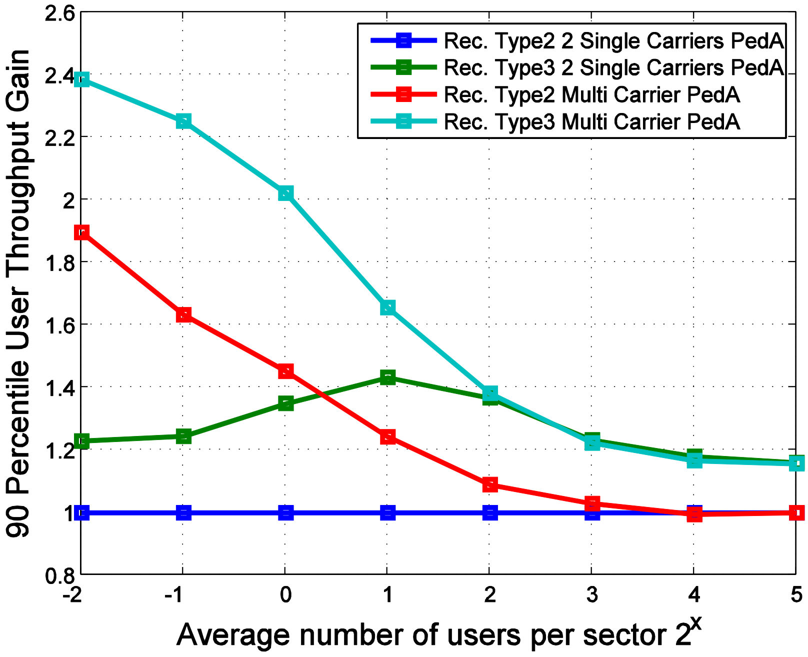


Figure 19: 90 percentile throughput gain vs average number of users per sector for Full buffer traffic

5.2.3 Simulation results provided by Source 3 [9]

System simulation results in Pedestrian A channel are shown in **Figure 20** and **Figure 21** assuming fairness factors 0.1 and 0.001, respectively. Actually first fairness factor is such that scheduling is pretty close to round robin. Results are shown both with and without receiver diversity. As can be seen in the results in **Figure 21** receiver diversity reduces gain due to multicarrier somewhat. In this case also sector throughput seems to be higher for 2xSC with receiver diversity than for multicarrier withour receiver diversity except the case where there is only one user per sector. Multicarrier gain reduces as number of users per sector increases. Highest gain of roughly 100% is achieved in a special case when there is only one user per sector since in that case multicarrier user can utilize both carriers all the time.

Parameters used in simulation are presented in detail in Annex A of [9] and are compliant with the scenario agreement in [6]. Full buffer traffic is used in all simulations.

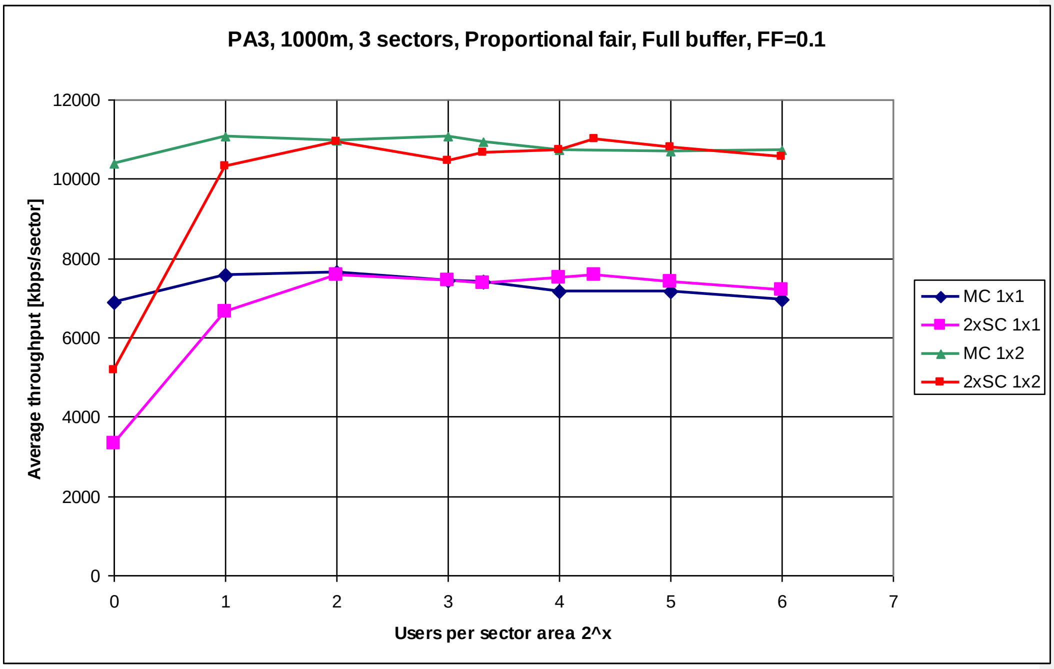


Figure 20 Average sector throughput in case of fairness factor 0.1

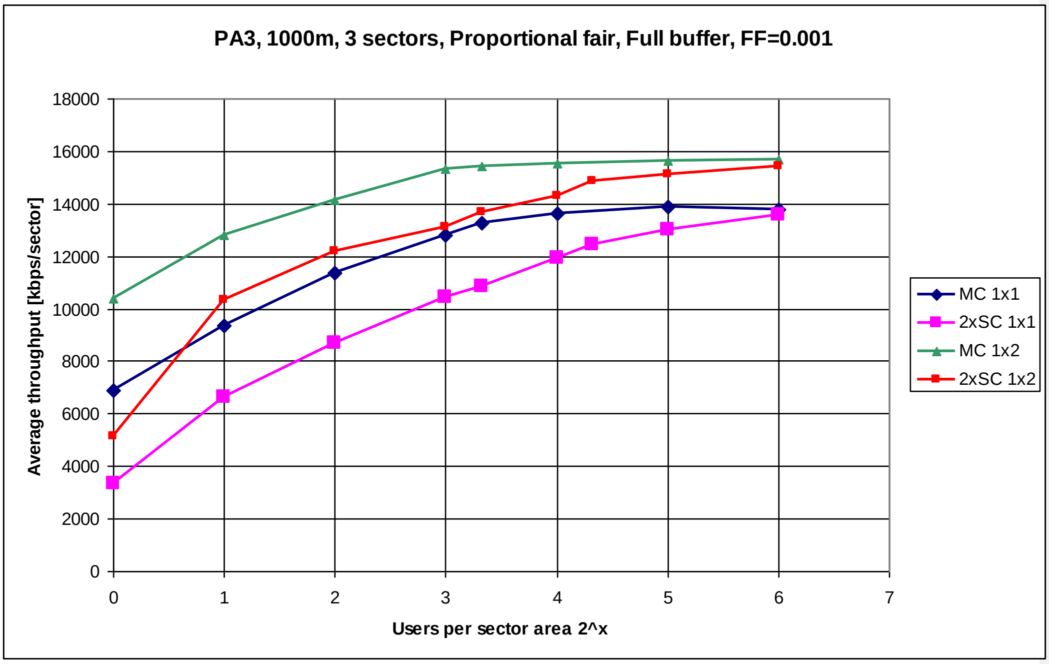


Figure 21 Average sector throughput in case of fairness factor 0.001

5.2.3.1 Annex A in [9]

System simulation parameters

Parameter	**Value**
Cellular system	WCDMA – HSDPA
Carrier bandwidth	5 MHz
Number of carriers	2
Carrier 1 frequency	2150 MHz
Carrier 2 frequency	2155 MHz
Sectors per cell	3
Site-to-site distance	1000 m
Minimum BS and MS separation	35 m
HS-PDSCH transmit power	75 %
CPICH transmit power	10 %
Thermal noise	-99 dBm
BS total transmit power	43 dBm
Propagation model	$16 + 37.6 \log_{10}(d[m])$
Correlation between sites	0.5
Correlation between sectors	1.0
Standard deviation of slow fading	8 dB
Mobile speed	3 km/h
Mobile receiver type	LMMSE chip equalizer
ITU channels	Extended Ped A
Number of multicodes	15 (variable)
CQI set	0.5 QPSK, 0.75 QPSK, 0.5 16QAM, 0.75 16QAM
AMC feedback delay	3 TTIs
AMC packet-error-rate target	50 %

Fast HARQ scheme	Chase combining
HARQ processes	6
HARQ transmissions	4
Packet scheduler	proportional fair
Traffic model	Full buffer

5.2.4 Discussion on the difference in the simulations results

In the full buffer results, the user and sector throughput provided by different sources are fairly close in comparable cases. The reasons for the minor difference include the following: different models on receiver performance; difference in the scheduler including the fairness criteria, channel sensitivity, assumptions on the channel fading correlations between the carriers and whether multiple users can be scheduled for the same TTI. For example, all the Sources use Proportional Fair (PF) scheduler. But an extra parameter of 'fairness factor' is used by Source 3. Longer time constant in the PF-Scheduler is used by Source 1 (2250 slots, or 1.5 seconds) than Source 2 (192 slots) and therefore higher multi-user diversity seen in results by Source 1.

In the results with bursty traffic, the burst rates reported by Source 2 are higher than those by Source 1 for the comparable cases although the results converge with a large number of users. The main reason, apart from listed above, is the interference from the non-central sectors. In the simulations provided by Source 1, N users (N=1,2,4,8,16,32,64) are dropped uniformly to the central sector. All the other sectors are assuming to transmit with full power all the time according to the assumption of OCNS=1 [6]. The reported results are the average performance over multiple drops. In the simulation provided by Source 2, 57*N users are dropped uniformly to the entire 57-sector system. The transmit power in the non-central sector is explicitly simulated. Therefore, with small to medium number of users per sector, the data rates seen by Source 2 will be higher since non-central sectors are not always transmitting with full power. When the number of users becomes large, the difference between the two simulations shrinks.

Considering all the simulation results provided by various sources, the following common trends can be observed:

- For full buffer traffic:
  - DC HSDPA results in user throughput and sector throughput gains. Such gains are more significant with small number of users per sector and decrease with number of users.
  - Low geometry users gain more in terms of throughput than high geometry users.
- For bursty traffic:
  - DC HSDPA results in a doubling of burst rates with low to medium loads, even after normalizing the number of users per 5 MHz.
  - At low to medium loads, for a given burst rate, DC HSDPA can support more than twice the number of users when compared to 2xSC-HSDPA.

Such gain decreases when the load is so high that the queues of users in bad geometry start to build up.

5.2.5 HS-DPCCH Cubic Metric Analysis

In the following, we present a cubic metric impact analysis, due to transmission of the 2nd HS-DPCCH as described in 4.3.2.1.1.1. The analysis assumes that a maximum of 1 dedicated channel is supported on the uplink.

5.2.5.1 CM analysis

As an initial analysis, we generate CM values to investigate the impact of introducing new HS-DPCCH (HS-DPCCH2).

Table 1 summarizes the channelization code and the gain factor values of the reference channel configuration which are used in the simulation. Table 2 describes the channelization code and gain factor values of HS-DPCCH2.

Table 1: Channel configuration of the reference channels

	Channel	Channelization code	Gain factor
$N_{max-dpdch}$=0	DPCCH	(Q,256,0)	15
	E-DPCCH	(I,256,1)	24
	E-DPDCH	SF4=(I,4,1) SF2x2=((I,2,1) (Q,2,1) SF2x2+SF4x2 = ((I,4,1),(Q,4,1),(I,2,1),(Q,2,1))	{17,27,47,67,84}
	HS-DPCCH	(Q,256,33)	{5,12,24,38}
$N_{max-dpdch}$=1	DPCCH	(Q, 256,0)	15
	E-DPCCH	(I, 256,1)	24
	DPDCH	(I, 64, 16)	21
	E-DPDCH	SF4=(I,4,2) SF2x2=((I,2,1) (Q,2,1)	{17,27,47,67,84}
	HS-DPCCH	(Q, 256,64)	{5,12,24,38}

Table 2: Channel configuration of the additional HS-DPCCH

	Channel	Channelization code	Gain factor
$N_{max-dpdch}$=0	HS-DPCCH2 mapped on I branch	(I, 256,33)	{5,12,24,38}
	HS-DPCCH2 mapped on Q branch	(Q, 256,32)	{5,12,24,38}
$N_{max-dpdch}$=1	HS-DPCCH2 mapped on I branch	(I, 256,63)	{5,12,24,38}
	HS-DPCCH2 mapped on Q branch	(Q, 256,63)	{5,12,24,38}

Figure 1, 2 and 3 shows the CM values in case of $N_{max-dpdch}$=0 and figure 4 and figure 5 shows the CM values in case $N_{max-dpdch}$=1. The blue line and the red line indicate CM values in each case and the green and the purple line indicate the CM increase compared to the case of no HS-DPCCH2.

a) $N_{max\text{-}dpdch}$=0

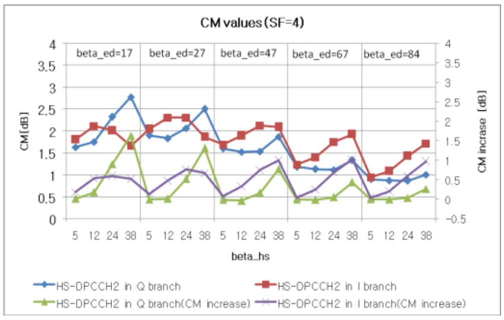


Figure 22: CM values in case of SF4

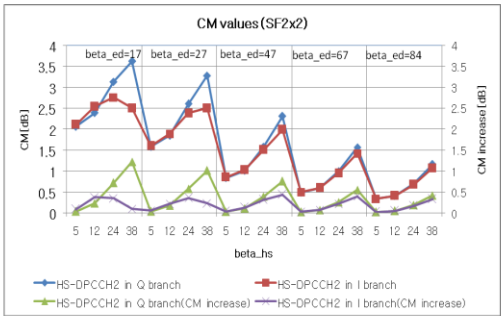


Figure 23: CM values in case of SF2x2

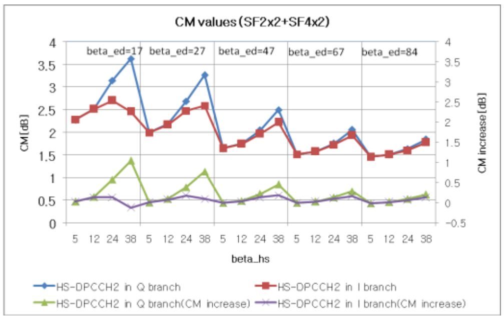
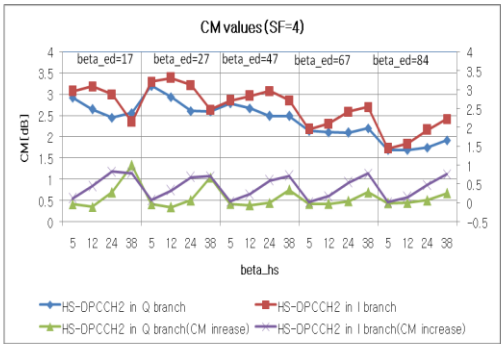


Figure 24: CM values in case of SF2x2+SF4x2

a) $N_{max\text{-}dpdch}$=1



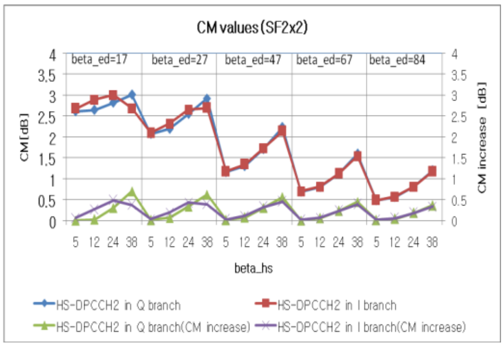


Figure 25: CM values in case of SF4

Figure 26: CM values in case of SF4

Observations

- In the case of $N_{max\text{-}dpdch}$=0, HS-DPCCH2 mapped to I branch results in the smaller CM increase compared to HS-DPCCH2 mapped to Q branch.

- In the case of $N_{max\text{-}dpdch}$=1, HS-DPCCH2 mapped to Q branch results in the smaller CM increase compared to HS-DPCCH2 mapped to I branch.
- Assuming HS-DPCCH2 mapped to I branch for $N_{max\text{-}dpdch}$=0 and HS-DPCCH2 mapped to Q branch for $N_{max\text{-}dpdch}$=1,
  - The maximum CM value is 3.38 dB in the case of SF4, beta_ed 27 and beta_hs=5.
  - The CM increase is higher when one E-DPDCH is used. In some case, 1dB CM increase is observed.

5.2.6 Alternate CM analysis

The possible channelization code indices that can be used for this 2nd HS-DPCCH under the worst case scenarios (different N_max_dpdch) is shown in Table 3.

In the cubic metric analysis performed here, we have run Monte-Carlo simulations to compare cubic metrics of single HS-DPCCH and dual HS-DPCCH with different code and channel allocation for the second HS-DPCCH.

Depending on N_max_dpdch, the 1st HS-DPCCH is still transmitted as before on the following channelization codes:

- N_max_dpdch = 0
  - Cch,256,33 on Q
- N_max_dpdch = 1
  - Cch,256,64 on Q

Irrespective of N_max_dpdch = 0 or 1, we transmit the 2nd HS-DPCCH on the following channelization codes:

- Cch,256,0 on I
- Cch,256,1 on Q
- Cch,256,32 on I
- Cch,256,33 on I

Tables 4, 5 and 6 list the different simulation parameter settings performed in this analysis. The results obtained are categorized into 35 cases for each TTI setting as shown in Tables 7, 8, 9 and 10. Table 11 provides a summary of the results obtained from all the simulations.

Table 3: Worst Case Code consumption for different N_max_dpdch

N_max_dpdch	UL Channels	Code Usage	I	Q
0	4 E-DPDCH (2SF2+2SF4) + 1 E-DPCCH + 1 DPCCH + 1 HS-DPCCH	Used	E-DPDCH1 Cch,2,1 E-DPDCH3 Cch,4,1 E-DPCCH Cch,256,1	DPCCH Cch,256,0 E-DPDCH2 Cch,2,1 E-DPDCH4 Cch,4,1 HS-DPCCH Cch,256,33
		Avail. for HS2, Cch,256,n	0≤n ≤63, n ≠ 1	1≤n ≤63, n ≠ 33
1	1 DPDCH + 2 E-DPDCH (2xSF2) + 1 E-DPCCH +	Used	DPDCH Cch,4,1 E-DPDCH2 Cch,2,1 E-DPCCH Cch,256,1	DPCCH Cch,256,0 E-DPDCH2 Cch,2,1 HS-DPCCH Cch,256,64
	1 DPCCH +	Avail. for HS2,	0≤n ≤63, n ≠ 1	1<=n<=127, n ≠ 64

	1 HS-DPCCH	Cch,256,n		
2,4,6	6 DPDCH + 1 DPCCH + 1 HS-DPCCH	Used	DPDCH1 Cch,4,1 DPDCH3 Cch,4,3 DPDCH5 Cch,4,2 HS-DPCCH Cch,256,1	DPCCH Cch,256,0 DPDCH2 Cch,4,1 DPDCH3 Cch,4,3 DPDCH6 Cch,4,2
		Avail. for HS2, Cch,256,n	$0 \le n \le 63$, $n \ne 1$	$1 \le n \le 63$
3,5	5 DPDCH + 1 DPCCH + 1 HS-DPCCH	Used	DPDCH1 Cch,4,1 DPDCH3 Cch,4,3 DPDCH5 Cch,4,2	DPCCH Cch,256,0 DPDCH2 Cch,4,1 DPDCH3 Cch,4,3 HS-DPCCH Cch,256,32
		Avail. for HS2, Cch,256,n	$0 \le n \le 63$	$1 \le n \le 63$, $n \ne 32$) Or $128 \le n \le 191$

Table 4: CM Analysis, Simulation Parameters

Parameter	Value	Comment
Nmax_dpdch	[0,1]	0 or 1 dedicated channels
TTI [ms]	[2 10]	
E-DCH Transport Block Size [bits]	[1406, 2798, 5772, 11484] – 2ms TTI [1406, 5772, 11484, 20000] – 10ms TTI	Corresponds to [1xSF4, 2xSF4, 2xSF2, 2XSF2+2xSF4] for 2ms TTI [1xSF4, 1xSF4, 2xSF4, 2xSF2] for 10ms TTI
β_d	1.0	
Channelization Code used for dedicated channel	Cch,64,16	
β_c	11/15	
$15{*}\beta_{hs}/\beta_c$	[0 12 15 19 24]	-0 corresponds to HS-DPCCH disabled. -Same beta setting on each of I and Q branches when dual HS-DPCCH is simulated.
$15{*}\beta_{ec}/\beta_c$	[15 19 24]	- For 10ms TTI, $\beta_{ec}/\beta_c = 24/15$ is not considered
$15{*}\beta_{ed,1}/\beta_c$	[17 21 27 34 42 53 67];	
$15{*}\beta_{ed,2}/\beta_c$	[24 27 38 47 53 67 84]	Only valid for 2xSF2+2xSF4

Table 5: CM Analysis, HS-DPCCH Settings

Parameter	Value
Pr [ACK/NACK/DTX]	[1/3, 1/3, 1/3]

Inter TTI ACK	1
Inter TTI CQI	1
N_acknack_transmit	1
N_cqi_transmit	1

Table 6: CM Analysis, Parameter Settings per TTI

Parameter	2ms TTI	10ms TTI
TTI	2	10
N_HARQ	8	4
MaxReTx	4	2

5.2.6.1 Maximum Cubic Metric with dual HS-DPCCH configurations

In Table 6.1A [12], it is specified that the CM shall be less than or equal to 3.5, for all combinations of DPDCH, DPCCH, HS-DPCCH, E-DPDCH and E-DPCCH. In the CM analysis performed on dual HS-DPCCH configurations (Tables 7 -10), we investigate whether this upper bound is exceeded for all combinations of DPDCH, DPCCH, HS-DPCCH, E-DPDCH and E-DPCCH.

Table 7: CM Analysis, N_max_dpdch = 0, 2ms TTI; E-DPDCH

Case	N_max_dpdch	TBS [bits] [SF]	$15*\beta_{hs}/\beta_c$	Max CM [dB] Single HS-DPCCH	Max CM [dB] Dual HS-DPCCH			
				256,33, Q	256,33,Q 256,0,I	256,33,Q 256,1,Q	256,33,Q 256,32,I	256,33,Q 256,33,I
1	0	1406 (1xSF4)	0	1.9236	1.9236	1.9236	1.9236	1.9236
2			12	1.8227	2.3894	2.0194	2.2741	2.2767
3			15	1.7732	2.5001	2.2433	2.3518	2.3552
4			19	1.6995	2.5696	2.4914	2.3978	2.4020
5			24	1.6410	2.5621	2.7066	2.3716	2.3766
6		2798 (2xSF4)	0	1.4849	1.4849	1.4849	1.4849	1.4849
7			12	1.8529	2.1157	2.2907	2.0224	2.0278
8			15	1.9735	2.2384	2.5336	2.1137	2.1201
9			19	2.0955	2.3301	2.7862	2.1665	2.1734
10			24	2.1765	2.3547	2.9927	2.1635	2.1691
11		5772	0	2.0395	2.0395	2.0395	2.0395	2.0395

12	**(2xSF2)**	12	**2.4728**	**2.7652**	**2.9743**	**2.6678**	**2.6740**
13		15	**2.6130**	**2.9000**	**3.2490**	**2.7679**	**2.7751**
14		19	**2.7513**	**2.9796**	**3.5281**	**2.8083**	**2.8161**
15		24	**2.8360**	**2.9889**	**3.7469**	**2.8058**	**2.8123**
16	**11484 (2xSF4 + 2xSF2)**	0	**2.5558**	**2.5558**	**2.5558**	**2.5558**	**2.5558**
17		12	**2.6259**	**2.8082**	**2.7997**	**2.7558**	**2.7569**
18		15	**2.6754**	**2.8976**	**2.9456**	**2.8267**	**2.8284**
19		19	**2.7573**	**2.9856**	**3.1360**	**2.8933**	**2.8958**
20		24	**2.8374**	**3.0323**	**3.3433**	**2.9291**	**2.9315**
	Maximum CM [dB]		**2.8374**	**3.0323**	**3.7469**	**2.9291**	**2.9315**

Table 8: CM Analysis, N_max_dpdch = 1, 2ms TTI; EDPDCH

Case	N_max_dpdch	TBS [bits] [SF]	15*βhs/βc	Max CM [dB] Single HS-DPCCH	Max CM [dB] Dual HS-DPCCH			
				256,64,Q	256,64,Q 256.0.I	256,64,Q 256,1,Q	256,64,Q 256,32,I	256,64,Q 256,33,I
1	1	1406 (1xSF4)	0	2.0517	2.0517	2.0517	2.0517	2.0517
2			12	3.0768	3.4057	2.9841	3.3822	3.3812
3			15	2.9849	3.4294	2.8784	3.3977	3.3963
4			19	2.8604	3.4198	2.7656	3.3788	3.3768
5			24	2.7025	3.3413	2.6696	3.2994	3.2974
6		2798 (2SF4)	0	2.6983	2.6983	2.6983	2.6983	2.6983
7			12	2.6514	2.9931	2.6928	2.9650	2.9633
8			15	2.6346	3.0641	2.7500	3.0270	3.0249
9			19	2.6052	3.1081	2.8384	3.0613	3.0586
10			24	2.5710	3.0861	2.9449	3.0389	3.0362
11		5772 (2SF2)	0	2.7243	2.7243	2.7243	2.7243	2.7243
12			12	2.6678	3.0174	2.7066	2.9885	2.9874
13			15	2.6450	3.0873	2.7563	3.0493	3.0477
14			19	2.6069	3.1296	2.8450	3.0816	3.0794
15			24	2.5481	3.1086	2.9516	3.0597	3.0576
Maximum CM [dB]				3.0768	3.4294	2.9841	3.3977	3.3963

Table 9: CM Analysis, N_max_dpdch = 0, 10ms TTI; E-DPDCH

Case	N_max_dpdch	TBS [bits] [SF]	$15*\beta_{hs}/\beta_c$	Max CM [dB] Single HS-DPCCH	Max CM [dB] Dual HS-DPCCH			
				256,33, Q	256,33,Q 256,0,I	256,33,Q 256,1,Q	256,33,Q 256,32,I	256,33,Q 256,33,I
1	0	1406 (1SF8)	0	1.5935	1.5935	1.5935	1.5935	1.5935
2			12	1.5718	2.2309	1.9734	2.1567	2.1609
3			15	1.5622	2.3327	2.2113	2.2469	2.2521
4			19	1.5937	2.3710	2.4717	2.2769	2.2828
5			24	1.6068	2.3071	2.6954	2.2524	2.2577
6		5772 (1SF4)	0	1.7165	1.7165	1.7165	1.7165	1.7165
7			12	1.6700	2.3346	2.0192	2.1967	2.2009
8			15	1.6498	2.4308	2.2427	2.2681	2.2732
9			19	1.6413	2.4610	2.4905	2.2799	2.2857
10			24	1.6407	2.3976	2.7055	2.2385	2.2436
11		11484 (2SF4)	0	1.4868	1.4868	1.4868	1.4868	1.4868
12			12	1.8541	2.1182	2.2922	2.0218	2.0260
13			15	1.9746	2.2406	2.5351	2.1126	2.1177
14			19	2.0963	2.3135	2.7877	2.1653	2.1708
15			24	2.1770	2.2917	2.9941	2.1337	2.1396
16		20000 (2SF2)	0	2.0379	2.0379	2.0379	2.0379	2.0379
17			12	2.4698	2.7632	2.9734	2.6659	2.6698
18			15	2.6097	2.8980	3.2479	2.7662	2.7709
19			19	2.7476	2.9693	3.5267	2.8074	2.8122
20			24	2.8321	2.9236	3.7453	2.7703	2.7741
Maximum CM [dB]				2.8321	2.9693	3.7453	2.8074	2.8122

Table 10: CM Analysis, N_max_dpdch = 1, 10ms TTI; E-DPDCH

Case	N_max_dpdch	TBS [bits] [SF]	$15*\beta_{hs}/\beta_c$	Max CM [dB] Single HS-DPCCH	Max CM [dB] Dual HS-DPCCH			
				256,64, Q	256,33,Q 256,0,I	256,33,Q 256,1,Q	256,33,Q 256,32,I	256,33,Q 256,33,I
1	1	1406 (1SF8)	0	2.0052	2.0052	2.0052	2.0052	2.0052
2			12	2.9939	3.3080	2.9247	3.3331	3.3318
3			15	2.9023	3.3187	2.8352	3.3520	3.3502
4			19	2.7638	3.2883	2.7377	3.3303	3.3280
5			24	2.5903	3.1830	2.6729	3.2321	3.2294
6		5772 (1SF4)	0	3.1777	3.1777	3.1777	3.1777	3.1777
7			12	2.9949	3.3222	2.9241	3.3196	3.3182
8			15	2.9034	3.3374	2.8342	3.3341	3.3322
9			19	2.7651	3.3118	2.7365	3.3076	3.3051
10			24	2.5922	3.2105	2.6669	3.2055	3.2025
11		11484 (2SF4)	0	2.6569	2.6569	2.6569	2.6569	2.6569
12			12	2.6213	2.9480	2.6890	2.9452	2.9425
13			15	2.6030	3.0077	2.7460	3.0042	3.0009
14			19	2.5931	3.0308	2.8344	3.0266	3.0226
15			24	2.5673	2.9857	2.9415	2.9817	2.9776
16		20000 (2SF2)	0	2.6696	2.6696	2.6696	2.6696	2.6696
17			12	2.6223	2.9622	2.7032	2.9597	2.9577
18			15	2.5978	3.0220	2.7532	3.0188	3.0162
19			19	2.5794	3.0447	2.8420	3.0406	3.0375
20			24	2.5431	2.9997	2.9491	2.9961	2.9929
Maximum CM [dB]				2.9949	3.3374	2.9491	3.3520	3.3502

Table 11: CM Analysis, Summary of Results

TTI	Nmax_dpdch	Max CM (single HS-DPCCH)	Max CM (dual HS DPCCH) (m = 33 when Nmax_dpdch=0, m=64 when Nmax_dpdch=1)			
		Cch,256,m Q	Cch,256,m Q Cch,256,0 I	Cch,256,m Q Cch,256,1 Q	Cch,256,m Q Cch,256,32 I	Cch,256,m Q Cch,256,33 I
2	0	2.8374	3.0323	3.7469	2.9291	2.9315
	1	3.0768	3.4294	2.9841	3.3977	3.3963
10	0	2.8321	2.9693	3.7453	2.8074	2.8122
	1	2.9949	3.3374	2.9491	3.3520	3.3502

Based on Tables 7, 8, 9, 10 and 11, we observe the following:

- For the 2nd HS-DPCCH
  - The performance of Cch,256,32 on I is very similar in performance of Cch,256,33 on I.
  - The performance of Cch,256,0 on I is slightly worse (0.1dB to 0.2dB) in performance when compared to the other code selections.
  - The performance of Cch,256,32 on I is the best when N_max_dpdch = 0 and the performance of Cch,256,1 on Q is the best when N_max_dpdch = 1.

Figures 27-42 illustrate the comparison of the CM for N_max_dpdch = 0 and 1, and for TTI = 2ms and 10ms for each of the test cases simulated. Figure 1 also illustrates the manner in which the test cases have been grouped. This is so that the figures can be cross-references with the tables.

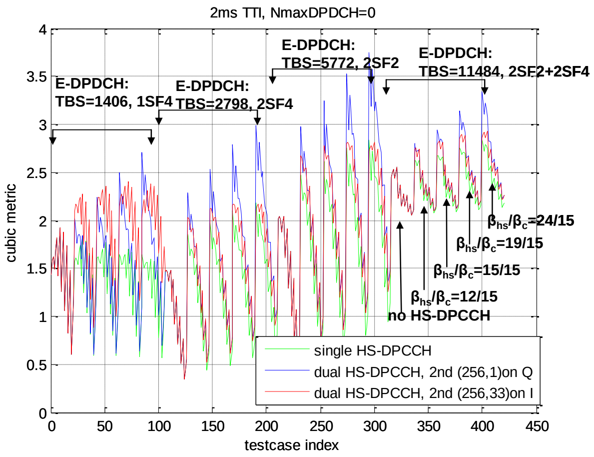


Figure 27: Cubic Metric for the proposed cases; 2ms TTI; N_max_dpdch=0.

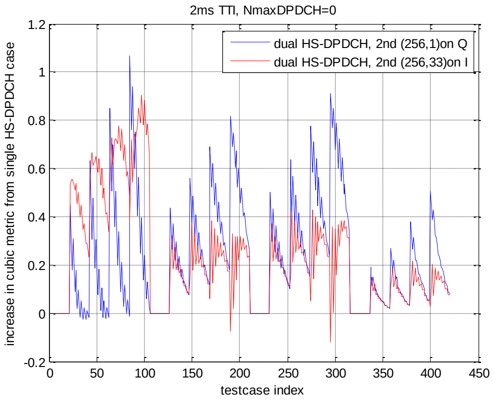


Figure 28: Increase in cubic metric for the proposed cases; 2ms TTI; N_max_dpdch=0.

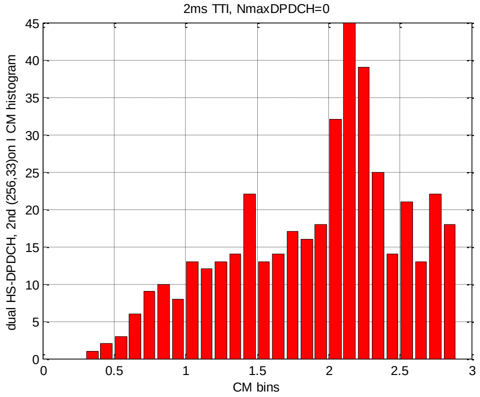


Figure 29: Histogram of the cubic metric for the (256, 33) on I; 2ms TTI; N_max_dpdch=0.

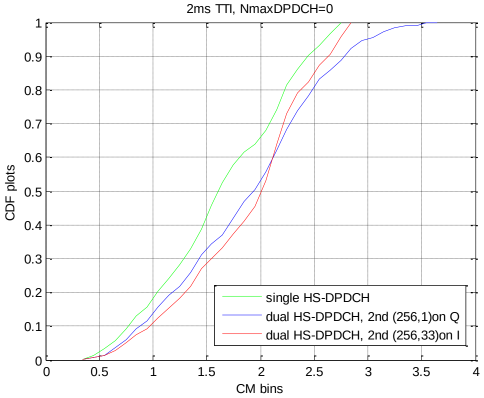


Figure 30: CDF of the cubic metric for the proposed cases; 2ms TTI; N_max_dpdch=0.

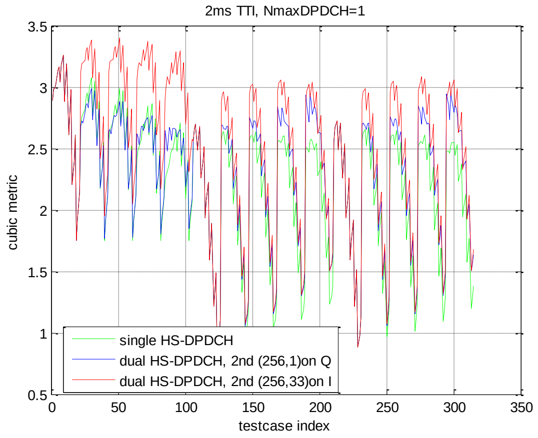


Figure 31: Cubic Metric for the proposed cases; 2ms TTI; N_max_dpdch=1.

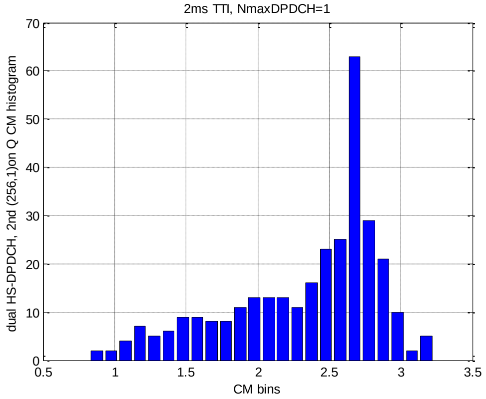


Figure 33: Histogram of the cubic metric for the (256, 1) on Q; 2ms TTI; N_max_dpdch=1.

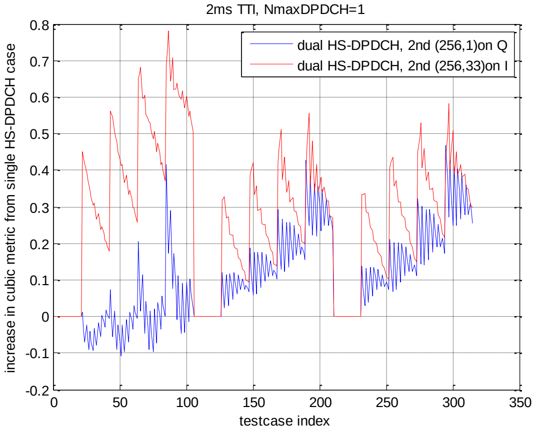


Figure 32: Increase in cubic metric for the proposed cases; 2ms TTI; N_max_dpdch=1.

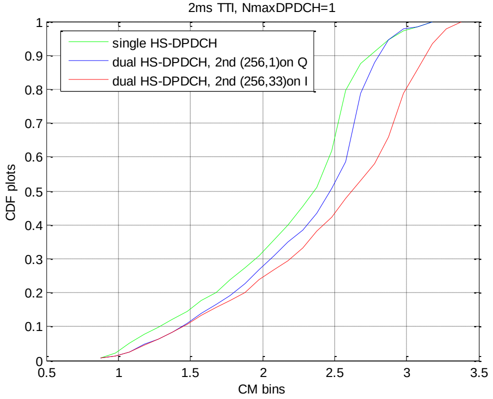


Figure 34: CDF of the cubic metric for the proposed cases; 2ms TTI; N_max_dpdch=1.

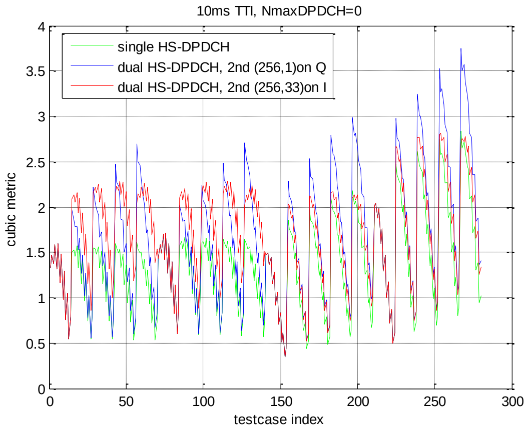


Figure 35: Cubic Metric for the proposed cases; 10ms TTI; N_max_dpdch=0.

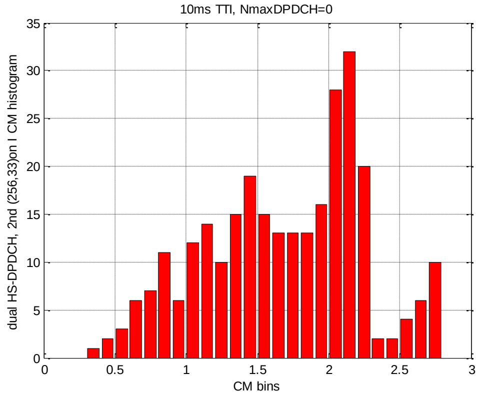


Figure 37: Histogram of the cubic metric for the (256, 33) on I; 10ms TTI; N_max_dpdch=0.

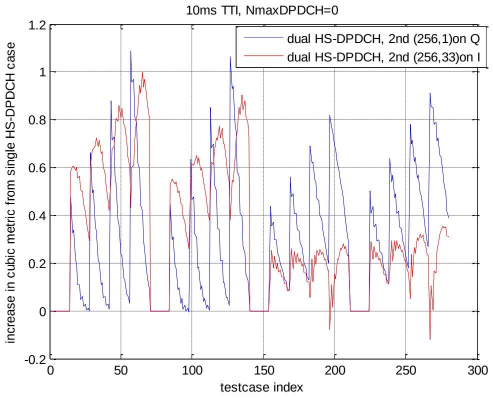


Figure 36: Increase in cubic metric for the proposed cases; 10ms TTI; N_max_dpdch=0.

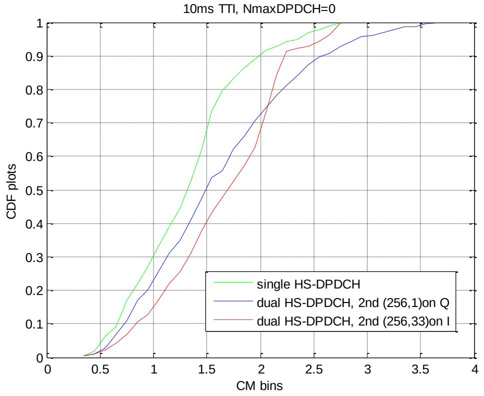


Figure 38: CDF of the cubic metric for the proposed cases; 10ms TTI; N_max_dpdch=0.

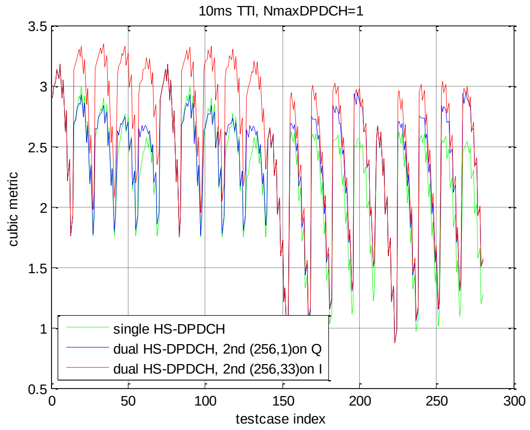


Figure 39: Cubic Metric for the proposed cases; 10ms TTI; N_max_dpdch=1.

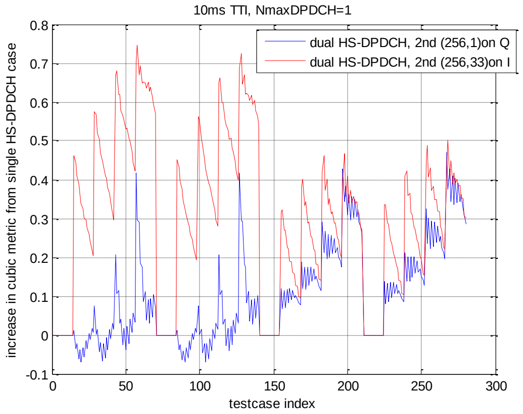


Figure 40: Increase in cubic metric for the proposed cases; 10ms TTI; N_max_dpdch=1.

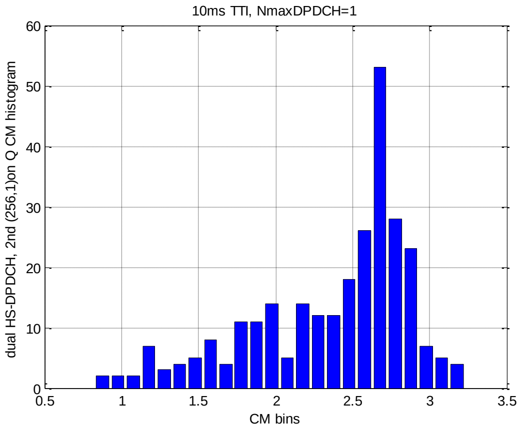


Figure 41: Histogram of the cubic metric for the (256, 1) on Q; 10ms TTI; N_max_dpdch=1.

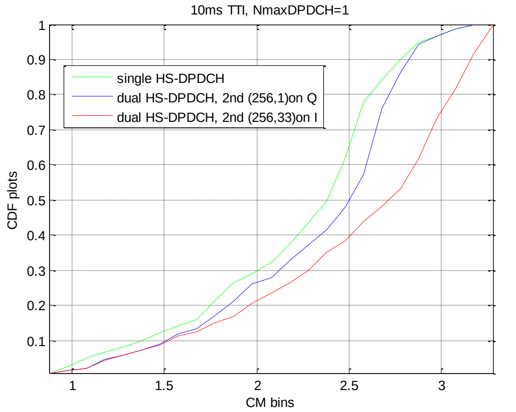


Figure 42: CDF of the cubic metric for the proposed cases; 10ms TTI; N_max_dpdch=1.

5.2.6.2 Impact on Coverage

5.2.6.2.1 Cubic Metric Increase Due to DC-HSDPA

The Maximum Power Reduction (MPR) for the UE is specified in [4] (Section 6.2.2) and is dependent on the cubic metric for the corresponding configuration of β_c, β_d, β_{hs}, β_{ec} and β_{ed}. The increase in cubic metric on a per-configuration basis is computed for the suggested design choices for each of the simulated test cases. Figures 28, 32, 36 and 40 show the increase in the cubic metric for all the test cases for N_max_dpdch = 0, 1 and for 2ms TTI as well as 10ms TTI. The results are also summarized in Tables 12 – 15 and show the maximum differences in the cubic metric for each test configuration group for when N_max_dpdch = 0, 1 for 2ms TTI and 10ms TTI.

Table 12: CM difference between Single and Dual HS-DPCCH, N_max_dpdch = 0, 2ms TTI

Case	N_max_dpdch	TBS [bits] (SF)	15*β_{hs}/ β_c	Max CM [dB] Single HS-DPCCH	Max CM difference from single HS-DPCCH case (dual HS DPCCH)			
				256,33, Q	256,33,Q 256,0,I	256,33,Q 256,1,Q	256,33,Q 256,32,I	256,33,Q 256,33,I
1	0	1406 (1xSF4)	0	1.9236	0	0	0	0
2			12	1.8227	0.72609	0.44714	0.55305	0.55729
3			15	1.7732	0.86567	0.63223	0.65888	0.66418
4			19	1.6995	0.95669	0.8501	0.77006	0.77441
5			24	1.6410	0.97636	1.0656	0.9005	0.90414
6		2798 (2xSF4)	0	1.4849	0	0	0	0
7			12	1.8529	0.44333	0.43782	0.31967	0.32398
8			15	1.9735	0.52148	0.56004	0.36913	0.37439
9			19	2.0955	0.55672	0.69067	0.37838	0.38447
10			24	2.1765	0.52035	0.81625	0.32498	0.33158
11		5772 (2xSF2)	0	2.0395	0	0	0	0
12			12	2.4728	0.50484	0.50152	0.36675	0.37169
13			15	2.6130	0.59032	0.63598	0.41982	0.42581
14			19	2.7513	0.62349	0.77686	0.42327	0.43018
15			24	2.8360	0.57177	0.91091	0.38022	0.38347
16		11484 (2xSF4 + 2xSF2)	0	2.5558	0	0	0	0
17			12	2.6259	0.1996	0.18947	0.14715	0.14823
18			15	2.6754	0.25648	0.27023	0.18556	0.18727
19			19	2.7573	0.30343	0.37868	0.2111	0.21357
20			24	2.8374	0.31113	0.50589	0.19872	0.20196

Table 13: CM difference between Single and Dual HS-DPCCH, N_max_dpdch = 1, 2ms TTI

Case	N_max_dpdch	TBS [bits] [SF]	15*βhs/βc	Max CM [dB] Single HS-DPCCH	Max CM difference from single HS-DPCCH case (dual HS DPCCH)			
				256,64,Q	256,64,Q 256.0.I	256,64,Q 256,1,Q	256,64,Q 256,32,I	256,64,Q 256,33,I
1	1	1406 (1xSF4)	0	3.2572	0	0	0	0
2			12	3.0768	0.45423	0.016843	0.4511	0.45014
3			15	2.9849	0.59535	0.073574	0.56227	0.56091
4			19	2.8604	0.74099	0.20556	0.68515	0.68213
5			24	2.7025	0.849	0.41554	0.78352	0.77985
6		2798 (2SF4)	0	2.6983	0	0	0	0
7			12	2.6514	0.3566	0.12	0.32848	0.32678
8			15	2.6346	0.46149	0.1881	0.42446	0.42228
9			19	2.6052	0.56007	0.29213	0.51328	0.51055
10			24	2.5710	0.6138	0.42836	0.55842	0.55521
11		5772 (2SF2)	0	2.7243	0	0	0	0
12			12	2.6678	0.36637	0.13669	0.33751	0.33636
13			15	2.6450	0.47557	0.21124	0.43761	0.43594
14			19	2.6069	0.58011	0.32317	0.53215	0.52987
15			24	2.5481	0.64093	0.46751	0.58417	0.58131

Table 14: CM difference between Single and Dual HS-DPCCH, N_max_dpdch = 0, 10ms TTI

Case	N_max_dpdch	TBS [bits] [SF]	15*β_{hs}/ β_c	Max CM [dB] Single HS-DPCCH	Max CM difference from single HS-DPCCH case (dual HS DPCCH)			
				256,33, Q	256,33,Q 256,0,I	256,33,Q 256,1,Q	256,33,Q 256,32,I	256,33,Q 256,33,I
1	0	1406 (1SF8)	0	1.5935	0	0	0	0
2			12	1.5718	0.70402	0.47455	0.60023	0.60556
3			15	1.5622	0.78997	0.66173	0.71839	0.7232
4			19	1.5937	0.83634	0.87802	0.85478	0.85901
5			24	1.6068	0.9258	1.0886	0.99339	0.99701
6		5772 (1SF4)	0	1.7165	0	0	0	0
7			12	1.6700	0.70882	0.44657	0.54574	0.5509
8			15	1.6498	0.79847	0.63148	0.64386	0.64852
9			19	1.6413	0.86257	0.84928	0.76903	0.773
10			24	1.6407	0.97676	1.0648	0.89931	0.90256
11		11484 (2SF4)	0	1.4868	0	0	0	0
12			12	1.8541	0.35534	0.43812	0.24719	0.25099
13			15	1.9746	0.38433	0.56057	0.25429	0.25901
14			19	2.0963	0.35764	0.6914	0.25614	0.2579
15			24	2.1770	0.32912	0.81709	0.27769	0.279
16		20000 (2SF2)	0	2.0379	0	0	0	0
17			12	2.4698	0.70402	0.47455	0.60023	0.60556
18			15	2.6097	0.78997	0.66173	0.71839	0.7232
19			19	2.7476	0.83634	0.87802	0.85478	0.85901
20			24	2.8321	0.9258	1.0886	0.99339	0.99701

Table 15: CM difference between Single and Dual HS-DPCCH, N_max_dpdch = 1, 10ms TTI

Case	N_max_dpdch	TBS [bits] [SF]	15*β_{hs}/ β_c	Max CM [dB] Single HS-DPCCH	Max CM differen ce from single HS-DPCCH case (dual HS DPCCH)			
				256,64, Q	256,33,Q 256,0,I	256,33,Q 256,1,Q	256,33,Q 256,32,I	256,33,Q 256,33,I
1	1	1406 (1SF8)	0	2.0052	0	0	0	0
2			12	2.9939	0.42846	0.017933	0.46348	0.46179
3			15	2.9023	0.54753	0.074334	0.57777	0.57562
4			19	2.7638	0.65788	0.20634	0.68351	0.68001
5			24	2.5903	0.72097	0.41654	0.74895	0.74496
6		5772 (1SF4)	0	3.1777	0	0	0	0
7			12	2.9949	0.43856	0.017341	0.452	0.45032
8			15	2.9034	0.56019	0.074336	0.56349	0.56129
9			19	2.7651	0.67284	0.20661	0.66659	0.66309
10			24	2.5922	0.73723	0.4169	0.73024	0.72616
11		11484 (2SF4)	0	2.6569	0	0	0	0
12			12	2.6213	0.32673	0.11923	0.32388	0.32121
13			15	2.6030	0.40826	0.18755	0.40471	0.40138
14			19	2.5931	0.46973	0.29202	0.46547	0.46147
15			24	2.5673	0.47671	0.42881	0.47187	0.46736
16		20000 (2SF2)	0	2.6696	0	0	0	0
17			12	2.6223	0.42846	0.017933	0.46348	0.46179
18			15	2.5978	0.54753	0.074334	0.57777	0.57562
19			19	2.5794	0.65788	0.20634	0.68351	0.68001
20			24	2.5431	0.72097	0.41654	0.74895	0.74496

Based on Tables 12 – 15, and Figures 28, 32, 36 and 40, we observe the following:

- The CM difference is more pronounced for lower packet sizes when N_max_dpdch = 0 and the 2nd HS-DPCCH is transmitted on Cch,256,32 or Cch,256,33 on I.
- The CM difference is more significant for high βhs values (15*βhs/ βc = [19, 24])
- When N_max_dpdch = 1, the CM difference does not appear to be significant when the 2nd HS-DPCCH is transmitted on Cch,256,1 on Q.

When the UE is power limited and coverage becomes a factor, the NodeB could switch the UE from DC-HSDPA to single carrier mode. This would enable the UE to experiencesimilar performance as would have been possible in Rel. 7.

5.2.6.2.2 Uplink Beta Gain Settings

5.2.6.2.3 Link Budget Impact Due to DC-HSDPA

5.2.6.3 Simulation Results when E-DCH is not transmitted or configured

In this section we investigate the CM performance for the following cases:

- Case 1
    - E-DCH is configured
    - $N_{max\text{-}dpdch} = 0$
    - UE is temporarily not transmitting on E-DCH
    - UE transmits DPCCH and HS-DPCCH
- Case 2
    - E-DCH is not configured
    - $N_{max\text{-}dpdch} = 1$
    - UE transmits DPCCH , DPDCH and HS-DPCCH

Table 16 summarizes the cubic metrics obtained from simulations in this case for N_max_dpdch = [0, 1]. The design schemes that have been simulated are the same as the ones proposed in Section 5.2.6.

Table 16: CM difference between Single and Dual HS-DPCCH, N_max_dpdch = 1

Case	N_max_dpdch	β_{hs}	Max CM [dB] Single HS-DPCCH	Max CM [dB] (dual HS DPCCH) (m = 33 when Nmax_dpdch = 0, m = 64 when Nmax_dpdch = 1)				
			256,m,Q	256,m Q 256,0,I	256,m Q 256,1,Q	256,m Q 256,32,I	256,m Q 256,33,I	256,m Q 256,1,I
1	0	0	-0.007141	-0.007141	-0.007141	-0.007141	-0.007141	-
2		12	2.667136	1.812998	4.007653	1.813891	1.814103	-
3		15	2.826695	1.749568	4.119521	1.750115	1.750450	-
4		19	2.828267	1.595027	4.093388	1.594830	1.595293	-
5		24	2.670100	1.375547	3.955712	1.374463	1.375043	-
6	1	0	-0.005334	-0.005334	-0.005334	-0.005334	-0.005334	-0.005334
7		12	0.568488	1.11465	1.44501	1.35546	1.35556	1.10804
8		15	0.739033	1.28058	1.78024	1.54347	1.54336	1.27333
9		19	0.912918	1.37577	2.08987	1.64663	1.64627	1.36831
10		24	1.04462	1.3701	2.31413	1.63207	1.63144	1.36293

Based on Table 16, we observe the following:

- When $N_{max\text{-}dpdch}$ = 0 (Case 1), the addition of the 2nd HS-DPCCH transmitted on Cch,256,33 on I, reduces the CM as compared to the single HS-DPCCH case.
- When $N_{max\text{-}dpdch}$ = 1 (Case 2), the addition of the 2nd HS-DPCCH transmitted on Cch,256,1 on Q, increases the CM as compared to the single HS-DPCCH case.

To address the issue related to Case 2, we suggest some options which have a lesser impact on the cubic metric for the case when E-DCH is not configured and $N_{max\text{-}dpdch}$ = 1 :

- Cch(256, 33) on I
- Cch(256, 0) on I
- Cch(256, 1) on I

6 Impacts

6.1 Impact on implementation and complexity

6.1.1 UTRAN

From the UTRAN perspective, there is no fundamental difference in complexity for operating DC-HSDPA with UEs receiving data over two carriers compared to operating two carriers with no UEs receiving data over two carriers if it can be assumed that both carriers are processed in the same processing unit of the Node B. Clearly, there is some impact on the scheduler implementation, which allows the scheduler to schedule data transmissions to a user considering the code resources from two carriers.

6.1.2 UE

6.1.2.1 DC-HSDPA High Level Requirements

Based on the scope of the DC-HSDPA study item [1], we list below some high level DC-HSDPA requirements that are relevant to the UE implementation. The texts marked in italics are excerpts taken from [1], which in turn are used to derive high level requirements for DC-HSDPA operation.

- *From a Node-B perspective this implies scheduling a UE across two cells (one transport block in each cell) which could be operating on different carrier frequencies…since the uplink transmission would be restricted to a single cell*
    - This implies a 2DL:1UL configuration
- *The two cells operate with a single TX antenna*
    - This implies that DL MIMO is disabled when DC-HSDPA is enabled.
- *The two cells operate in the same frequency band*
    - For this case (Intra-Band), the study item does not explicitly rule out non-adjacent carrier operation. Hence we assume further the following 2 cases:
        - Case A: The carriers are 5 MHz apart.
        - Case B: The carriers are 10 MHz apart.

- *The two cells belong to the same Node-B* and *The two cells operate with a single TX antenna*
  - This implies that the serving sector is the same for both carriers
- *Without increasing the peak user rates defined in Rel-7, this operation could potentially result in significantly increased user throughput across the cell, in particular in the outer area of the cell*
  - This implies an aggregate peak rate of 28.8 to 43.2Mbps
    - 16-QAM: 2*14.4 Mbps = 28.8 Mbps
      - Same as Single Carrier R7 MIMO+16-QAM peak rates
    - 64-QAM: 2*21.6 Mbps = 43.2 Mbps
      - Same as Single Carrier R8 MIMO+64-QAM peak rates
- Rx Diversity
  - We allow for the study of a UE that is capable of 2-Rx diversity on each carrier.

6.1.2.2 UE Receiver Types

In the following, we perform a comparison of the following 2 receiver types:

- Baseline Receiver
  - Single Carrier
  - 2 Rx-Diversity
  - 2x2 MIMO enabled
    - 2 independent data streams, S1 and S2.
  - 64-QAM Operation
    - Peak Rate of 43.2 Mbps
- DC-HSDPA Receiver
  - Dual Carrier (Intra-Band)
    - Capable of both adjacent and non-adjacent carrier operation
      - In the case of non-adjacent operation, the carriers are assumed to be 10MHz apart.
  - 2 Rx-Diversity on each carrier
  - MIMO disabled
  - 64-QAM operation on each carrier
    - Aggregate Peak Rate of 43.2 Mbps

6.1.2.3 High Level UE Receiver Block Diagram

Figures 43 and 44 illustrate high level receiver block diagrams for both the baseline SC-HSDPA MIMO enabled UE and the DC-HSDPA non-MIMO enabled UE.

The receiver can be partitioned into 3 parts:

- RF/Front End
- Base-Band Detector
- Base-Band Decoder

In the subsequent sections, we further discuss the UE implementation impact when we compare these two types of receivers.

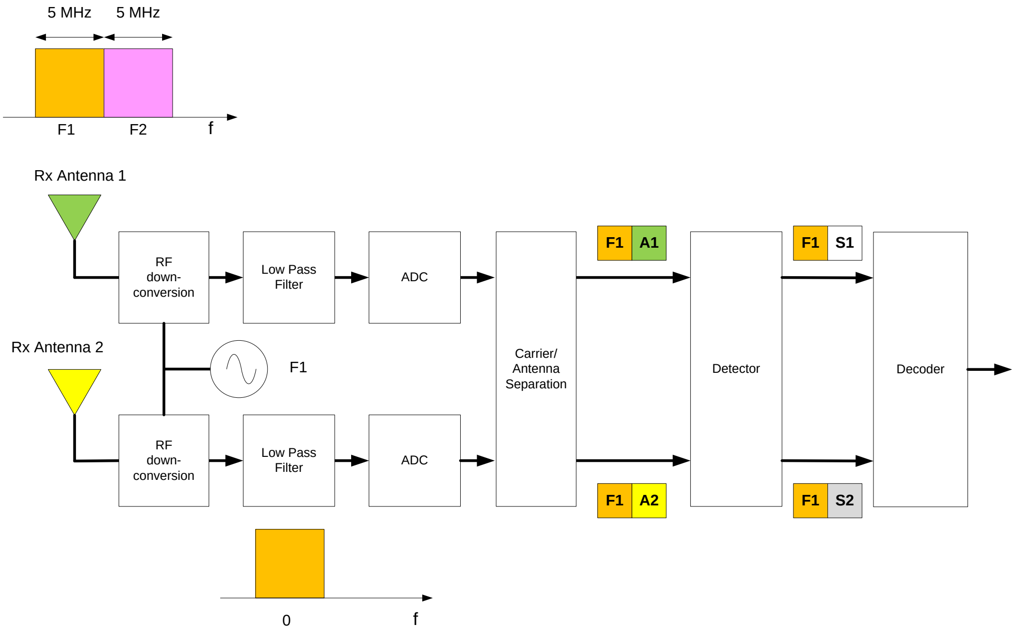


Figure 43: Baseline SC-HSDPA UE Receiver: High Level Block Diagram

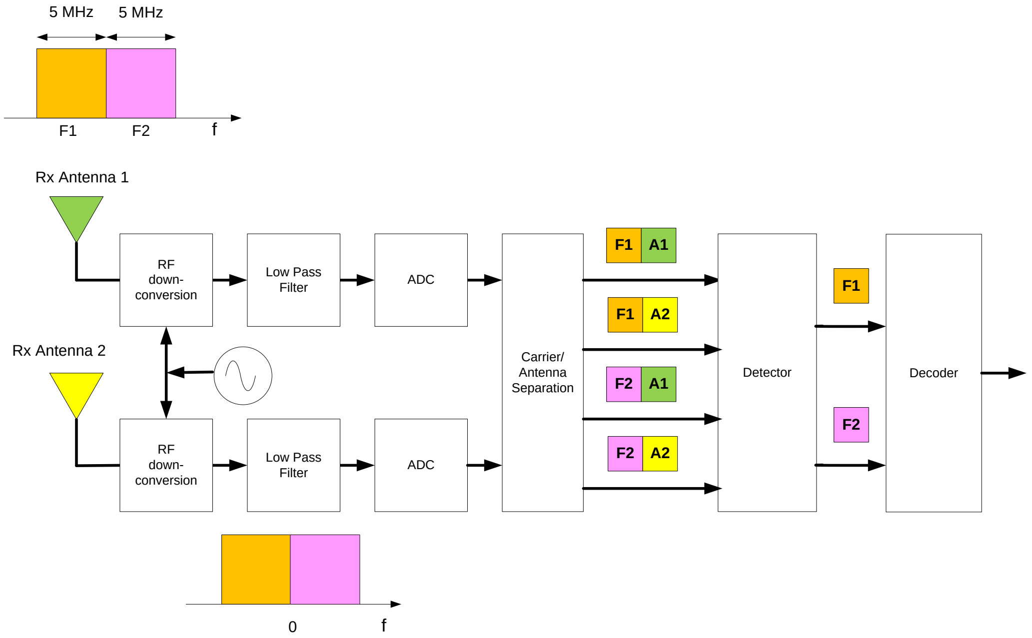


Figure 44: DC-HSDPA UE Receiver: High Level Block Diagram

6.1.2.4 RF and Digital Front End

Figures 45 and 46 illustrate examples of RF and digital front end receiver portions for both the baseline SC-HSDPA MIMO enabled UE and the DC-HSDPA non-MIMO enabled UE.

As seen in these block diagrams, the RF processing impact is very minimal when migrating from the baseline SC-HSDPA MIMO enabled UE to a DC-HSDPA non-MIMO enabled UE:

- In both cases, a single local oscillator implementation is assumed for the purpose of RF down-conversion.
- The analog low pass filter (LPF) is now a wider bandwidth (10MHz) when compared to the baseline case (5 MHz bandwidth).
- Even though the block diagrams illustrate the case for the adjacent carrier allocation case, the only modification to handle the non-adjacent case (10MHz apart) is to tune the analog LPF bandwidth to 15MHz, which is very feasible with today’s state of the art RF/analog technology.
- The ADC sampling rate increases linearly in accordance with the analog LPF bandwidth.
- For the DC-HSDPA case, a base-band implementation is assumed at the output of the ADC output, for the purpose of carrier and antenna separation.
  - For each carrier and antenna pair, a digital down-conversion and digital filter is required.
  - The complexity of the digital filter is comparable to an FIR implementation of the W-CDMA Square Root Raised Filter (roll-off factor = 0.22).
  - Note that in the case of SC-HSDPA, no digital down-conversion is necessary; however the base-line receiver still makes use of two such digital filters (one for each antenna).
  - The output bandwidth of the carrier/antenna separation is 2x compared to the base-line case.

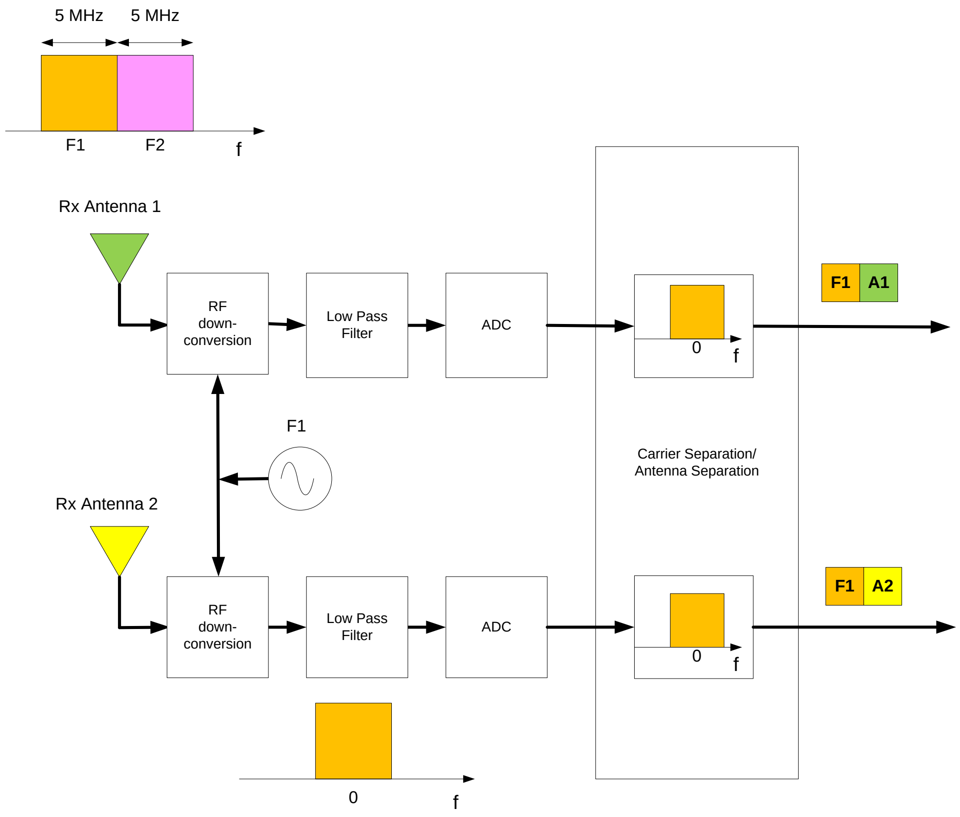


Figure 45: Baseline SC-HSDPA Receiver: RF/Front End Block Diagram

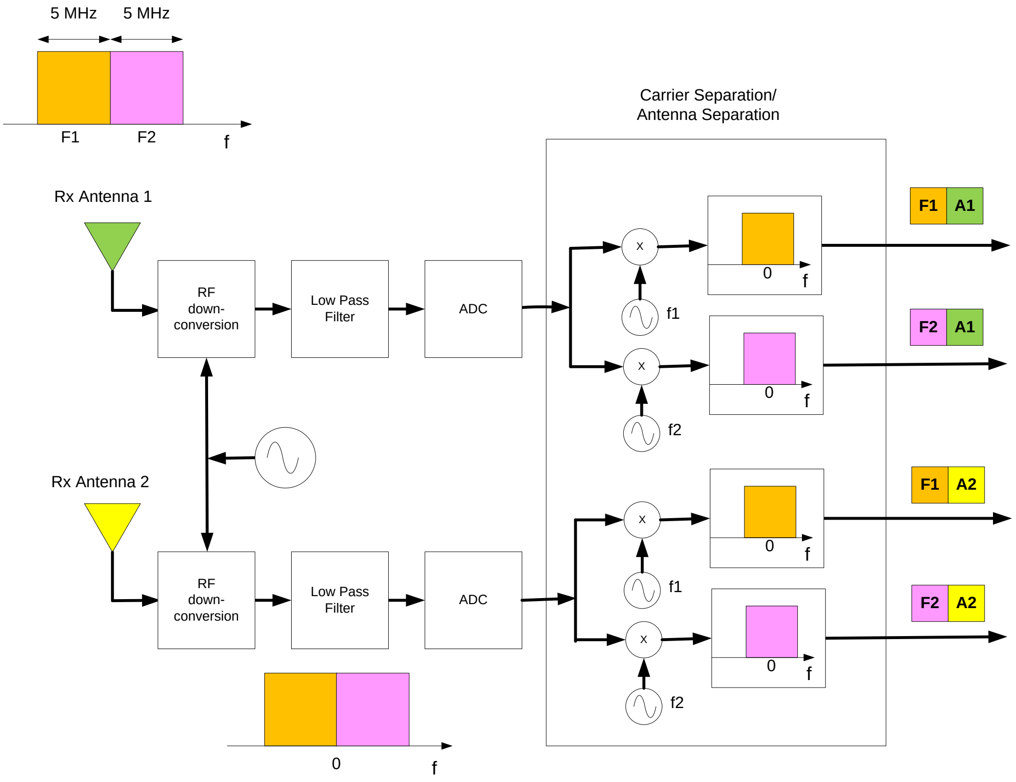


Figure 46: DC-HSDPA Receiver: RF/Front End Block Diagram

In summary, the impact to the RF/Front end of the UE implementation could be summarized in Table 17 as follows:

Table 17: Relative RF/Front End complexity figure of merit

	Baseline SC-HSDPA	DC-HSDPA
Number of Rx Antenna chains	2	2
Number of RF Local Oscillators	1	1
Number of RF down-conversion units	2	2
Number of Analog LPF	2	2
Analog LPF bandwidth	5 MHz	10 MHz (Adjacent Carriers) 15 MHz (Non-Adjacent Carriers)
Normalized ADC Sampling Rate	1	2 (Adjacent Carriers) 3(Non-Adjacent Carriers)
Number of Digital Oscillators	0	4
Number of Digital FIR filters	2	4
Normalized input bandwidth to base-band detector	1	2

6.1.2.5 Base-band Detector

In this section, we examine the differences in base-band processing of the HS-PDSCH detector portion between the baseline SC-HSDPA and DC-HSDPA receiver structures. Figures 47 and 48 depict high level block diagrams for the detector portions of these receivers.

Since the baseline UE is capable of MIMO processing, it is required to estimate the channel impulse response on all 4 channels (there are 4 transmit antenna pairs in a 2x2 system). Also we assume that the baseline UE receiver uses a linear MMSE receiver operating in 2x2 mode as shown in Figure 47.

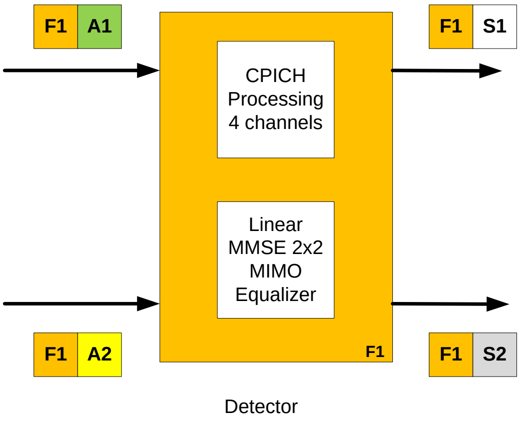


Figure 47: Baseline SC-HSDPA Receiver: Base-band Detector Block Diagram

For each carrier and receive antenna pair, the DC-HSDPA receiver also needs to perform channel estimation for 4 different wireless channels. Furthermore, as shown in Figure 48, we assume that the DC-HSDPA UE receiver uses two LMMSE receivers, each operating in 1x2 mode.

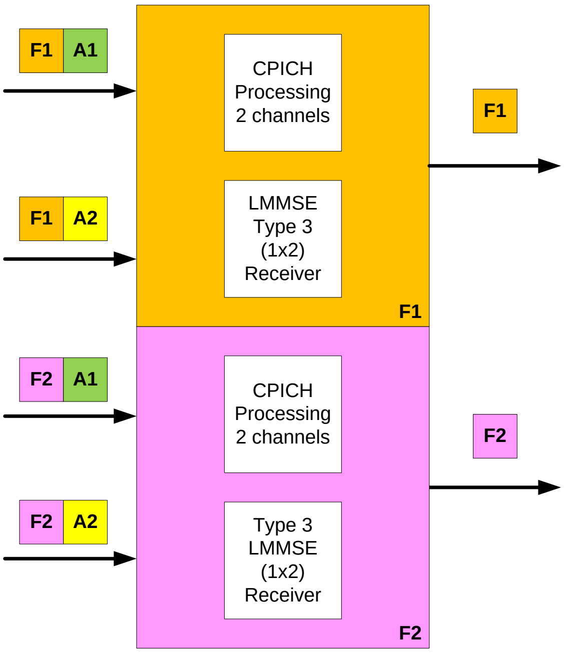


Figure 48: DC-HSDPA Receiver: Baseband Detector Block Diagram

In the next sub-section, we compare the complexity of LMMSE processing of two 1x2 LMMSE receiver structures and a single 2x2 LMMSE receiver structure.

6.1.2.5.1 LMMSE Processing

The complexity of the LMMSE processing block has been well documented for both the 1x2 or 2x2 configurations in [2]-[5]. In the following, we revisit the complexity analysis performed in these technical contributions.

R1-051510, "UE complexity evaluation for UTRA-FDD MIMO", Qualcomm Europe

Based on the UE complexity analysis in [2], Table 18 summarizes the relative complexity of 1x2 LMMSE when compared to 2x2 LMMSE (MIMO). From this table, we conclude that DC-HSDPA (Two 1x2 LMMSE receivers) is very similar in complexity to SC-HSDPA utilizing a 2x2 LMMSE when MIMO is enabled.

Table 18: Relative LMMSE complexity figure

Configuration	*Relative Complexity*
1x2 LMMSE	1
2x2 LMMSE	1.94

R1-060428, "Further Consideration of MIMO for Rel.7 WCDMA", Texas Instruments

In [3], the following conclusion was made on the complexity of 2x2 LMMSE when compared to 1x2 LMMSE.

We can conclude that ***compared to the baseline complexity of 1X2 LMMSE:***

- ***The complexity of 2X2 LMMSE is approximately 2X.***

R1-060565, "UE complexity for WCDMA MIMO", Ericsson

An overview of the additional required memory and computational complexity has been given for a WCDMA MIMO configuration. We conclude that

- Different MIMO RX structure options exist, allowing trade-offs between the complexity and MIMO performance
- Estimated complexity growth may be assessed as roughly linear with the number of MIMO streams (offered bit rate), which should be construed as acceptable.
- Area and cost are subject to Moore's law, which applies even in a few years' time scale. We can thus expect the availability of terminals with MIMO features and corresponding bit rates at today's cost or lower.

From the above, we conclude that DC-HSDPA UEs which will utilize two Type 3 LMMSE (1x2) receiver structures, will be very similar in complexity to a SC-HSDPA MIMO enabled UE capable of 2x2 LMMSE processing.

6.1.2.6 Base-band Decoder

As far as the base-band decode processing is concerned, since the peak rates are assumed to be the same in both the baseline SC-HSDPA receiver and the DC-HSDPA receiver, we do not expect any UE implementation impact.

Figures 49 and 50 illustrate a high level block diagram of the base-band decoding process for both the baseline SC-HSDPA receiver and the DC-HSDPA receiver respectively. In the baseline case, the IR buffer requirement and Turbo decoder requirement is based on the requirement to process two MIMO streams. Each stream can have a peak data rate requirement of 21.6 Mbps (64-QAM) or 14.4 Mbps (16-QAM). In the DC-HSDPA case, instead the IR buffer requirement and Turbo decoder requirement is based on the requirement to process two cells. Each cell transmission to a UE can have a peak data rate requirement of 21.6 Mbps (64-QAM) or 14.4 Mbps (16-QAM).

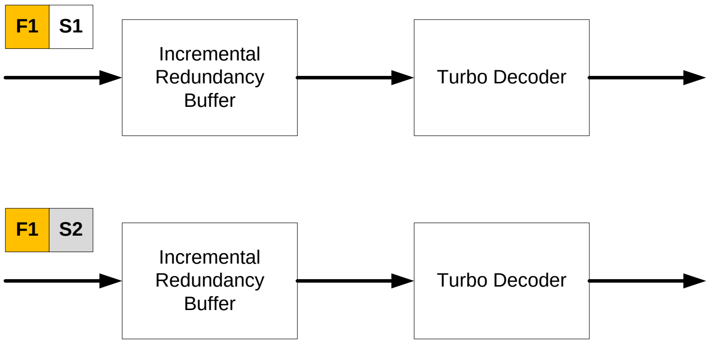


Figure 49: Baseline SC-HSDPA Receiver: Base-band decoding

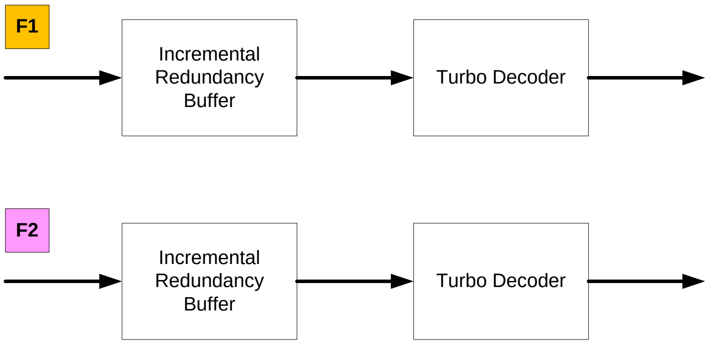


Figure 50: DC-HSDPA Receiver: Base-band decoding

Hence we conclude that due to the constraint that the peak data rates are the same in both systems (SC-HSDPA and DC-HSDPA), there is no impact to the base-band implementation of the IR buffer and the turbo-decoder.

6.1.2.7 UE Transmitter

Since we assume a 2DL:1UL configuration,, there is a need to design a control structure for H-ARQ feedback and CQI reporting for the second carrier. One of the techniques that have been investigated is the addition of another HS-DPCCH in the UE transmitter. For a detailed analysis of the CM impact because of the additional HS-DPCCH, see section 4.3.2.1.1. As a result, a minimum amount of physical layer changes may be expected on the UL transmitter implementation as follows:

- Introduce a second uplink channel to carry the HS-DPCCH information for the 2nd carrier.
- Due to the introduction of a new channel, the TFC-MPR and E-TFC-MPR tables as specified in 25.133 may need to be re-defined.

6.1.2.8 Conclusions on UE Complexity

A detailed UE complexity analysis was performed to investigate the impact of DC-HSDPA on the UE complexity. For the purpose of comparison, the baseline UE was assumed to be a MIMO enabled SC-HSDPA UE. The analysis was performed on both the RF/Front-end portion as well as the base-band detector and decoder portions of the UE.

The UE complexity comparison can be summarized in Table 19.

Table 19: UE Complexity Comparison between SC-HSDPA (MIMO enabled) and DC-HSDPA

	Baseline SC-HSDPA	DC-HSDPA
RF/Front End		
Number of Rx Antenna chains	2	2
Number of RF Local Oscillators	1	1
Number of RF down-conversion units	2	2
Number of Analog LPF	2	2
Analog LPF bandwidth	5 MHz	10 MHz (Adjacent Carriers) 15 MHz (Non-Adjacent Carriers)
Normalized ADC Sampling Rate	1	2 (Adjacent Carriers) 3(Non-Adjacent Carriers)
Number of Digital Oscillators	0	4
Number of Digital FIR filters	2	4
Normalized input bandwidth to base-band detector	1	2
Base-Band Detector		
LMMSE Processing	1	1.03
Base-Band Decoder		
IR Soft Metric Buffer	1	1
Turbo Decoder	1	1

As seen in Table 19, for each of the sub-systems, the complexity impact is negligible or non-existent:

- For the Base-Band decoder sub-system, which constitutes a significant percentage of the UE implementation in terms of logic and memory, there is no impact at all, due to the same peak-rate assumption between both the baseline SC-HSDPA and DC-HSDPA receiver.
- For the Base-Band detector portion, there is a 3% impact to complexity when comparing two 1x2 LMMSE receiver structures with a single 2x2 LMMSE receiver structure.
- For the RF/Front-End portion, there is no additional increase in RF chains due to DC-HSDPA operation. The minor differences can be summarized as follows:
  - Larger Analog LPF bandwidth
  - Faster ADC sampling rate
  - Digital down-conversion logic for each carrier/antenna pair.
  - 2 more digital FIR filters (span = 4 to 8 chips) operating at 1x or 2x chip rate.

From this analysis, we conclude that DC-HSDPA UE terminal is of similar complexity to that of a SC-HSDPA MIMO enabled UE terminal. Given the availability of SC-HSDPA MIMO enabled UEs in the near future, this proves that the implementation of DC-HSDPA UEs is highly feasible.

6.2 Impact on specifications

6.2.1 Impact on L1 specifications

DC-HSDPA operation can be introduced without major modifications to the physical channels. The coding and modulation of the data can be done per carrier as today. The signaling of the modulation and coding scheme can be done using the Type-1 HS-SCCH format available in Release 7 using one HS-SCCH on each carrier. Other solutions would be possible as well.

Signaling of HSDPA feedback information (CQI and HARQ ACK/NACK) for the supplementarysupplemenary carrier is needed. A second HS-DPCCH channel can be introduced to achieve this (see subclause 4.3.2.1.1). Other solutions would be possible as well.

6.2.2 Impact on RRC specifications

6.2.2.1 URA_PCH and CELL_PCH states

It is FFS whether changes to the Idle mode, URA_PCH state and CELL_PCH state procedures are needed. The measurement reporting (the measurement results on RACH) may need to be updated.

6.2.2.2 Number of carriers from sectors in the active set

There are two possible ways to manage the active set and the serving cell:

1. The UE is either assigned one carrier from every sector in the active set, or it is assigned two carriers from every sector in the active set, i.e. the same number of carriers from every sector in the active set
2. The UE is assigned one or two carriers from every sector in the active set, i.e. possibly a different number of carriers from every sector in the active set

Alternative 1 makes the standard changes simpler, but alternative two does not add significant implementation complexity. Additionally, alternative 2 allows for the deployment of hotspots.

The working assumption is that the DC-HSDPA feature can support the deployment of hotspots, i.e. it will be possible to assign an active set containing sectors A and B; where sector A operates with DC-HSDPA and sector B operates with a single carrier HSDPA.

6.2.2.3 Channel assignment

Changes to messages like the Radio Bearer Setup and the Radio bearer Reconfiguration messages are needed.

6.2.2.4 Intra-frequency and Inter-frequency measurement

6.2.2.4.1 Reporting event 1D: Change of best cell

The control and reporting of this event may need to be changed.

6.2.2.4.2 Event 2a: Change of best frequency

The control and reporting of this event may need to be changed.

This event will need to be redefined to compare frequencies other than the ones assigned to the UE to one of the two assigned frequencies or to a combination of both.

6.2.3 Impact on UE RF requirements

For UE-complexity reasons, we would like to prioritize our investigations on Dual-Carrier operation to the case of the transmission of adjacent carriers. This approach makes it possible to build receivers that can reuse the same antenna and RF circuitry for both carriers, thereby reducing complexity, power consumption and cost compared to the operation with non-adjacent carriers. Furthermore, in order to be able to use the same RF parts for reception of 10 MHz LTE as for Dual Cell operation, an effort should be made to align the RF requirements between the standards.

This section treats a selected set of the core requirements from [12], for which there is a possible impact on the requirements. These apply to the case of the transmission of adjacent carriers and further study will/would be needed to evaluate the impacts in case of transmission of non-adjacent carriers is considered.

6.2.3.1 New DL reference measurement channel

The existing receiver characteristics test requirements in [12] are defined for the 12.2kbps DL reference measurement channel. In the description of the feasibility study however; it is explicitly stated that the dual cell operation only applies to the HS-DSCH. Under this assumption, due to the lack of a DPCH in the supplemental carrier, there may be a need to define a new DL reference measurement channel.

A couple of options could be studied:

- Since DC-HSDPA is intended primarily for data, one option could be to define new reference DL reference measurement channels for each of the carriers using the HS-PDSCH and introduce a requirement on the sum data throughput across both the carriers for each of the receiver characteristic tests.
- Another option could be to define a new DL reference measurement channel, based on the HS-PDSCH for only the supplemental carrier and introduce a requirement on the data throughput on the supplemental channel, while still maintaining the same BER requirement on the DPCH (12.2kbps DL reference measurement channel) on the anchor carrier.

In the following, for all the test requirements discussed, we assume that a new DL reference measurement channel will be defined as above, to characterize the receiver operation. The details of this new DL reference measurement channel are FFS.

6.2.3.2 UE maximum output power

The introduction of dual carrier operation in the downlink, without adding an extra carrier in the uplink necessitates the transmission of an additional HS-DPCCH, carrying CQI information for the supplementary DL carrier. Different concepts for adding this extra channel can be anticipated and this may or may not have a significant impact on the cubic metric of the uplink signal. As long as the cubic metrics of the resulting signals that include an additional HS-DPCCH are within the range of cubic metrics for legacy UL signals, there should not be any need for changes in the allowed power reduction.

6.2.3.3 Reference Sensitivity Level

Assuming operation with adjacent carriers, relaxations to the reference sensitivity should generally not be needed, although it could be considered for certain bands.

Since a new DL reference measurement channel based on HS-PDSCH maybe defined for the supplemental carrier and/or the anchor carrier, there maybe a need to define a new receiver sensitivity level for this channel. A new table similar to Table 7.2 may be defined to accommodate this new receiver sensitivity level.

Option 1: DL reference measurement channel based on HS-PDSCH for both anchor and supplemental carriers.

In this case, a new set of parameters needs to be defined for the reference sensitivity for both the anchor and supplemental carriers as shown in Table 7.2.1 and Table 7.2.2 respectively.

Table 7.2.1: Test parameters for reference sensitivity for Anchor Carrier

Operating Band	Unit	HS-PDSCH_Ec <REFSENS>	<REFI$_{or}$>

Table 7.2.2: Test parameters for reference sensitivity for Supplemental Carrier

Operating Band	Unit	HS-PDSCH_Ec <REFSENS>	<REFI$_{or}$>

Option 2: DL reference measurement channel based on DPCH for the anchor carrier and based on HS-PDSCH for the supplemental carrier.

In this case, the test parameters for reference sensitivity for Anchor carrier are identical to Table 7.2 in [12] as shown in Table 7.2.3. A new set of parameters need to be defined for the reference sensitivity for the supplemental carrier as shown in Table 7.2.4 similar to Option 1.

Table 7.2.3: Test parameters for reference sensitivity for Anchor Carrier

Operating Band	Unit	DPCH_Ec <REFSENS>	<REF$\hat{I}_{or}$>

Table 7.2.4: Test parameters for reference sensitivity for Supplemental Carrier

Operating Band	Unit	HS-PDSCH_Ec <REFSENS>	<REF$\hat{I}_{or}$>

6.2.3.4 Maximum Input Level

The current requirement for single carrier HSDPA, specifies a maximum input power of -25 dBm. For LTE, the maximum input power regardless of bandwidth is -25 dBm.

In order to facilitate efficient receiver structures, LTE and HSDPA Dual-Cell requirements on maximum input level should be aligned such that the total received power of the two carriers does not exceed -25 dBm.

6.2.3.5 Adjacent Channel Selectivity (ACS)

Following the concept used in LTE, where ACS requirements are converging towards being the same for 5 and 10 MHz, there should be no need for additional relaxations with dual carriers. Absolute power levels should be selected such that they do not violate the Maximum Input Level requirement.

We could apply the same ACS requirement as specified in Tables 7.4 and 7.5 in [12], except that, for the supplemental carrier, the DPCH Ec in Table 7.5 in [12] can be replaced by the HS-PDSCH Ec. If the DL measurement channel is based on the HS-PDSCH for the anchor carrier, then DPCH Ec may also be replaced by HS-PDSCH Ec.

Furthermore:

- In this case, the offset frequency of the interferer Fuw (offset) should be defined with respect to the closest carrier to the interferer.
- The received powers ($\hat{I}_{or}$) of both the carriers (anchor and supplemental) can be set to the same value.

6.2.3.6 In band blocking

We could apply the same In-band blocking requirement as specified in Table 7.6 in [12], except that, for the supplemental carrier, the DPCH Ec in Table 7.6 can be replaced by the HS-PDSCH Ec. If the DL measurement channel is based on the HS-PDSCH for the anchor carrier, then DPCH Ec may also be replaced by HS-PDSCH Ec.

Furthermore:

- In this case, the offset frequency of the interferer Fuw (offset) should be defined with respect to the closest carrier to the interferer.
- The received powers ($\hat{I}_{or}$) of both the carriers (anchor and supplemental) can be set to the same value.

6.2.3.7 Narrowband blocking

We could apply the same narrow band blocking requirement as specified in Table 7.7A in [12], except that for the supplemental carrier, the DPCH Ec in Table 7.7A can be replaced by the HS-PDSCH Ec. If the DL measurement channel is based on the HS-PDSCH for the anchor carrier, then DPCH Ec may also be replaced by HS-PDSCH Ec.

Furthermore:

- In this case, the offset frequency of the interferer Fuw (offset) should be defined with respect to the closest carrier to the interferer.
- The received powers ($\hat{I}_{or}$) of both the carriers (anchor and supplemental) can be set to the same value.

6.2.3.8 Out of band blocking

For an efficient receiver architecture which uses a single RF chain for the whole 10 MHz bandwidth, the operation of Dual-Cell operation using adjacent carriers will impose more stringent requirements on channel filtering. This is due to the scaling of the passband of the receive filters which leads to a corresponding scaling of the transition region. However, when it comes to requirements on filters that provide selectivity for out of band blockers, which normally has a passband equal to the whole band of interest, the bandwidth of the filters will remain unchanged regardless of the number of carriers that are simultaneously received. It is therefore proposed that the tests for out of band blocking can be performed using a single received carrier without any risk of performance degradation to the system.

6.2.3.9 Intermodulation Characteristics

We could apply the same receiver intermodulation characteristic requirement for both wide-band and narrow band interferers as specified in Tables 7.9 and 7.9A in [12], except that for the supplemental carrier, the DPCH Ec in Table 7.8 can be replaced by the HS-PDSCH Ec. If the DL measurement channel is based on the HS-PDSCH for the anchor carrier, then DPCH Ec may also be replaced by HS-PDSCH Ec.

Furthermore:

- In this case, the offset frequency of the interferer Fuw (offset) should be defined with respect to the closest carrier to the interferer.
- The received powers ($\hat{I}_{or}$) of both the carriers (anchor and supplemental) can be set to the same value.

6.2.3.10 “In-band” ACS

The amount of power imbalance between the two received adjacent carriers can have a negative impact on the received signal quality for the weaker carrier if it becomes too large. Whether there is a need for such an imbalance, whether it should be allowed in RAN1 specifications and whether there is a need for specific test cases addressing these issues is FFS.

6.2.3.11 Spurious Emissions

We could apply the same spurious emissions requirement for both wide-band and narrow band interferers as specified in Tables 7.9 and 7.9A in [12], except that for the supplemental carrier, the DPCH Ec in Table 7.8 can be replaced by the HS-PDSCH Ec. If the DL measurement channel is based on the HS-PDSCH for the anchor carrier, then DPCH Ec may also be replaced by HS-PDSCH Ec.

Furthermore:

- In this case, the offset frequency of the interferer Fuw (offset) should be defined with respect to the closest carrier to the interferer.
- The received powers ($\hat{I}_{or}$) of both the carriers (anchor and supplemental) can be set to the same value.

6.2.4 Impact on UE demodulation performance requirements

As there should be very little performance difference between the UE demodulation performance when in DC-HSDPA operation as compared to single carrier operation, it should be possible to create a selected set of demodulation performance requirements by scaling of existing requirements, for the case when both anchor and supplemental carriers are similarly configured. Thus, while it would still be necessary to create new FRC definitions and formulate new requirements, the actual throughput values used in the new requirements might be possible to derive from existing requirements by scaling them with a factor of two. The need for additional requirements for HS-SCCH are still for FFS.

6.2.5 Impact on NodeB RF requirements

Quite many of the existing requirements in the Node-B transmitter already cover the multi-carrier operation but some slight modification in some aspects may be needed when introducing Dual-Cell HSDPA. On the receiver side depending on the outcome of control channel structure some receiver tests might need modification.

The following is a short summary of requirement areas that may need modifications assuming the UTRA physical layer is maintained as much as possible.

6.2.5.1 Frequency bands and channel arrangement

By introduction of Dual-Cell HSDPA, the relation/association between the two carriers needs to be established and signaled towards the UE. This may only influence other working groups e.g. RAN2 but may have some impact on RAN4 and need to be investigated.

6.2.5.2 Transmitter characteristics

All requirements related to transmitter characteristics can be kept as is when the Dual Cell HSDPA is introduced. The only requirement that may need some modification is the frequency accuracy where possibly requirements on relative frequency accuracy needs to be introduced. This relates to UE receiver and needs further discussions within RAN4.

The out-of band emissions e.g. ACLR, spurious emission etc already cover the scenarios that the node-B operates with multiple carriers and need no modification when Dual-Cell HSDPA is introduced.

In TS 25.104, both ACLR and spurious emission contains the following requirement:

"The requirements shall apply whatever the type of transmitter considered (single carrier or multi-carrier). It applies for all transmission modes foreseen by the manufacturer's specification."

The modulation quality as well should cover Dual-Cell operation as long as the EVM and PCDE are measured per carrier.

6.2.5.3 Receiver characteristics

Since Dual-Cell operation only concerns the DL, the only impact in the RBS receiver requirements would be on performance of HS-DPCCH. Depending on the design of the new HS-DPCCH carrying ACK/NACK and CQI from two cells, a new requirement would be needed for Node-B.

7 Conclusion

Annex A: Proportional Fair Schedulers

In a single-carrier case, for a proportional fair scheduler, the priority for user k may be computed as follows:

$$\left.\frac{R_{request}}{\tilde{R}_{served}}\right|_{k} \qquad (1)$$

where $R_{request}$ is the instantaneous requested rate based on CQI, and $\tilde{R}_{served}$ is the average served data rate computed as the IIR filtered average of instantaneous served rate R_{served} with time constant T_c:

$$\tilde{R}_{served} = R_{served}/T_c + (1-1/T_c)\tilde{R}_{served}.$$

The default value of T_c is 1024 slots (0.68 second).

The proportional fair principle can be extended to schedulers in DC HSDPA. One straightforward implementation is to use the single carrier proportional fair scheduler independently on each carrier.

Another implementation of a DC-HSDPA proportional fair is to define the scheduling metric on carrier I as the following:

$$\left.\frac{R_{request,i}}{\tilde{R}_{served,total}}\right|_{k} \qquad (2)$$

Here $R_{request,i}$ is the instantaneous requested rate on carrier i based on CQI and $\tilde{R}_{served,total}$ is the total average served rate:

$$\tilde{R}_{served,total} = (R_{served,1} + R_{served,2})/Tc + (1-1/Tc)\tilde{R}_{served,total},$$

where $R_{served,1}$ and $R_{served,2}$ are the instantaneous served rates on the two carriers. Here the scheduler in each carrier makes individual decision in choosing users. The only information exchange between the carriers is $R_{served,total}$ of all the users.

Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2008-04					TR skeleton agreed in RAN1#52b	0.0.1	0.1.0
2008-05					TR update as agreed after RAN1 #53 and RAN4 #47 (TPs agreed via email approval)	0.1.0	0.2.0

2008-05	40	RP-08….			TP approved and TR version raised to 1.0.0; presented for information to TSG RAN #40	0.2.0	1.0.0