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DUAL-CELL HSDPA OPERATION AND ITS PERFORMANCE EVALUATION

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ABSTRACT

One main target for the evolution of 3G mobile communication is to provide the possibility of significantly higher end-user data rates compared to what is achieved with the first releases of the 3G standards. This also refers to higher data rates over the entire cell area including users at the cell edge. 3GPP standards body has significantly enhanced the peak user throughput as part of Release-7 with features as MIMO and Higher Order Modulation (HOM) and this has helped to improve the average user throughput to some extent. One approach to increase the typical user experience consists in pooling the radio resources of two or more carriers in the same base station and enabling a collaborative operation on the lower radio layers (i.e. L2 layer) for a better resource utilization efficiency by dynamic radio resource management over multiple carriers. Within 3GPP such operation has been investigated under the work item "Dual-Cell HSDPA operation on adjacent carriers" (hereafter DC-HSDPA).

In this paper, a detailed description on DC-HSDPA is presented. DC-HSDPA operation has the purpose of enhancing the user experience throughout the whole cell range, in particular in outer area of the cell coverage (at the cell edge where MIMO cannot be operated with dual stream transmission). In terms of system performance, DC-HSDPA operation enables efficient and flexible spectrum asset utilization offering efficient inherent load balancing across the carriers.

KEYWORDS: DC-HSDPA, Carrier Aggregation, Resource Utilization Efficiency, Channel Quality Indicator, Quadrature Amplitude Modulation

INTRODUCTION

Dual cell HSDPA (DC-HSDPA) is a 3GPP Release 8 feature, which aims at increasing the peak data rate per user. It can be defined as natural evolution of HSPA by means of **carrier aggregation** in the downlink. UMTS licenses are often issued as 10 or 15 MHz paired spectrum allocations. The basic idea of the mutli-carrier feature is to achieve better resource utilization and spectrum efficiency by means of coordinated resource allocation and load balancing across the downlink carriers. This coordinated resource optimization over multiple carriers requires dynamic RRM in CELL DCH state to achieve higher peak data-rates per HADPA user within a single Transmission Time Interval (TTI), as well as enhanced terminal capabilities. The overall goal is to provide enhanced and consistent user experience across the cell especially at the edges where the channel conditions are not favorable and techniques such as MIMO cannot be used.

DC-HSPA provides twice the average burst rate compared to two separate carriers. Simply speaking the scheduler can send a packet twice as fast and a burst of one user is likely to be sent before a burst of another user arrives. Parallel transmission with 64-QAM modulation on each carrier can theoretically provide an aggregate downlink peak data rate of 43.2Mbps in 10MHz without the support of MIMO. The Single-Carrier and Dual-Carrier HSDPA transmission is shown in Figure 1.

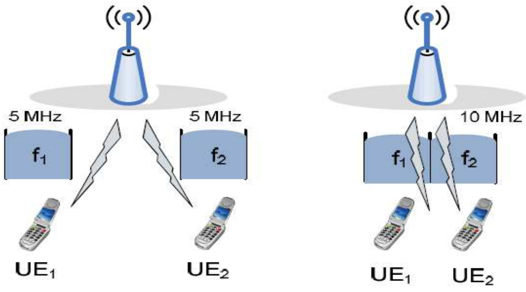

Figure 1: Single Carrier v/s Multicarrier Transmission [10]

The Dual-Carrier HSDPA is based on the primary and secondary carrier. Both carriers provide all the downlink physical channels for the User Equipment (UE) both for downlink data transmission as well as the channels supporting the uplink data transmission. The physical channels are High Speed Downlink Shared Channel (HS-DSCH), High Speed Signaling Control Channel (HS-SCCH) and High Speed Dedicated Physical Control Channel (HS-DPCCH).

In Dual-Carrier HSDPA without MIMO, the UE estimates Two Channel Quality Information (CQI) for both carriers separately to the link adaption. The UE also provides in the uplink, two Hybrid Automatic Repeat Request (HARQ) acknowledgements for both downlink carriers separately.

GAIN OF DUAL CARRIER

An advanced HSPA network can theoretically support up to 28Mbps and 42Mbps with a single 5MHz carrier for Rel7 (MIMO with 16QAM) and Rel8 (MIMO with 64QAM), in good channel condition with low correlation between transmit antennas. An alternative method to double the data rates could be to use double the bandwidth, i.e. 10MHz. Additionally, some diversity and joint scheduling gains can also be expected with improved QoS for end users in poor environment conditions.

However, any fair assessment of DC gains requires comparison of a collaborative dual-carrier setup with an independent use of 2 single carriers as reference. Hence, the true gains of DC operations result from two factors:

- The dynamic statistical multiplexing of users offers improved load sharing compared to static load sharing at connection management level. Additionally, it allows double the instantaneous data rates by assigning all the code and power resources to a single user in a TTI.
- The possibility to assign resources to a user dynamically either on the serving or the secondary serving cell (or even both), leads to additional frequency selectivity and improved QoS from coordinated scheduling.

Besides throughput gain, also gains in the reduction of latency can be seen particularly for IP based bursty traffic sources that can efficiently be assigned with DCHSPA. For low resource utilization, DC-HSPA provides twice the average burst rate compared to two separate carriers. This is achieved by making the scheduler send a packet twice as fast by transporting the bursty packet of one user before the bursty packet of another user is received. By doing so, Parallel transmission with 64-QAM modulation on each carrier can theoretically provide an aggregate downlink peak data rate of 43.2 Mbps in 10MHz without the support of MIMO.

PHYSICAL CHANNELS

The simplified transmission system of HSDPA is shown in Figure 2. The Node B scheduler sends data to the user by the shared downlink channel based on the UE channel quality report. Based on the outcome of the decoding, the UE will then reply with an Acknowledgement (ACK)/Negative Acknowledgement (NACK) message by the HS-DPCCH.

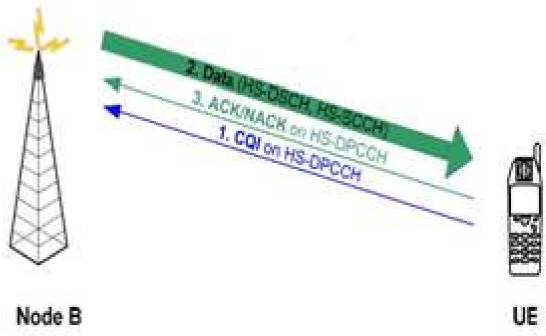

Figure 2: Simplified HSDPA Transmission System [9]

The High Speed Downlink Shared Channel (HS-DSCH) supports modulation and adoptive coding. The Dual-Carrier HSDPA used 64 Quadrature Amplitude Modulation (QAM).

The High Speed Signaling Control Channel (HS-SCCH) signals the dynamic resource allocation to the users by the Node B scheduler (per 2 ms Transmission Time Interval (TTI)). The HS-SCCH carries the following information:

- The addressing specific UEs like UE identity via a UE specific Cyclic Redundancy Check (CRC).
- Transport Format and Resource Indicator (TFRI), which identifies the transmission format and the scheduled resource.
- The combining process is to identify redundancy versions, the Hybrid-ARQ-related information use in HS-SCCH.

Up to 4 HS-SCCHs can be monitored by a user.

The High Speed Dedicated Physical Control Channel (HS-DPCCH) supports the HARQ and channel based scheduling for feedback signaling in the uplink. The HS-DPCCH carries the following information:

- Channel Quality Information (CQI) is used to inform about the instantaneous channel condition to the scheduler.
- HARQ ACK/NACK is used to inform the decoding process to the sender and request for retransmission.

CHARACTERISTICS

Feature is characterized as simultaneous reception of more than one HS-DSCH transport channel. Certain categories of UEs may be configured into Dual Cell operation in CELL_DCH state. When UE is configured into Dual Cell operation and a common transmitting Mac-ehs entity is used for data transmission, the HS-DSCH channels shall be operated in following manner:

- The receiving Mac-ehs entity supports more than one HS-DSCH transport channel.
- Each of these HS-DSCH transport channels has its own associated uplink and downlink signaling, and own HARQ entity (further composed of multiple HARQ processes)

- Reordering, duplicate detection, segmentation and reassembly functions are common for these HS-DSCH transport channels and HARQ entities.

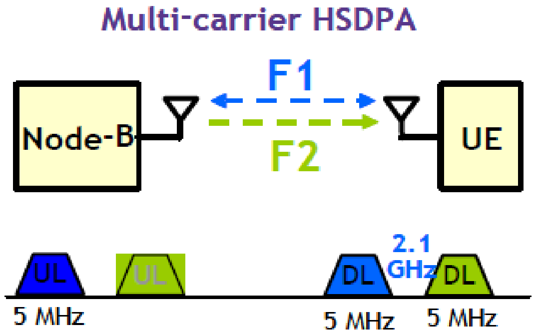

Figure 3: Multi-Carrier HSDPA Operation [11]

Two HS-DSCH transport channels for single UE are transmitted on two adjacent carriers as shown in Figure 3. These carriers are classified as Anchor and Supplementary carrier as follows:

- **Anchor Carrier:** All uplink physical channels from the UE are sent only on anchor carrier. Cell corresponding to this carrier is called as Serving Cell.
- **Supplementary Carrier:** This carrier is only used for sending downlink HSDPA physical channels and there is no uplink physical channel expected from UE on this carrier. Cell corresponding to this carrier is called Secondary Serving Cell.

Two cells corresponding to anchor and supplementary carriers belong to the same Node-B and operate with a single TX antenna (Inter-working with MIMO is excluded of dual carrier operation so that at most two data streams per UE are configured). When UE is configured into Dual Cell operation:

- It can be served dynamically (on per TTI granularity) on either or both of the allocated cells at the same time.
- The UE shall simultaneously monitor an HS-SCCH set in the secondary serving HS-DSCH cell, and receive HS-DSCH if it is scheduled in that cell as shown in Figure 3. The maximum size of the HS-SCCH set in a secondary serving HS-DSCH cell is 4 and the maximum number of HS-SCCHs monitored by the UE across both the serving HS-DSCH cell and the secondary serving HS-DSCH cell is 6. It shall be able to receive up to 1 HS-SCCH on serving cell and 1 HS-SCCH on secondary serving cell simultaneously.

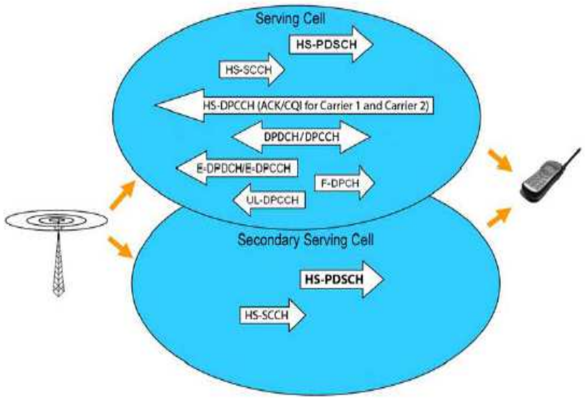

Figure 4: Dual Cell Physical 391 Channel Structure [11]

- It should have the capability to feedback ACK/NACK and CQI for both the cells simultaneously.
- UE will assume that all the HS-PDSCH channelization codes and HS-SCCH from single cell shall be under a single scrambling code. However, serving and secondary serving cells can have different scrambling codes.
- Legacy mobility procedures are supported based on the serving cell only. The secondary serving HS-DSCH cell does not belong to the active set of the UE.
- From UE perspective and inter-frequency measurements (2A, 2B, etc), frequency of secondary serving HS-DSCH cell shall be treated as non-used frequency

UE CATEGORIES

Four new UE HS-DSCH physical layer categories (21-24) have been introduced which support Dual Cell HSDPA operation as shown in Table 1.

UEs of categories 21 shall also support one of category 9, 10, 13, 14, 15, 16, 17 or 18 when dual cell operation is not configured. UEs of categories 22 shall also support one of category 10, 14, 16 or 18 when dual cell operation is not configured. UEs of categories 23 shall also support one of category 13, 14, 17, 18, 19 or 20 when dual cell operation is not configured. UEs of categories 24 shall also support one of category 14, 18 or 20 when dual cell operation is not configured.

Table 1: HS-DSCH Physical 418 Layer Category [11]

HS-DSCH category	Maximum number of HS-DSCH codes received	Minimum inter-TTI interval	Maximum number of bits of an HS-DSCH transport block received within an HS-DSCH TTI NOTE 1	Total number of soft channel bits	Supported modulations without MIMO operation or dual cell operation	Supported modulations simultaneous with MIMO operation and without dual cell operation	Supported modulations with dual cell operation
Category 21	15	1	23370	345600	-	-	QPSK, 16QAM
Category 22	15	1	27952	345600			
Category 23	15	1	35280	518400			QPSK, 16QAM, 64QAM
Category 24	15	1	42192	518400			

Mac-ehs ARCHITECTURE

A single Mac-ehs entity as shown in Figure 4 on the UTRAN 472 and UE side will support HS-DSCH transmission/reception in more than one cell served by same NodeB. However, there is separate HARQ entity per HS-DSCH channel, i.e. one HARQ process per TTI for single carrier and two HARQ processes per TTI for dual carrier transmission/reception. Hence, at physical layer, dual carrier transmission can be logically viewed as independent transmissions over two HS-DSCH channels, each having associated downlink and uplink signaling.

A separate transport block with same or different Transport Format Resource Combination (TFRC) is transmitted on both carriers based on the HARQ and CQI feedback received on associated uplink HS-DPCCH channel. The HARQ retransmissions will be transmitted with the same Modulation and Coding scheme (MCS) at the first transmission on the same HARQ entity as the latter.

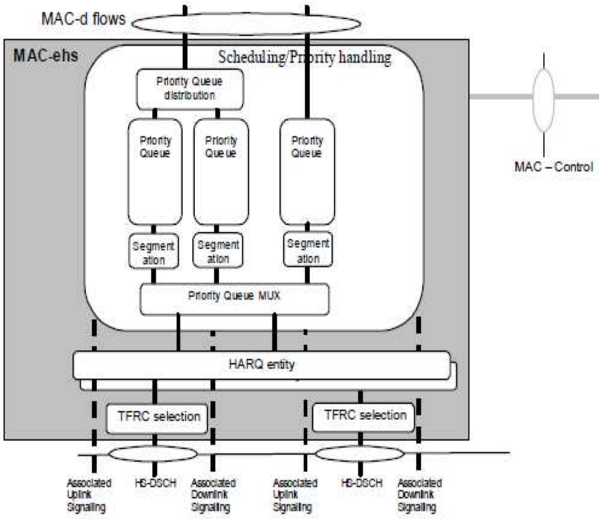

Figure 5: UTRAN Side Mac-ehs Architecture [11]

DUAL-CELL HSDPA OPERATION

In Release 8, if the number of users is low, then Dual-Cell HSDPA can double the user data rate because each user can utilize two parallel frequencies. When the number of users increases, then the probability is low that each user utilizes the full capacity of both parallel frequencies. But even at high system load, Dual-Cell HSDPA provides lots of capacity benefits for users compared to two single carriers. The gains and principles of the Dual-Cell HSDPA are shown in Figure 6.

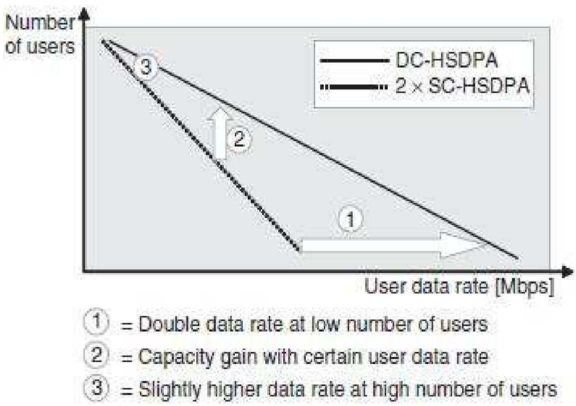

Figure 6: Data Rate Gain of Dual-Cell HSDPA [3]

In the following, features are discussed about the capacity gain of Dual-Cell HSDPA:

Frequency Domain Packet Scheduling Gain

In both carriers of HSDPA, the UE provides separate CQI reports and no faded data or packets transmit on the frequency by the Node B packet scheduler. When moving some distance like tens of centimeters, the fast fading is uncorrelated and location dependent. Between two UEs, the fast fading is independent. The frequency domain scheduling and its principles shown in Figure 7.

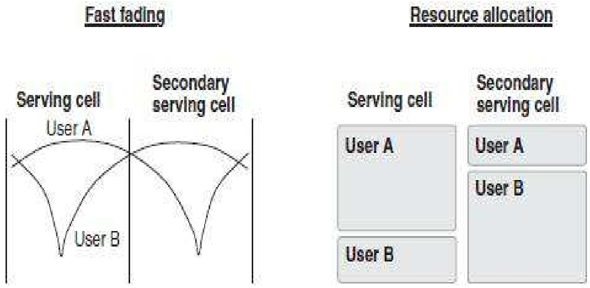

Figure 7: Frequency Domain Scheduling with DC-HSDPA [3]

In the serving cell, if user A allocated huge amount of resources and user B allocated little amount of resources, then in the secondary serving cell, user B will be allocated a huge amount of resources and user A will be allocated a little amount of resources. For obtaining capacity gains, LTE also uses frequency domain scheduling. LTE provides higher capacity gains by using the frequency domain scheduling compared to HSDPA because HSDPA frequency resolution is 5 MHz and LTE is 180 kHz.

Statistical Multiplexing or Tracking Gain

Dual-cell HSDPA can be balanced the load between two frequencies with 2ms TTI resolution but the two SC-HSDPA needs for balanced the load redirections or slow inter-frequency handovers. So the load is not ideally balanced for the two SC-HSDPA.

Multiuser Diversity Gain

The proportional fair algorithm can be utilized by HSDPA packet scheduling in the time domain. When there is a huge number of UEs, then the HSDPA packet scheduling algorithm gives a higher gain. For the optimized scheduling, now Dual-Cell HSDPA allows and accepts the users from two frequencies.

COMPARISON BETWEEN REL'7 MIMO AND DOWNLINK DC-HSDPA

Rel'7 MIMO

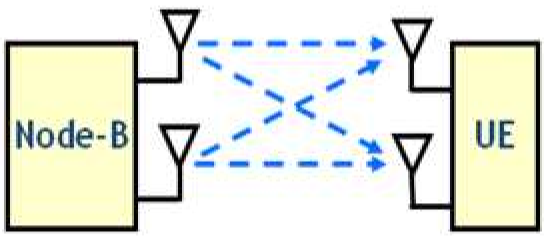

Figure 8

Two parallel data streams are sent to the UE using the same carrier (5 MHz), by exploiting rich scattering in a 2x2 spatial channel

- Requires 2 Transmit and 2 Receive antennas and radio paths.
- Doubles the number of boards per sector-carrier v/s non-MIMO Rel'7.
- When the channel is rank deficient or has low SINR, can only send a single stream.
- Suffers from inter-stream interference; space-time LMMSE or SIC at UE to suppress ISI (complexity).

DC-HSDPA

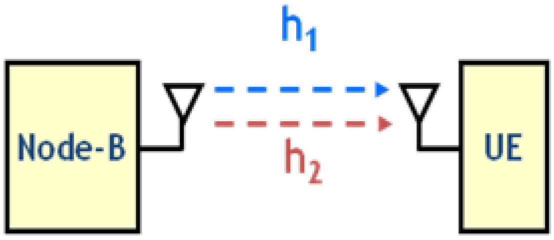

Figure 9

Two parallel data streams are sent to the UE using two carriers (5 MHz + 5 MHz)

- Only needs 1 Transmit and 1 Receive antenna and radio path.
- Same number of boards per sector-carrier v/s non-MIMO Rel'7.
- No inter-stream interference.
- Increased UE complexity to support dual carrier reception and increase in HS-SCCH channel monitoring.

CONCLUSIONS

The extreme growth of wireless data usage is leading the continuing evolution of today's mobile broadband networks. HSPA has introduced a base for high speed data connectivity in more than 150 countries with almost 412 commercial networks and over 700 million subscribers worldwide. The Dual-Cell HSDPA is the natural and greatest economical evolution for HSPA. The Dual-Cell HSDPA allows operators and subscribers to make the highest efficient use of their existing investments and assets in network, spectrum and devices at low cost. The Dual-Cell HSDPA increased the network

Capacity and now operators are able to offer voice services and mobile broadband at low cost. The Multi-Carrier HSDPA enhances the end user experience by increase the data rates, lower latency and increase talk time.

Carrier aggregation allows obtaining twice the peak rate for a single user than on a single carrier. In contrast to dual stream MIMO, a doubling of the user rate can be achieved in all channel conditions (i.e. even at the cell edge) and without the expenses of dual Transmit antennas and power amplifiers.

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