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Agenda item: AH24, HSDPA
Source: Lucent Technologies.
Title: Semi-static Code Space Division of physical HS-DSCH
Document for: Discussion and decision

1. Introduction

In the High Speed Downlink Packet Data Access (HSDPA) feasibility study being conducted to enhance UMTS downlink, the notion of high speed downlink shared channel (HS-DSCH) is being considered. The resources of power and code space are first provisioned for power controlled dedicated channels (e.g. voice). Then the power and code space resources leftover are made available to the physical HS-DSCH to be shared between packet data users mainly in the time domain and possibly in the code domain over 'short' frame duration or TTI. For example, [1] considers 3.3333 ms while 0.6666 ms and its variable multiples are considered in [2]. It is proposed that this channel employs adaptive modulation and coding (AMC) to enable matching the rate to the user's channel quality (e.g. SNR) and hence guarantee error performance of each user. The AMC approach is expected to take advantage of the diverse temporal variations of the fading channel across different users and schedule with priority at each TTI the UE (s) that have favorable channel conditions. This idea works especially well for delay tolerant packet data applications (e.g. HTTP, FTP, e-mail etc.) since the scheduler can selectively delay these packets. The channel quality (e.g. SNR) estimated by each UE is fed back in a fast manner to the Node B.

<u>Solution I</u>
In a solution for the HSDPA HS-DSCH, as in [1], simultaneous downlink transmission to multiple HSDPA UEs is considered, by dynamically code multiplexing one or more UEs in a manner to be decided by implementation at the resource manager residing in the access network. In general, in proposals favoring this solution, at each scheduling instant, the Node B decides to allocate either a portion or all or none of the available code space to each UE for the TTI that follows (i.e. 3.333 ms). The decision to code multiplex UEs is expected to be based on the instantaneous amount of data in each user's buffer arising from bursty traffic and the channel conditions of each user, so as to improve channel utilization. Overhead signaling channel structure that supports this type of code multiplexed allocation has also been proposed. The important motivating factor for this type of multi-user CDM structure of the HSDPA physical HS_DSCH channel is to ensure good frame fill or packing efficiency.

This solution is quite intensive in overheads, because at each scheduling instant (or TTI), the portion of code space allocated to each scheduled UE has to be transmitted via a dedicated power controlled overhead channel. Thus there is a requirement to transmit information about code space structure at every TTI (scheduling interval) even though the available code space itself is expected to change at a much slower rate. Furthermore, each UE is being informed whether or not it is being selected for service at each scheduling instant via dedicated power controlled channel. This solution packs users in code space across where there are no variations to exploit. On the other hand, this method fails to take advantage of finer granularity time variations in ordering users based on their channel conditions in time via smart scheduling algorithms.

<u>Solution II</u>
A second solution being considered is to dynamically vary the TTI [2], such that small blocks of information can be carried with all the available resources (i.e. at high channel rate) but over a shorter period of time. Several other advantages of the dynamically variable TTI have been presented in [2]. With respect to solution I, if the minimum TTI was reduced by a factor of five, then the channel would be very well utilized for carrying small packets in each reduced TTI (0.666 ms) and can be given to other UEs during the reduced TTIs that follow. The advantage of this one-user-at-a-time solution over the previous one is that time variations in the channel can be exploited so that better users are given priority over weaker users in scheduling, to increase network throughput. The ability to schedule the best over N active UEs who have sufficient data to send is an additional gain. Whereas, in the previously described solution, several UEs ranging from the best to much weaker ones could potentially be scheduled together for

simultaneous transmission. This can dilute the network throughput since it does not take advantage of finer time scale channel variations of the composite downlink constituted by several independent UEs.

In this second solution, the granularity of the TTI can be made fine only up to a point beyond which the returns diminish due to overheads. Thus with the constraint in achievable time granularity (e.g., minimum TTI of one power control group i.e., 2/3 ms in UMTS), the problem of packing efficiency may still need addressing in a high bandwidth system such as 5 MHz UMTS. In HSDPA, extremely high channel rates are possible, coupled with bursty traffic characteristics of data wherein small packet sizes (ranging from hundreds to thousands of bits) are possible. For example, a TCP segment of 1500 bytes (MTU) would have less than 100% packing efficiency at rates larger than 1.8 Mbps.

2. Proposed Solution

2.1. The dual advantages of fine time granularity AMC / scheduling as well as good packing efficiency

The method proposed in this contribution efficiently combines the scheduling advantages and fine time granularity for packing efficiency of solution II with the ability of solution I to simultaneously serve several UEs if necessary, for further packing efficiency, while minimizing the overhead signaling used for code space fraction indication. The method essentially calls for semi-static division of the channelization code space available for HSDPA UEs primarily as a function of the number of available codes in the space and the number of active HSDPA UEs. The physical channel structure proposed for supporting. HSDPA UEs is essentially based on comb ining the notion of code space division of one very high bandwidth physical HS-DSCH into a few parallel multi-coded channels of medium bandwidth (near-optimum and near-equal) and the notion of one UE at a time being packet switched independently onto each code space divided (CSD) parallel channel via time division multiplexing.

2.2. The overheads of indicating code space allocation to the different HSDPA UEs are kept minimal

The code space division has an implicit structure that is indicated by broadcast to all users no more often than the slow change in available code space and/or in the number of HSDPA UEs. The structure of the set of partitioned parallel physical HS_DSCHs is well understood by the HSDPA UEs by simply knowing the full code space available to them and the number of its divisions M. The implicit structure arises from the fact that in this method, the total available code space is divided into M approximately equal tiers, with the remainders after dividing the code space by M to an integer quotient allocated sequentially to the top most tier or tiers. For example, if M = 2 (i.e two tiers) and there are 29 orthogonal codes available (of fixed spreading factor W, say 32) for packet data, then the top tier is allocated 15 codes and the bottom 14 codes. In the case of M = 3 (i.e. three tiers) the top tier is allocated 10 codes, the middle tier is allocated 10 codes and the bottom tier is allocated 9 codes. If there are 30 codes available, then for the M=2 case, each tier gets 15 codes and for the M=3 case, each tier gets 10 codes. Thus the ordering of the codes and their grouping into tiers can be made unambiguously on the basis of their pre-designated code indices. Hence the information needed by the HSDPA UEs to determine the channel structure is simply the map of the code sub-tree which is available for HSDPA and the number of parallel CSD channels (M), i.e. the factor of division.

The updates of the value of M are semi-static i.e., the structure involving a variable number of parallel CSD HS-DSCHs changes very slowly (e.g. order of 100 ms or more). The changes occur when the available code space itself changes and crosses some threshold and/or when the number of active HSDPA UEs cross some threshold. The change in structure (i.e. number of parallel CSD HS-DSCHs) is reliably communicated via broadcast to all HSDPA UEs typically together with the available code space message, thus implying low overheads in power and bandwidth. The map of the available code space sub-tree is proposed to be broadcast to all HSDPA UEs in the sector, including those in handoff from other sectors. Bitmap signaling of W (e.g. 32) bits at a low frequency of the order of changes in the code sub-tree over a physical layer channel or via other signaling can be used. For example, if 32 bit map and M=2 maximum (signaled via one bit) is broadcast every 100 ms, then the information bit rate overhead is 330 bps. This low overhead is to be contrasted against solution I where the code space fraction allocated to each scheduled UE has to be communicated via dedicated channel at every scheduling instant. If a 32 bit map is used per user and five users are scheduled on average every 3.33 ms then the information bit-rate overhead is 48 kbps in solution I.

2.3. Adaptation to the available resources and load for providing maximum throughput efficiency

The additional overhead cost of this solution with respect to solution II is the multiplication of the packet switching overhead (i.e. MAC signaling to identify served users and associated control information on each CSD HS-DSCH) by a factor of M. This is expected to be a small price paid for preserving both scheduling advantage and packing efficiency. However, this overhead can be controlled if the Node B decides the number of semi-static divisions of the code space as an optimized function of the number of available codes, the number of HSDPA UEs and if feasible, of also their application dependent traffic characteristics. The number of such CSD parallel channels M is thus adapted and optimized for each value of number of codes available for the HSDPA UEs and the number of HSDPA UEs. As a simple rule, if the number of codes available are small, i.e less than a threshold “low_code”, then M = 1. The reasoning is that when limited in codes, the reduction in system bandwidth throttles down the rates for all HSDPA users and reduces the probability of major packing inefficiency, thus making it an issue of less concern. Hence M can be chosen as the smallest integer such that for a given number of total available codes, the number of multi-codes per code multiplexed HS-DSCH <= “low_code”. Thus a choice of small M would reduce replication and lessen the signaling overhead.

Secondly, if there are very few active HSDPA users, then M can very well be chosen to be small e.g. one, which is readily apparent in the extreme case of one user. In other words, if the number of HSDPA users falls below a threshold “low_user”, then M = 1. The reason is that there is not much point in dividing up the code space and increase signaling overhead when the system is under utilized in the first place. The motivation behind choosing M > 1 stems from the notion of efficiently utilizing the system bandwidth via better packing when there are reasonably large number of packet data users, each with relatively “thin” pipes of data flow. This issue becomes moot when there are too few HSDPA users active in the sector.

Furthermore, a reasonable upper limit on M, i.e. a value M_{max} should be placed to reduce the number of bits for its signaling and mainly to reduce the replication of overhead signaling on each parallel CSD physical HS-DSCH. In practical implementations of the UMTS system of chip rate 3.84 Mcps that avails of the benefits of fine time granularity as in solution II, it may turn out that a maximum value of two for M would suffice.

2.4. Unrestricted scheduler operation over the parallel CSD physical HS-DSCHs

Any one or more (even all) of the parallel CSD physical HS-DSCHs can in principle be allocated to any arbitrary user at a given instant of scheduling. In other words, the users assigned to each parallel CSD HS-DSCH can be independently decided based on extraneous conditions of source and channel. Thus either the same user could be simultaneously utilizing more than one or all of the parallel CSD HS-DSCHs or these pipes could each be carrying distinct users or any combination thereof. Typically, the power allocated to the parallel physical CSD HS-DSCHs will be proportional to the number of multi-codes in each and hence nearly equal.

2.5. Transparent to hybrid ARQ operation and Fast Cell Switching

Each user data stream can avail of any of the M parallel code multiplexed physical HS-DSCHs (i = 1,…, M) and a given new code block of user data can be scheduled and transmitted on any one of those M parallel channels for initial transmission. However, subsequent hybrid ARQ retransmissions (in stop-and-wait mode) of the same code block of information must be scheduled on the same i^{th} parallel code multiplexed HS-DSCH and is so understood by the user. Thus there is no *apriori* splitting of the user’s data stream into M equal sub-streams for mapping into code multiplexed physical HS-DSCHs as such an approach will not be effective to solve the packing efficiency problem. Furthermore, each of the parallel CSD HS-DSCHs can be operated in N-channel hybrid ARQ mode by further dividing the CSD HS-DSCH channel in time to up to N parallel sub-channels per user, each in stop-and-wait mode. Associated overhead channels can be defined for supporting each CSD HS-DSCH independently to carry user identification, rate and hybrid ARQ control information. These overhead channels will consume minimum resources when operating in power controlled broadcast mode. When the number of code space divisions as seen by a UE change from a current value of M to a later value of N (either within the same cell or at another cell due to FCS) then the first min{M,N} parallel CSD HS-DSCHs will be mapped one-to-one between the previous and current epochs and hybrid ARQ re-transmissions on these pipes can proceed uninterrupted.

2.6. No increase in the reverse link burden

A small additional overhead necessitated by this solution is the requirement of M ACK/NACK bits in the reverse link to support Hybrid ARQ. Thus the ACK/NACK field in the standard implementation must be provisioned for M_{max} bits as opposed to the one bit currently employed. These additional bits can be code multiplexed, for example, on reverse link so that they can easily be turned off when not in use. As the base station (Node B) implicitly knows this turning off no additional detection burden is implied. In terms of net overhead on the reverse link, the total ACK/NACK portion of the reverse throughput is expected to be similar to solution I.

3. Illustrative Example

Solution I:

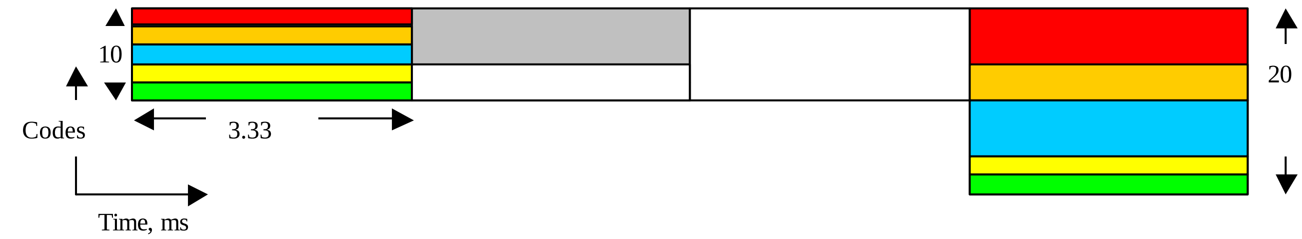

Fig. 1(a)

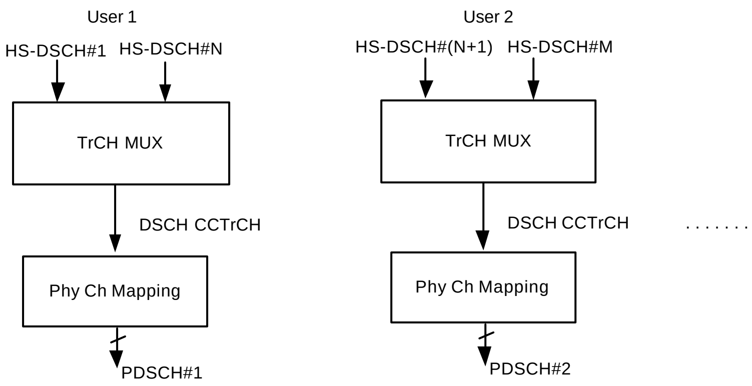

Fig. 1(b)

Solution II:

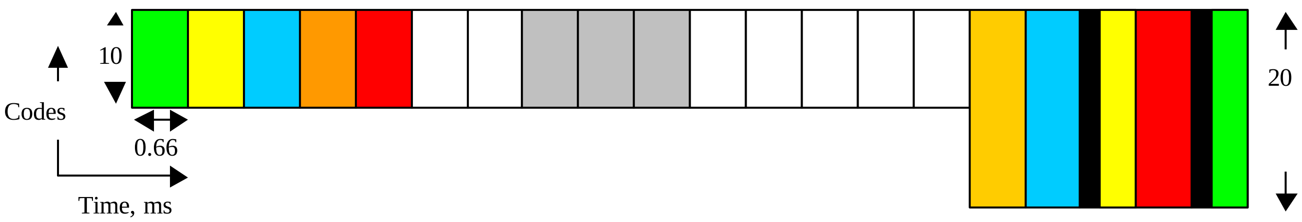

Fig. 2(a)

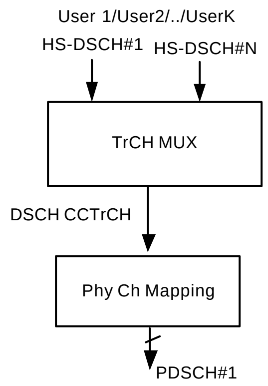

Fig. 2(b)

Solution proposed:

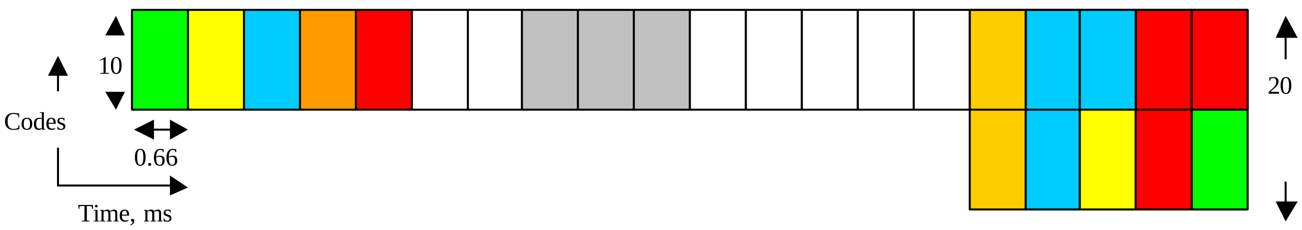

Fig. 3(a)

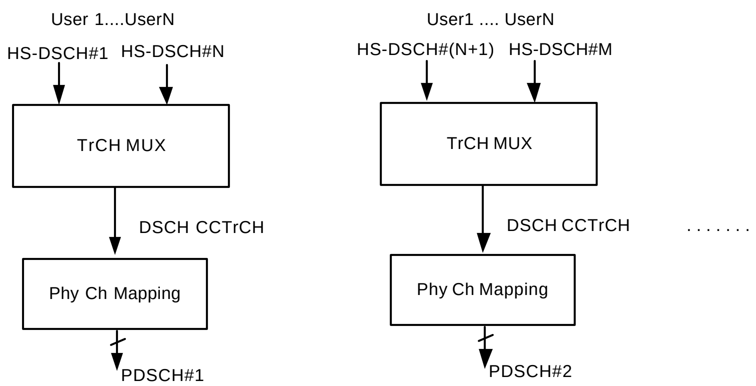

Fig. 3(b)

Figures 1(a), 2(a) and 3(a) above are examples depicting the various proposals for physical channel structures. Different colors are used to represent different UEs.

In solution I, high overheads present a problem, since the code multiplex structure (i.e. allocation of codes to different users) changes every 3.33 ms and this must be communicated to each scheduled user although the overall code space itself does not change. Also there is a restriction in scheduling users in time since a larger frame is used and thus fast changing channel conditions between users cannot be exploited.

In solution II, specific ordering of the users (colors) in time is used to exploit multi-user diversity due to their varying channel conditions. Packing efficiency is addressed by finer time granularity. But there remains a problem of packing inefficiency as seen by the black spaces when the number of codes available becomes large (e.g. 20).

In the solution proposed, the problem is solved by having just one physical HS-DSCH initially that is time multiplexed between users and later, when the code space doubles, by dividing the code space equally between two physical HS-DSCHs and time multiplexing users one-at-a-time on each. Both scheduling gains and packing efficiency can be obtained this way with minimal overheads.

Figures 1(b), 2(b) and 3(b) indicate the corresponding structures at the transport channel level.

4. Concluding Remarks

This contribution suggests the adoption of text in the Technical Report of the new resource allocation (i.e. code space division) strategy and corresponding physical channel structure presented herein that attempts to achieve higher throughput efficiency by combining:

A) adaptive semi-static code space division (CSD) into several physical HS-DSCHs for better packing efficiency with low overheads and
B) time multiplex (TDM) of HSDPA UEs one-at-a-time at fine granularity for scheduling gains and packing efficiency over each parallel physical HS-DSCH

Suggested Text and Figure for HSDPA RAN 1 TR in section 6.1.1, '*Physical layer structure in the code domain*':
"Code space division of the physical HS-DSCH into several 'equal' multi-coded parallel physical HS-DSCHs as shown in figure (insert figure 3(a)) should be considered as an alternative physical channel structure, in conjunction with minimum TTI of one slot. Such a structure combines the dual aspects of: a) adaptive semi-static code space division into several physical HS-DSCHs for better packing efficiency with low overheads and
b) time multiplexing HSDPA UEs one-at-a-time at fine granularity over each physical HS-DSCH for scheduling gains and packing efficiency."

5. References

[1] Motorola, "HSDPA System Performance Based on Simulations (II)", TSGR1#17(00) 1397, Stockholm, Sweden, November 2000.

[2] "Variable TTI Proposal for HSDPA", Lucent Technologies, TSGR1#18(01) R1-01-0079, Boston, USA, January 2001.