White Paper – Dual Cell HSDPA and its Future Evolution

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Summary

3GPP has recently started activities on joint scheduling across two HSDPA carriers to increase the peak data rates per user and better utilize the available resources by multiplexing carriers in CELL DCH state. This dual carrier approach called DC-HSDPA offers both higher resource utilization efficiency and frequency selectivity in order to achieve better performance gains particularly for UEs in unfavourable channel conditions.

This paper gives an overview of the related study and work items on dual carrier operations. We discuss the changes required to support the flexible operation of dual carrier and highlight the expected gains. Furthermore, some preliminary technological proposals for future evolution of Multi-Carrier HSPA are introduced and briefly evaluated. Nomor Research has been involved in 3GPP standardisation, simulation and demonstrations since the establishment of the work item and offers related services.

Introduction

UMTS Release 99, based on dedicated resource allocation per user, was not well suited for IP packet data traffic. Therefore High Speed Packet Downlink Access (HSDPA) and Enhanced Dedicated Channel (E-DCH) have been introduced as new features of UMTS for Downlink and Uplink in UMTS Release 5 and Release 6, called High Speed Packet Access. [1] provides an overview about the HSPA technology. Dual Cell (DC-)HSDPA is the natural evolution of HSPA by means of carrier aggregation.

The initial UMTS deployments mostly aimed for coverage maximization, and hence, single carrier capacity was sufficient to meet the subscriber requirements. By now rapid subscriber growth took place due to several factors not limited to HSPA global deployments, better user experience for broadband multimedia applications, high speed internet and availability of cheap UMTS/HSPA handsets. Consequently, the operators (in most cases) deployed (or are even deploying) HSPA networks with multiple WCDMA carriers to meet the capacity requirements. This multicarrier deployment is further supported by the fact that UMTS licenses are often issued as 10 or 15 MHz paired spectrum allocations. Nevertheless, in all practical scenarios, these multiple carriers are operated independently on L2 & L1, whereby coordination only takes place at the level of connection management for the purpose of load balancing. Since IP based traffic is bursty in nature and unpredictable, a well balanced load between carriers with such a slow adaptation rate is not feasible.

Thus, the basic idea of the multicarrier feature is to achieve better resource utilization and spectrum efficiency by means of joint resource allocation and load balancing across the carriers. This joint resource optimization over multiple carriers requires dynamic RRM in CELL DCH state to achieve higher peak data-rates per HSDPA 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 favourable and existing techniques such as MIMO cannot be used.

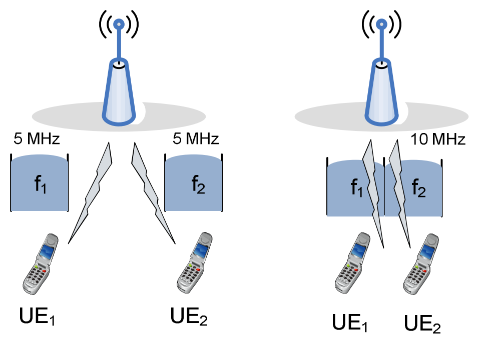

Figure 1: Single carrier versus Dual-Carrier Transmission

Dual Carrier HSPA Standardisation

Dual carrier operation has been promoted in the

3GPP standardization by Qualcomm [5] and Ericsson [6], and a RAN1/4 Study Item (SI) entitled "Feasibility Study on Dual Cell HSDPA Operation" was proposed and approved [3][4] in TSG RAN #39. In TSG RAN #40 the SI was further maintained considering the good progress status, and a Work Item (WI) entitled "Dual-Cell HSDPA Operation on Adjacent Carriers" was approved [11]. The WI was completed in December 2008 TSG RAN#42 with the final status report [12] and with a complete set of change requests to the specification. The work item "Conformance Test Aspects – Dual-Cell HSDPA operation on adjacent carriers" [13] was started to allow for conformance testing for the new specification.

Definitions

The following definitions [1] will be used frequently in the remaining part of this paper:

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.

Gains of Dual Carrier

An advanced HSPA network can theoretically support up to 28Mbps and 42Mbps with a single 5MHz carrier for Rel7 (MIMO) and Rel8 (Higher Order Modulation + MIMO), 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 [6] 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 anchor or the supplementary carrier (or even both), leads to additional frequency selectivity and improved QoS from joint scheduling.

The respective gains are demonstrated in Figure 2 [8] for a scenario with full buffer traffic and a Proportional Fair scheduler. As can be observed, the DC gain is more pronounced at low load (25% at 2 users/sector) compared to high load (7% at 32 users/sector).

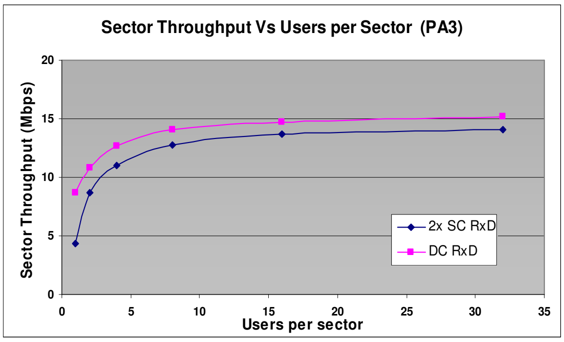

Figure 2: Capacity gains of DC-HSDPA over 2*SC HSDPA

This is because low geometry users see a higher variation in their proportional fair metric. 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 DC-HSPA. For low resource utilization 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 each carrier can theoretically provide a aggregate downlink peak data rate of 43.2 Mbps in 10MHz without the support of MIMO.

Physical Channels

HS-DPCCH: A couple of design options were considered, such as introducing a second HS-DPCCH or the modification of HS-DPCCH to carry CQI and ACK/NACK of both carriers. After a thorough analysis, RAN1 agreed to map the HSDPA related feedback information to a single HS-DPCCH [17] instead of two. Main arguments to select a single HS-DPCCH design have been a better cubic metric performance and related coverage benefit. The number of Channel Quality Indicator (CQI) bits is 5 or 10, depending on whether the secondary carrier is active or not. The composite CQI is formulated from 2 independent CQI's, one for each carrier. In addition, new channel coding schemes have been specified for composite HARQ feedback.

HS-SCCH: The HS-SCCH is transmitted on both the anchor and supplementary carriers, whereby the UE has to monitor up to 4 HS-SCCH codes on each carrier. 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 [18].

The UE shall be able to receive up to 1 HS-SCCH on serving cell and 1 HS-SCCH on secondary serving cell simultaneously. This approach will provide flexibility to scheduling.

Impact on UEs

Legacy UEs (HSDPA category 1-20) do not support dual carrier operation. Hence, new HSDPA UE categories 21-24 have been introduced [15] with the following operational considerations:

- Co-existence with legacy UEs.
- Capability to be served dynamically (on per TTI granularity) on either or both of the allocated carriers at the same time.
- Capability to feedback ACK/NACK and CQI for both the carriers simultaneously.
- HS-SCCH less operation and uplink power control to be carried on anchor carrier.
- The Node-B may dynamically enable and disable the supplementary carrier to save UE battery power depending upon the downlink traffic and channel considerations by means of HS-SCCH orders.
- No support of MIMO and dual cell simultaneously.
- Capability to perform measurements on the supplementary carrier without compressed mode [16].
- Mobility procedures are supported based on serving HS-DSCH cell.

In a baseline DC-HSPA configuration Transmit Diversity (STTD) and Receive Diversity (2 Rx-Antennas) are used on each carrier.

Scheduling Considerations

One of the major tasks within 3GPP Rel8 WI was the proposal of optimized operations across L2 (even more specifically at the MAC layer). While the downlink Node-B queues could be operated jointly or disjointly, the first option was chosen, as it offers more flexibility in scheduling operations according to the assumption for simulations in [7].

A single MAC-ehs entity as shown is figure 3 on UTRAN and UE side will support HS-DSCH transmission/reception in more than one cell served by the same Node-B. Therefore the DC operation can be introduced with minor changes on the Layer 2 design. However, there will be 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 [19]. Hence, at the physical layer, dual carrier transmission can be viewed as independent transmissions over 2 orthogonal HS-DSCH channels, each having associated downlink and uplink signalling as shown.

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 the associated uplink HS-DPCCH channel. The HARQ retransmissions will be transmitted with the same Modulation Coding Scheme (MCS) as the first transmission on the same HARQ entity as the latter.

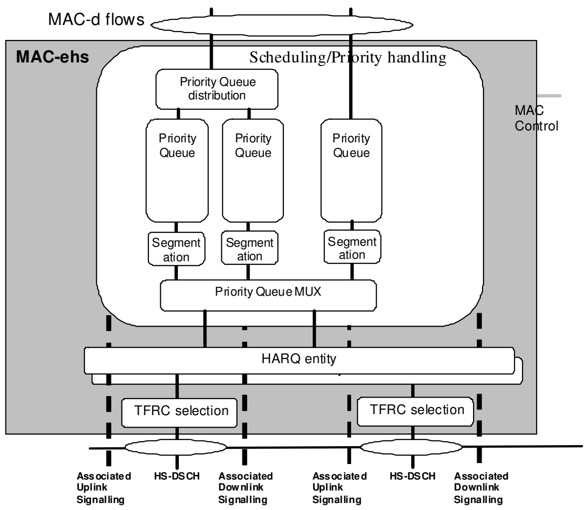

Figure 3: UTRAN MAC-ehs Architecture

Scheduling is the most important feature determining the gain that can be achieved by collaborative (DC) over independent (2*SC) configurations. In a first step, all the existing SC schedulers need to be updated to support DC scheduling in a backward compatible manner.

Systematic optimization of DC scheduling algorithms then poses a challenging task, which needs to take into account the dynamic and static system, as well as the application parameters in a joint manner. For example, dual carrier-capable UEs may utilize the available resources on both carriers in every TTI (statistical multiplexing gain), prefer the carrier with the higher CQI in case of single carrier allocation (frequency selectivity), or allow for dual carrier allocation whenever this brings a benefit. However, the legacy UEs will be only considered for scheduling on their respective anchor carrier.

Future Multi-Carrier HSPA Evolution

As data usage will continue to grow there is a continuous need to increase user and system throughput. The specification work on DC-HSPA is close to completion and there is already work ongoing to add further enhancements as part of UMTS Release 9. A work item for this work called Multi Carrier Evolution that comprises various technology enhancements has already been proposed by Qualcomm, Ericsson, Huawei and others [14]. Discussed improvements could be categorized in the following way:

I. Inter-Band Dual-Carrier HSDPA Operation

DC-HSDPA operation in Rel.8 is restricted to two adjacent carriers operating in the same frequency band. A more flexible aggregation of carrier would simplify deployment in fragmented spectrum allocations and would also allow the efficient re-farming of 2G technologies to 3G HSPA.

II. Dual-Carrier HSUPA Operation

DC-HSDPA is currently limited to the downlink operation only. For DC-HSUPA in the uplink similar performance gain as seen for the downlink can be expected.

III. Combinations of DC-HSDPA and MIMO

The use of MIMO is not allowed for DC-HSDPA in Rel.8, but would surely offer higher peak data rates to fulfil the further increasing broadband requirements without introducing new features. Basically the aggregate downlink peak data rate within 10 MHz would be increased from 43.2 Mbps to 86.4 Mbps in 10MHz.

IV. Multiple Carrier (MC-)HSDPA Operation

Instead of two carriers the MC-HSDPA operation would allow three or four adjacent carrier to be scheduled jointly. Since the data rate scales with the bandwidth, this could significantly enhance peak data rates as well as the system capacity. An aggregate downlink peak data rate of 86.4 Mbps could be achieved with 4 carriers covering 20 MHz without MIMO or of 129.6 Mbps with the use of MIMO.

Of course those improvements come at the expense of UE and Node B complexity. RF complexity, the increase of feedback information such as CQI and HARQ ACK/NACK as well as the control channel overhead for configuration and resource allocation are of particular importance.

In summary HSPA will continue to evolve into a competitive standard also for the long term. With the described improvements the HSPA technology has been enhanced significantly. Within UMTS Release 9 we can expect the system to evolve further from a dual-cell to a multi-carrier system with several other enhancements that are being discussed in 3GPP standardisation right now. Official completion data of Release 9 is end of 2009. With those improvements the MC-HSPA technology could become competitive to LTE Release 8 even in larger or in fragmented spectrum allocations. Compromises that come with a technology that has been improved over time are be compensated by early availability and maturity of a well established technology.

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