Exhibit 1016

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Title: Code limitation and code reuse in HSDPA

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1 Introduction

The orthogonal code space is an important system resource for WCDMA DL transmission. Orthogonal transmission is achieved by allocating OVSF codes to different control and data channels. For HS-DSCH, multiple SF=16 codes can be used for DL transmission within a subframe. The HS-DSCH provides a highly efficient radio link and can potentially support a large number of users. However, the capacity of HS-DSCH can be limited considerably due to a shortage of available orthogonal codes.

1.1 Causes of Code Limitation in HSDPA

The shortage of codes can result due to various reasons including inefficient code space usage by associated DPCH for HSDPA users (basically carrying pilot and power control information) and other dedicated channels [1]. For R'99 data services, an inactivity timer is typically employed to ensure that code resources are released for other users. However, there are certain data applications (e.g. chatty applications, TCP acknowledgements) for which long inactivity timers may be needed in order to ensure low delay. As a result, these applications tend to use up significant fractions of the code space but have very low power requirements. Voice users could also make inefficient use of code space since codes remain assigned during periods of inactivity. This leads to power code imbalance, an effect further compounded by soft handoff on the downlink. Enhancements that provide power benefit (e.g. beamforming) also need corresponding improvements in the code dimension so that the system capacity benefits can be realized. These effects can result in a disproportionately large amount of power available for HS-DSCH as compared to codes.

1.2 Effect of Code Limitation on HSDPA

In this section, we show how code limitation can substantially constrain the throughputs achieved in HSDPA. Precisely, we present the OTA and service throughput attained using single antenna (i.e., no transmit diversity) and CLTD Mode-1. In particular, we consider two cases: one where only 25% of the code space is available for HSDPA (i.e., the system is code space constrained) and another where 62.5% of the code space is available (i.e., the system is not code space constrained). In both cases, 63% of the overall power fraction is assumed to be available for HSDPA. Figure 1 and Figure 2 below plot the OTA and service throughput attained in each of the above cases in a single path Rayleigh fading channel model. Observe that in the code-constrained case, the service throughput and OTA remain virtually unchanged as the load in the system – measured in terms of the number of UEs – increase. This clearly illustrates the effect on system capacity due to the code-power imbalance in the code-constrained case.

With the availability of 2 transmit antennas, transmit diversity schemes such as closed loop (TxAA) can be used for HS-DSCH [2]. These transmit diversity techniques provide link level performance improvements leading to overall system capacity improvement. However, the gains achieved by the transmit diversity schemes can be small when the system is code limited. This is due to the fact that transmit diversity provides power benefit by achieving a given performance with smaller power (E_c/I_{or}) required compared to a single antenna transmission but does not help solve the code limitation problem.

The code limitation problem can be partly resolved by using higher coding rates and high order modulations. However, high coding rates and higher order modulations come with associated penalties thus impacting the overall

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system capacity. Furthermore, in some cases, higher order modulations may not be available – the highest order modulation available for HS-DSCH is 16QAM. Moreover, the introduction of HSDPA UE classes that only support QPSK ensures that higher rates can be achieved only by using a larger number of codes. MIMO techniques can also solve the code limitation problem but require multiple transmit *and* multiple receive antennas.

In what follows, we address the code limitation problem through OVSF *code reuse* approaches that allow higher system capacity to be achieved without requiring multiple receive antennas.

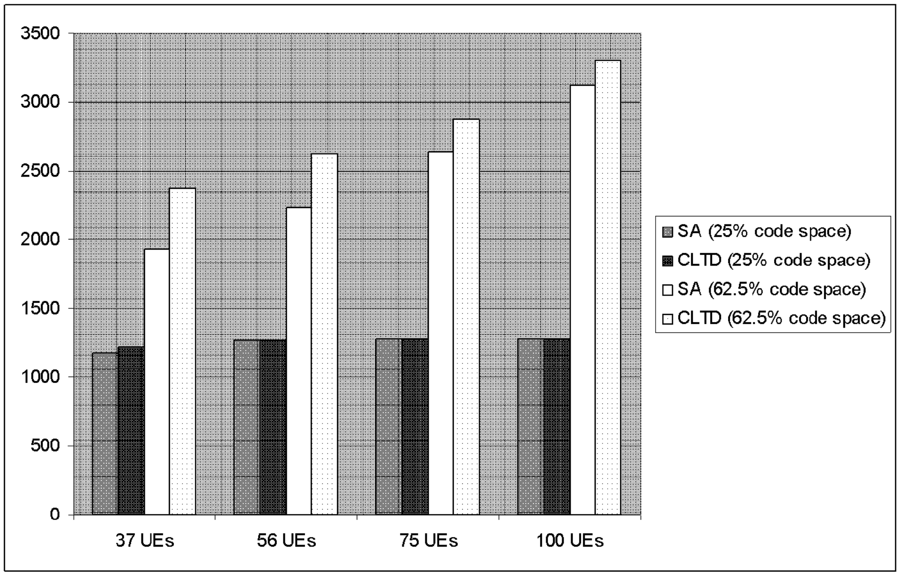

Figure 1. OTA with single antenna and CLTD Mode-1.

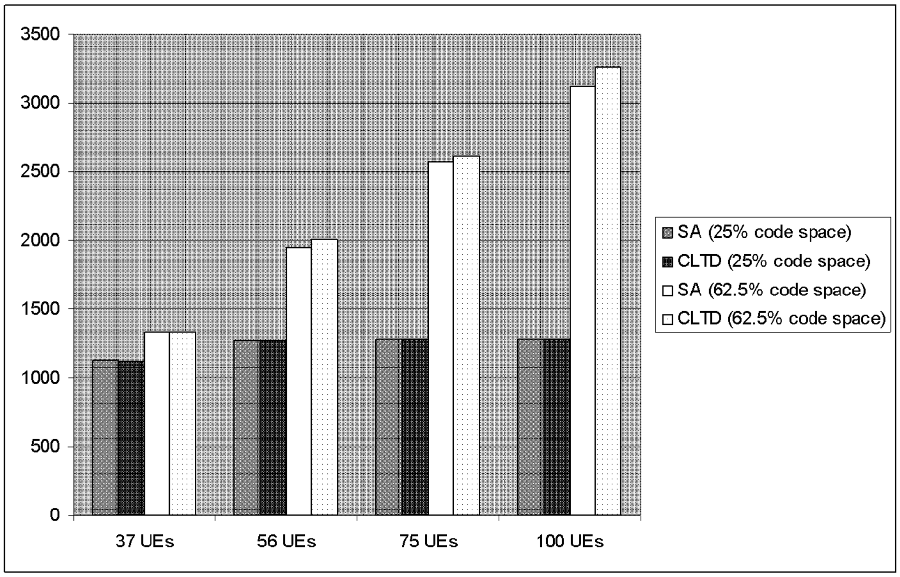

Figure 2. Service throughput with single antenna and CLTD Mode-1.

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2 Code Reuse

The reuse of OVSF codes results in additional in-sector interference that needs to be managed through suitable techniques (interference averaging, interference cancellation and/or interference rejection) in order to achieve the desired benefits without a significant power penalty.

R'99 specifications allow the OVSF code space to be expanded through the use of one or more Secondary Scrambling Codes (SSCs) [3] (also see related references on code space expansion through QoFs and related topics [4][5]). Here, we explore both the use of SSCs and/or multi-antenna scheduling techniques to achieve code reuse in HSDPA with effective management of resultant interference.

2.1 Code Reuse Options

Two alternatives for code reuse in HSDPA are now described:

- Option-1: Partial Code Reuse – Here, only the codes set aside for HSDPA are candidates for reuse (see Figure 1). Reusing the codes set aside for dedicated channel users is not an option as they do not get any processing gain benefit in rejecting the cross interference. This approach does not expand the code space to the maximal extent but has the advantage of maintaining orthogonal transmissions to the dedicated channel users, thereby leaving the interference to them unchanged. The basic transmission approach suggested here is to simultaneously schedule data intended for different UEs by utilizing two transmit antennas and reusing the available OVSF space for HSDPA UEs. The fundamental principle exploited in the simultaneous scheduling of multiple users with code reuse is to ensure that users selected on each antenna have good "cross-antenna rejection" [6], i.e., a user scheduled on antenna 1 has a strong channel from that antenna *and* a comparatively weak channel from antenna 2. Users on antenna 2 are selected in the same manner. This will keep the cross interference experienced by each user low. With sufficient load, pairs of users that satisfy this condition can be found in the cell with high probability. The power distribution across the two antennas can be performed in a number of ways. A useful method is to split the *total* cell power equally across the two antennas (in a manner similar to STTD and CLTD Mode-1).

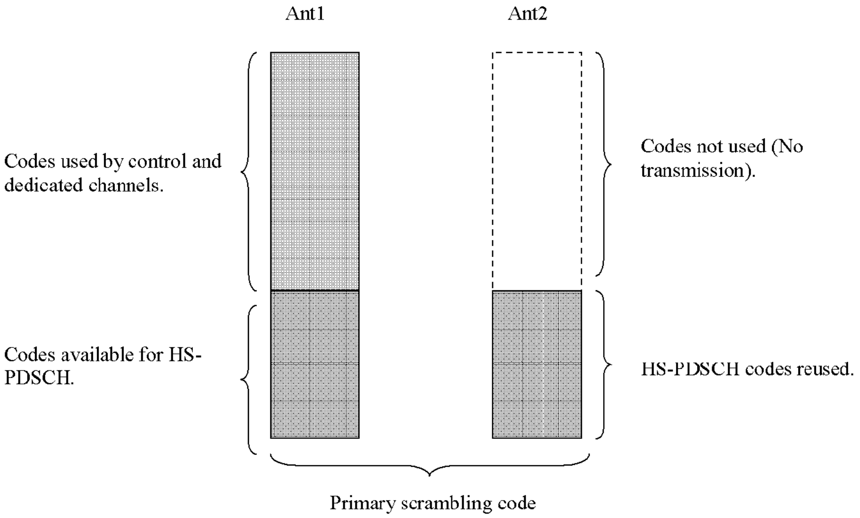

Figure 1. Partial code reuse scheme

- Option-2: Full Code Reuse – If a secondary scrambling code is activated, then the entire OVSF code space on the SSC is available. So HSDPA users can be scheduled on a part of the Primary Scrambling Code (PSC) space originally assigned and the *entire SSC code space*. The introduction of a SSC allows full reuse of the OVSF code space and can be achieved in the following ways:

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1. Introduction of SSC on Same Antenna(s) as PSC: The use of a SSC on the same antenna(s) as a Primary Scrambling Code (PSC) may lead to excessive interference to UEs on both the PSC and the SSC since the instantaneous channel gains on the desired signal and interference components are perfectly correlated. Multi-user detection techniques can be applied to cancel out the resulting interference, albeit at the cost of additional UE complexity [5].

2. Introduction of Antenna Specific SSC: This allows cross antenna interference rejection through scheduling, in a manner similar to that in Option 1 above, in addition to the interference rejection benefits of the SSC itself. .

Although dedicated channel users on the PSC get the processing gain benefit in rejecting SSC interference, unlike in Option 1, some additional interference due to the SSC cannot be avoided. This increase in interference will therefore have to be offset by increasing the power allocation to dedicated channel users. Although this does result in a reduction in the overall power fraction left for the data users, the increase in the code space available due to the introduction of the SSC still results in system capacity improvement in code-limited situations.

Depending on the severity of code limitation encountered, full or partial code reuse may be employed in order to expand the OVSF code space. These techniques can be combined with other interference avoidance techniques (e.g. beamforming) in order to further improve performance. The signalling support needed for full or partial code reuse is for further study. Additional signalling – both in the uplink and downlink – will improve the performance of code reuse and improve the robustness of the schemes.

3 Conclusions

Code reuse is proposed as a method of increasing the OVSF code space for HS-DSCH. The schemes can alleviate the code limitation problem and enhance HSDPA throughput in these situations. The quantitative benefits of these schemes and the signalling support necessary to accommodate them are for further study.

References

[1] "DL structure in support for HS-PDSCH", R1-01-0478, Qualcomm.

[2] "Transmit diversity for HSDPA", R1-02-0530, Lucent.

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[5] L. Jalloul and A. Shanbhag, "Enhancing Data Throughput Using Quasi-Orthogonal Functions Aggregation for 3G CDMA Systems," Proceedings, Spring VTC, 2002.

[6] Achilles Kogiantis and Lawrence Ozarow, "Downlink Best Effort Packet Data with Multiple Antennas," submitted to International Conference on Communications, ICC 2003, Anchorage, Alaska, May 11-15, 2003.

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