DPCCH Gating Gain for Voice over IP on HSUPA

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***Abstract*—In this paper, the concept of DPCCH (Dedicated Physical Control Channel) gating for HSUPA (High Speed Uplink Packet Access) is analyzed. Gating technique has recently been under consideration within WCDMA to inactivate control channels during silent periods of the users, and hence, not to misuse capacity. In order to study the concept benefit, a concrete real-time service is selected in this paper: Voice over IP (VoIP) for mobile communications. It will be shown that VoIP would be highly beneficed by DPCCH gating inclusion in 3GPP specifications. Both analytical and simulation studies were run to confirm the gain expectations.**

Keywords- DPCCH gating, VoIP, HSUPA

I. INTRODUCTION

High speed uplink packet access (HSUPA) concept was elaborated in the release 6 of the 3GPP specifications for the third mobile generation. It is the uplink counterpart of the high speed downlink channel (HSDPA) that was already introduced in release 5. Both high speed channels were conceived in order to achieve higher capacities and coverage for high transmission rates by the means of innovative techniques such as HARQ (Hybrid-ARQ), short frame size and Node B controlled packet scheduling.

Release 7, currently under development, continues to enable even higher data rates and capacity improvements in addition to improved support for real-time services e.g. Voice over IP (VoIP). At the radio access network side, continuous connectivity is one of the enhancements. The main problem to support continuous connection in WCDMA is the high number of UE's not transmitting, while keeping the control channels in use which overwhelms the cell capacity. One of the proposals to overcome this situation is the discontinuous transmission of the DPCCH channel when the UE is in idle mode. This is referred to as the DPCCH gating technique.

Voice over IP service has been proposed thinking on the evolution of UMTS to an all-IP network. It is meant to substitute the present circuit switched voice connections, thus it should show a clear gain over them in order to be worth implementing. As one of the real-time services considered in the continuous connectivity work item, VoIP would be highly beneficed by the gating technique inclusion. What is more, the characteristics of VoIP service makes it easier to implement the gating process as we will explain later.

The paper is organized as follows: in section II, the DPCCH gating technique is described. Section III details the VoIP concept. Section IV covers the analytical study previous to the simulation process. Through section V the modeling and assumptions considered in the simulator are presented. The actual simulation results are analyzed in section VI and final conclusions are drawn in Section VII.

II. DPCCH GATING CONCEPT

Previously to release 7 (figure 1), DPCCH channel was transmitted continuously regardless whether there is actual user data to be transmitted or not, thus highly loading the cell. An ideal solution for increasing the uplink capacity would be to keep the UE silent during the periods that is not transmitting any data and activate the control channels just for the transmissions periods. Therefore, the interference to other users would be reduced. This is the basic idea behind the DPCCH gating concept presented in [1] and depicted in figure 2.

Due to DPCCH gating, it might be difficult for the network to distinguish an inactive period from a loose connection. That is why the DPCCH transmission is desirable to not be totally silent but transmitted periodically following a predefined pattern.

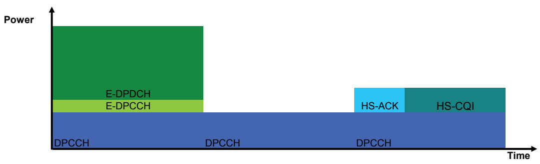

Figure 1. HSUPA transmission in Rel'6

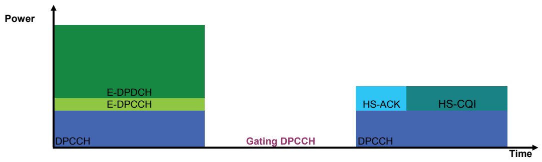

Figure 2. HSUPA transmission with gating DPCCH

Another issue to consider is the transmission power. After a gating period without tracking the received SIR, the channel response variations could degrade the transmission and increase the interference between the UEs. In the 3GPP specifications for DPCCH gating [1], optional power control preambles are defined to be sent previous to the data channel reactivation. It is interesting to point out here that the HARQ protocol specified for HSUPA helps to decrease the impact of inaccuracies in the power control algorithm, as it was illustrated in [2], and so it will reduce the gating technique on the power control performance.

III. VoIP over HSUPA

A. *VoIP packet delay requirements*

VoIP is defined as a conversational class service and thus the packet delay should be maintained strictly under some reasonable limits. According to [3], the maximum mouth-to-ear delay acceptable for a good quality communication should be lower than 250ms. Supposing that the network delays, such as core network, RNC processing and Iub transport is approximately 100ms, there is a 150ms margin for the air interface delays. Supposing also that both UE's are communicating through HSDPA/HSUPA channels, then the maximum acceptable delay of one way transmission must be under a 80ms delay budget.

VoIP follows a predictable pattern of data packets and silence periods, which are generated by the Adaptive Multi-Rate (AMR) speech codec. In our study we suppose that the AMR speech codec produces one packet every 20ms, compounded of 320 information bits, during the activity periods.

B. *VoIP trasnmission over E-DCH with HARQ*

Two possible TTI sizes have been specified for HSUPA: 2ms and 10ms. Every third generation-compatible user's equipment must support 10ms TTI while 2ms is optional. 2 ms will transmit at higher peak rates, with lower delays, but requiring higher transmission power from the UE than 10ms TTI and therefore performing worst in the cell edge and soft handover situations.

The synchronous HARQ protocol is used in HSUPA, i.e., retransmissions have to take place at a fixed duration after the previous transmission). For the 10ms TTI frame size, 4 parallel processes are specified in [4], thus a packet retransmission would be sent 40ms after the first transmission. Therefore, the maximum allowed transmission number would be two, since a third retransmission would imply packet delays beyond the 80ms delay budget. The transmission process is sketched in the following figure. As it can be seen, the retransmission of packet #1 implies an extra delay for packet #3, setting the maximum packet delay to 60ms.

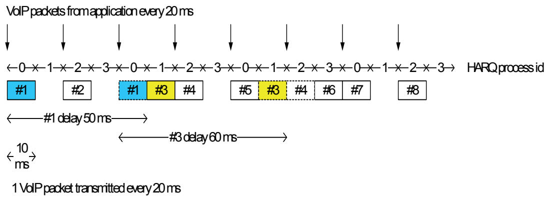

Figure 3 VoIP over HSUPA with 10ms TTI size

For a 2ms TTI size, [4] defines the HARQ protocol with 8 parallel processes, delaying a retransmission by 16 ms from the first transmission. In this case, up to 4 transmissions could be contemplated without exceeding the 80ms margin. Figure 4 shows a possible transmission process with a maximum of 3 transmissions.

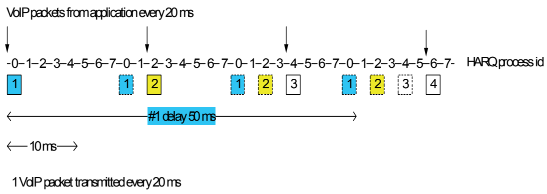

Figure 4 VoIP over HSUPA with 2ms TTI size

C. *Scheduling scheme*

Two scheduling schemes are defined for HSUPA: Node B controlled scheduling transmission and RNC controlled non-scheduling transmission. However, the former scheme does not guarantee a minimum bit rate since the scheduling algorithm decides whether to allocate any power to the user or not. On the other hand non-scheduled transmission defines a minimum data rate that the UE can transmit at without any previous request. Therefore, NRC controlled non-scheduling transmission is the most suitable choice for VoIP traffic.

VoIP can be clearly beneficed by the gating technique since usually a mean of 50% of the time a user keeps silent during a voice conversation. Drawing on this fact, only silence descriptors (SID) are sent every 160ms as soon as a silence is detected. Thus, during the user's silence periods, the UE could transmit discontinuously on the DPCCH. On the other hand, during the active periods, the voice coder produces one packet every 20ms. As the transmission is not continuous, a DPCCH gating transmission could be also considered during voice activity periods. However, it should be taken into consideration the retransmissions due to the HARQ algorithm, which would decrease the gating opportunities during activity periods as it can be seen in figure 1.

IV. Semi-analytical Study

We should answer now to the question of how much gain we can expect from the DPCCH gating technique. We can take as initial point for the analysis the time percent that DPCCH should be on, i.e. the DPCCH activity factor that we will call ν_c. From the gating concept definition, ν_c will be equivalent to know the percent of the time that data is sent in any channel dependent on DPCCH transmission,

$$\nu_c = \nu_e + \nu_{ACK} + \nu_{CQI} \, . \quad (1)$$

Here ν_e is the HSUPA activity factor and ν_{ACK} and ν_{CQI} correspond to the activity factors of HS-DPCCH and feedback channel for HSDPA, respectively, considering that HSDPA holds the VoIP downlink transmission. On the other hand, ν_e is equal to the product of the voice DTX activity factor (ν_i), the frames arrival rate to the physical layer (R_F) and the average transmission number due to the HARQ scheme (AvgTx). That is,

$$\nu_e = \nu_i \cdot R_F \cdot AvgTx \, . \quad (2)$$

In equation (1) we have assumed that HSUPA and HS-DPCCH never overlap in time, so the DPCCH activity equals the sum of activities. On the other hand, we are considering the ideal DPCCH gating, i.e. DPCCH is not transmitted if no dependent channel is transmitted and thus no power control preambles are in consideration. We presume that both assumptions somewhat compensate each other.

Once we got the percent of time the DPCCH will be on, we can measure the system capacity through the noise rise formula [5],

$$NR_{dB} = -10 \log_{10} \left(1 - EcNo \cdot N \cdot \nu \cdot (1 + i)\right). \quad (3)$$

Where N is the amount of UEs, ν is the activity factor and finally i represents the interference level from other cells. *EcNo* is the signal to noise target per chip after the antenna combining.

Four physical channels take part in VoIP communications, each one with different *EcNo* requirements and activity factor. Hence, we can divide the formula as

$$NR_{dB} = -10\log_{10}\left[\, 1 - (EcNo_c \cdot \nu_c + EcNo_e \cdot \nu_e + \right. \\ \left. + EcNo_h \cdot \nu_h) \cdot N \cdot (1+i) \,\right] . \quad (4)$$

Where $EcNo_c$ and ν_c correspond to DPCCH, $EcNo_e$ and ν_e to HSUPA related physical channels (E-DPCCH and E-DPDCH together) and finally $EcNo_h$ and ν_h to HS-DPCCH. ν_h is the sum of ν_{ack} and ν_{cqi} supposing they share the same target $EcNo_h$.

At this point we are able to draw the cell noise rise figure with respect to the number of UEs in the cell in figure 5. The required *EcNo* values will be obtained from the link level simulations.

We can first focus on continuous DPCCH. It is noticeable that VoIP shows similar or worse performance than 12.2 Kbps on DCH channels using 10ms TTI size: the reduction on channel activity (0.67 for 12.2 Kbps on DCH to 0.41 – 0.31 for 10 ms) does not compensate the worse channel condition for higher data rates needed in VoIP. 2ms TTI already improves 12.2kbps on DCH thanks to a farther reduction on the activity factor down to 0.15.

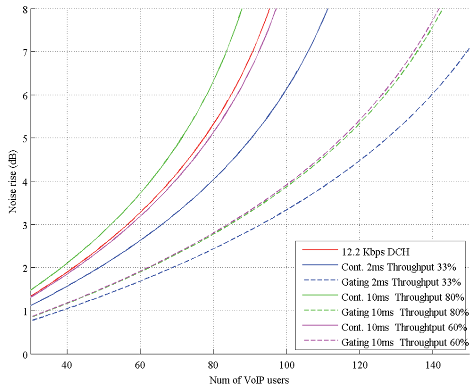

Figure 5 Semi-analytical cell noise rise for two different throughput values

The DPCCH gating technique will permit VoIP to finally beat voice 12.2 kbps circuit switched capacities. With 10ms TTI size and considering a maximum allowed noise rise of 6dB, we obtain gating gains of 50% and 64% respecting the continuous DPCCH simulations. In the other hand, 2ms gets a 40% gating gain. With this improvement in performance, 10 ms TTI presents capacities around 50% higher than circuit switched transmissions, meanwhile 2ms TTI goes up to 64% gain.

The throughput is defined as the inverse of the average transmission number. In continuous DPCCH transmission, a lower throughput (higher transmission number) presents lower noise rise (see figure 5) due to the fact that lower power is needed as the received SIR for each transmission will be finally combined.

However, Gating DPCCH behaves in the opposite way with the average transmission number. In (2), a smaller AvgTx value results in lower DPCCH activity factor and therefore, longer gating periods are be possible. This is why we obtain better gating gains: higher throughput means smaller amount of retransmissions, which results in lower DPCCH activity. Consequently we observe in figure 5 that both throughput values get the same results with the Gating DPCCH technique: there is a tradeoff between the gating DPCCH and HARQ.

V. Modeling and Assumptions

A. VoIP modelling

The VoIP call duration is fixed to 60s. Considering discontinuous transmission, the 'on' and 'off' periods durations are both modeled as a decaying exponential with 3s mean. During the 'on' phases, VoIP packets are generated every 20 ms, containing 31 bytes from the voice codec and 9 bytes of header from layers on top of MAC. 31 bytes every 20 ms corresponds to a source rate of 12.2 Kbps. During the 'off' periods no SID transmission is implemented.

B. DPCCH gating modelling

The gating concept has been modeled in the simplest manner. At any TTI that a packet is not received in the MAC layer, DPCCH is not transmitted at all, i.e. no activity pattern is considered when neither HSUPA nor HS-DPCCH is transmitted. Regarding the fast power control, after a gating period the UE transmits with exactly the same power as before the off period, as DPCCH power control preamble is neither implemented.

C. HSUPA modeling

Three different physical channels, I/Q code multiplexed [6], are need for the uplink transmission of VoIP traffic: DPCCH, Enhanced dedicated physical control channel (E-DPCCH) and Enhanced dedicated physical data channel (E-DPDCH). The high speed downlink physical control channel (HS-DPCCH), feedback channel for HSDPA, has also been included in the study, supposing that the downlink VoIP frames are delivered through HSDPA. As pointed out in the semi-analytical study in section IV, HS-DPCCH should be contemplated for the DPCCH activity factor calculations in gating scenario.

D. VoIP quality of service criteria

In our study, two different criteria have been considered to measure the system capacity: the cell outage percent and the cell noise rise. The cell outage deals with the percent of discarded frames. We state that an UE is in outage situation if 5% of the frames are erroneous or discarded over a 10ms period. Therefore, the system will reach the maximum allowed capacity when up to 5% of the UE in the cell are in outage.

The second criteria, the cell noise rise level, provide us a link with the semi-analytical study, as the latest is based on the received signal to noise ratio at the base station. The capacity will be given by the number of UEs in the cell when a 6dB mean noise rise is measured at the base station.

E. Environment

In order to analyze system level performance, a quasi-static simulator is used based on description in [7]. The protocol layers implemented are MAC and Physical layers. Layers above MAC are only considered in the MAC SDU size. All the needed RRM algorithms were implemented. The main simulation parameters are summarized in table 1.

TABLE I. SIMULATION PARAMETERS SETTINGS

Parameter	Value
Frame Size	10ms and 2ms TTI
Inter site distance	2.8 km
Cell configuration	ITU Veh-A, Macrocell
Voice call length	60 seconds
Voice on/off mean length	3 seconds
Payload size	31 bytes
VoIP packet arrival interval	20 ms (with 10ms, 2 packets transmitted every 40ms)
Compressed header size	9 bytes
UE speed	3kmh
Voice Activity	0.5
Number of HARQ channels	4 (10ms) / 8 (2ms)
Max number of L1 transmissions	2 (10ms) / 4 (2ms)
$(\beta_{ec}/\beta_c)^2$	-7.96 dB (10ms) / 3 dB (2ms)
$(\beta_{ed}/\beta_c)^2$	8 dB
Scheduling algorithm	Non-scheduled
DPCCH gating patern	No transmission patern
DPCCH gating power preamble length	0 slots
Discarded timer	80 ms
Delay budget	80 ms
Outage observation window length	10 seconds
Cell outage threshold	5%

Notice that 10ms is implemented to send two packets per frame, aiming to give more chances for DPCCH gating keeping still the packet delay under 80ms but requiring to double the data rate in order to send two packets at once. In 2ms TTI transmission the possible performance improvement does not justify the increase in data rate.

VI. SYSTEM LEVEL SIMULATION RESULTS

Fig. 6 depicts the noise rise behavior from the system level simulation. Considering settled a 6dB cell noise rise limit, a gating gain around 42% and 50% is obtained for the 10ms cases and 41% for 2ms. The system level performance is under the semi-analytical results in Fig. 2 where 50% and 64% gains for 10ms and 40% for 2ms were reached. The semi-analytical study assumes that there is not limit for the UE tx power, whereas in the actual system simulations the UE power shortage limits performance, as explained in [8] for the 2ms continuous scenario.

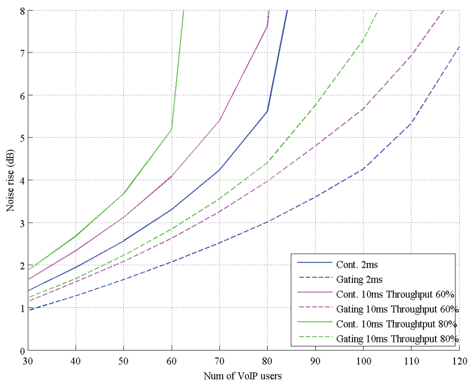

Figure 6 Mean noise rise for different throughput values

A better gating performance was observed regarding the outage capacity in figure 7: 50% and 77% gating gains can be observed for the throughput values of 60% and 80%, respectively. 2 ms shows lower gating gain (47%) getting the 10ms gating results quite close to the 2ms performance.

The main drawback concerning gating is the effect that its implementation might cause to the power control performance. As the DPCCH would not be continuously transmitted, the fast power control algorithm will not be able to follow the changes in the channel characteristics during the inactivity periods. That is why the use of a power control preamble, previous to the reactivation of the data channels is contemplated in [1]. In our study, no preambles are considered to analyze the effect of gating on power control.

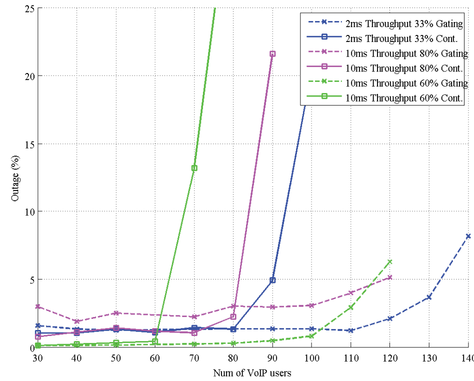

Figure 7 Cell outage for different throughput values

VII. CONCLUSIONS

In this paper we have considered the performance of DPCCH gating technique for HSUPA. Gating technique has recently been proposed within WCDMA to release unused resources by inactivating control channels during silent periods of the users. In order to study the concept benefit, Voice over IP was selected as the service under consideration. Both analytical and simulation studies were run to confirm the gain expectations. It was shown that VoIP would be clearly beneficed by the DPCCH gating inclusion in 3GPP specifications. Farther study concerning the use of power control preambles seems to be necessary to diminish the power control variability that the DPCCH gating technique introduces.

REFERENCES

[1] 3GPP TR 25.903 V1.0.0 (2006-05), "Continuous Connectivity For Packet Data Users".

[2] Y. Kim; J.-K Han; H. Kwon; D. Kim "Effect of imperfect power control on the performance of HARQ in CDMA2000 reverse link", 15th PIMRC, vol.3,pp.2046–2050,Sept2004.

[3] ITU-T recommendation G.114, One way transmission time

[4] 3GPP TR 25.309 V6.4.0 (2002-06), "FDD Enhanced Uplink; Overall description".

[5] H. Holma, A. Toskala (Editors), "WCDMA for UMTS - Radio Access for Third Generation Mobile Communications", John Wiley and Sons, Third Edition, 2004.

[6] 3GPP TR 25.213 V6.4.0 (2005-09), " Spreading and modulation (FDD)".

[7] 3GPP2 Technical Specification Group C, 3GPP2/TSG-C.1002: "1X EV-DV Evaluation Methodology".

[8] T. Chen; M. Kuusela; E. Malkamäki "Uplink Capacity of VoIP on HSUPA", VTC Spring 2006.