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Power-efficient scheduling for voice services in high-speed packet access systems

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Abstract: The high-speed downlink packet access (HSDPA) system can effectively support real-time voice services if the HS-SCCH-less feature is adopted in the 3GPP Release 7 standard. In this paper, we point out that the feature only offers a limited statistical multiplexing capability and it also causes serious power consumption at the user equipment. This paper proposes an HSDPA scheduling operation that utilizes the entire code space and considers the packet generation pattern of voice services.

Keywords: high-speed packet access, voice capacity, power saving

Classification: Wireless circuits and devices

References

[1] 3rd Generation Partnership Project, "High Speed Downlink Packet Access (HSDPA) (Release 8)," *3GPP TS 25.308 v8.8.0*, March 2010.
[2] 3rd Generation Partnership Project, "Continuous connectivity for packet data users (Release 8)," *3GPP TR 25.903 v8.0.0*, Dec. 2008.
[3] 3rd Generation Partnership Project, "Status report for WI CS voice service over HSPA," *3GPP RP-080042*, March 2008.
[4] 3rd Generation Partnership Project, "Physical layer procedures (FDD)," *3GPP TS 25.214 v7.14.0*, Dec. 2009.
[5] Enhanced UMTS Radio Access Network Extensions for NS2, [Online] http://eurane.ti-wmc.nl/eurane, Sept. 2005.
[6] 3rd Generation Partnership Project, "User Equipment (UE) radio transmission and reception (FDD)," *3GPP TS 25.101 v7.17.0*, Dec. 2009.
[7] 3rd Generation Partnership Project, "Base Station (BS) radio transmission and reception (FDD)," *3GPP TS 25.104 v7.13.0*, Sept. 2009.
[8] 3rd Generation Partnership Project, "Response to LS (R1-020855) on HARQ ACK/NAK error requirements for HSDPA," *3GPP R2-021736*, June 2002.

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[9] J. H. James, et al., "Implementing VoIP: a voice transmission performance progress report," *IEEE Commun. Mag.*, pp. 36–41, July 2004.

1 Introduction

The high-speed downlink packet access (HSDPA) system was standardized in the 3rd Generation Partnership Project (3GPP), and improved the Release 99 WCDMA system by using multi-code transmission, hybrid ARQ, adaptive modulation/coding and dynamic scheduling [1]. In HSDPA, a high-speed physical downlink shared channel (HS-PDSCH) is used to transmit user data packets, and characterized by a channelization code having a spreading factor of 16. A base station (BS) can assign more than one HS-PDSCH to a user during a transmission time interval (TTI) of 2 ms, which is composed of 3 slots (i.e., 1 slot = 2/3 ms). HS-PDSCH transmission is always associated with a high-speed shared control channel (HS-SCCH), which contains decoding parameters of the associated HS-PDSCH(s). The uplink feedback is carried on a high-speed dedicated physical control channel (HS-DPCCH).

Recently, a special feature called the HS-SCCH-less operation was introduced to reduce the downlink signaling overhead for low-rate voice services [2]. However, the HS-SCCH-less operation only offers a limited statistical multiplexing capability and it also causes serious power consumption at the user equipment (UE). In this paper, a power-efficient scheduling operation is proposed to improve downlink voice capacity and to reduce power consumption in the UE receiver.

2 HS-SCCH-less operation and voice services

In Release 5 HSDPA, the HS-SCCH always notifies the UE of the upcoming HS-PDSCH transmission. The UE is being addressed via a UE specific identity on HS-SCCH. The explicit HS-SCCH signaling in Release 5 is not suitable for a large number of low-rate voice services because the number of HS-SCCHs configured in a cell is limited (usually up to 4) and it corresponds to the maximum number of UEs that can be code-multiplexed during a TTI. In Release 7, the conventional operation is complemented by the HS-SCCH-less operation, which is optimized for services with relatively small packets.

In the HS-SCCH-less operation, a UE performs blind decoding for a predefined HS-PDSCH code without HS-SCCH signaling. The HS-PDSCH code assigned to each UE is determined by higher layers during connection establishment. Each packet is transmitted by using a QPSK modulation and one of four transport formats. In case of successful reception, the UE will send an ACK on HS-DPCCH. If the packet was not received successfully, the UE will send nothing (i.e., DTX) and the BS may retransmit it. In contrast to the first transmission, the retransmissions are associated with HS-SCCH signaling. The number of retransmissions is limited to two in this operation.

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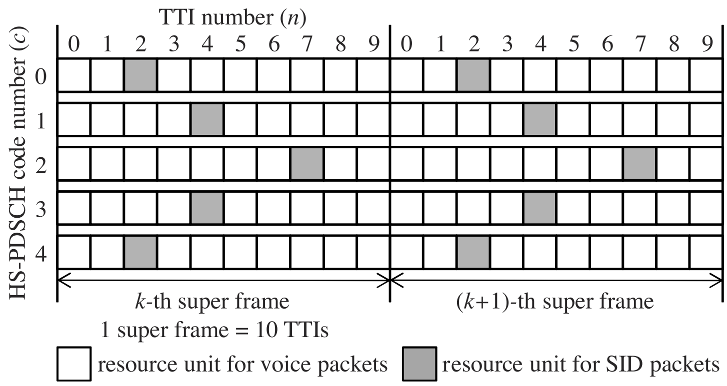

Fig. 1. Resource unit structure for voice services.

The voice services in HSDPA can be supported in the form of VoIP (voice over IP), with some changes in the packet-switched core network. As an alternative, voice packets can also be transported over a legacy circuit-switched core network in 3GPP Release 8, wherein this feature is called CS voice over HSPA [3]. The AMR (adaptive multi-rate) codec generates a voice packet ($\leq$ 244 bits) every 20 ms during a Talkspurt mode, and a 39-bit silence insertion descriptor (SID) packet every 160 ms during a Silence mode. Generally, the acceptable delay over the air interface should not exceed a certain limit for real-time voice services (usually less than 100 ms).

The main objective of the HS-SCCH-less operation is to increase voice capacity of the HSDPA system by reducing signaling overhead. In this operation, a single HS-PDSCH code can be shared by multiple UEs to support statistical multiplexing, but the multiplexing gain is limited when compared to the resource allocation over the entire HS-PDSCH codes. In addition, from the power consumption point of view, the blind decoding requires significant decoding and processing resources at the UE. The UE should persistently monitor the predefined HS-PDSCH code because the UE does not know the scheduled TTI for itself before decoding the received HS-PDSCH.

3 Proposed scheduling operation

The voice and SID packets of the AMR codec are periodically generated during the Talkspurt and Silence modes, respectively. Therefore, the periodic packet reception can be an optimal solution for the power-efficient scheduling operation. In the HSDPA standard, a transport block size is usually much larger than a voice packet and just one HS-PDSCH code is sufficient to transmit one voice packet during a single TTI [4]. Considering the generation interval of voice packets in the Talkspurt mode, multiple UEs can share the downlink time-code resources within 10 TTIs. Fig. 1 shows the downlink resource structure in the proposed operation assuming 5 HS-PDSCH codes for voice services. A super frame is defined as the time period of 20 ms (= 10 TTIs) for supporting the periodic voice transmission. A resource unit (RU) is defined as the downlink resource composed of one HS-PDSCH code (code domain) and one TTI (time domain), required for transmitting a sin-

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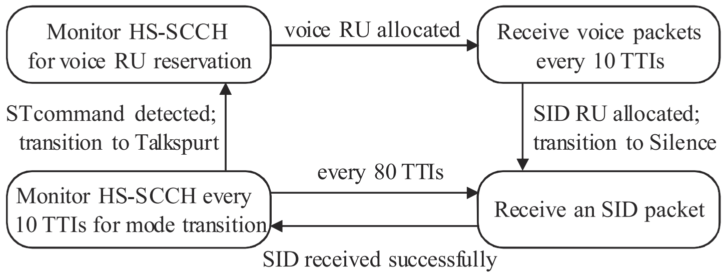

Fig. 2. UE state transition diagram.

gle voice packet or a single SID packet. Every super frame has a capacity of $N \times C$ RUs, where N is the number of TTIs in a super frame (i.e., $N = 10$) and C is the number of HS-PDSCH codes configured for voice services.

In the proposed operation, some RUs are exclusively used for SID transmissions (shown grayed in Fig. 1), considering the fact that the generation interval of SID packets does not coincide with that of voice packets. Let $\mathrm{RU}(k, c, n)$ be the RU having code c and TTI n at the k-th super frame. When a BS transmits the first packet of each mode at $\mathrm{RU}(k, c, n)$ by HS-SCCH signaling, it assumes that the following RUs are reserved for the UE:

$$\mathrm{RU}(k+i, c, n),\ \ i = 0, 1, \cdots, \frac{T_{on}}{10\tau} \text{ for Talkspurt} \tag{1}$$

$$\mathrm{RU}(k+8i, c, n),\ \ i = 0, 1, \cdots, \left\lfloor \frac{T_{off}}{80\tau} \right\rfloor - 1 \text{ for Silence} \tag{2}$$

where T_{on} and T_{off} are the durations of Talkspurt and Silence modes, respectively. T_{on} is an integer multiple of 20 ms and τ is the duration of one TTI (= 2 ms). After the reservation, the UE performs blind decoding for the received packet in the reserved RU. If the packet is not decoded successfully, the UE monitors the HS-SCCH for a certain amount of time to receive the retransmitted packet.

In the Silence mode, the SID generation interval is 8 times longer than the voice interval and too long inactivity makes it difficult to detect the mode transition to Talkspurt. To detect the mode transition, the UE in the Silence mode periodically searches for a special format of HS-SCCH, which is called a Silence-to-Talkspurt (ST) command. When a new Talkspurt begins, the BS transmits the ST command in accordance with the periodic activation pattern of the UE. If the ST command is received successfully, the UE transmits an ACK to the BS. Otherwise, it transmits nothing (i.e., DTX).

Fig. 2 illustrates a state transition diagram for the voice UE in the proposed operation. At the beginning of the Talkspurt, the UE continuously monitors the HS-SCCH to receive the first voice packet and reserve the future RUs. After the reservation, the UE will receive its voice packets periodically at the same RU in the next super frames, without HS-SCCH signaling. At the end of the Talkspurt, because the UE does not receive voice packets at the reserved voice RUs, it will monitor the HS-SCCH continuously for reception of retransmitted packets. This monitoring is continued until an SID RU is allocated by HS-SCCH signaling. If a new voice RU is allocated

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by HS-SCCH signaling before the SID RU allocation, the UE regards the reception as the beginning of a new Talkspurt mode. The SID RU is used every 8 super frames (= 80 TTIs), and the UE monitors the HS-SCCHs every 10 TTIs to receive the ST command. If the UE receives the ST command, it will transition to the Talkspurt mode. In order to consider the detection error of the ST command at the BS, the UE begins to monitor the HS-SCCH as soon as unexpected retransmissions of voice packets are detected.

Note that the BS can allocate any unoccupied RU in the entire code domain during the reservation phase. Thus, a high statistical multiplexing gain is expected when compared to the HS-SCCH-less operation. Moreover, the proposed operation can achieve a significant energy saving gain at the UE, because the UE receives the voice/SID packets and the ST commands at a predetermined TTIs, except during the initial reservation and retransmission phases. Assuming no retransmissions and no signaling errors in a light traffic load, the receiver activation time (RAT) is approximately given by as follows during one cycle of the Talkspurt and Silence modes:

$$\mathrm{RAT} = \frac{5}{3}\tau + \frac{T_{on}}{10} + 70\tau + \left(\left\lceil \frac{T_{off} - 80\tau}{10\tau} \right\rceil + 1 \right) \tau. \qquad (3)$$

The first two terms are calculated in the Talkspurt mode considering physical channel timing and periodic reception of voice packets. The third term corresponds to the HS-SCCH monitoring period for SID RU reservation after detecting a missing voice packet. The last term comes from periodic reception of SID packets and periodic monitoring of HS-SCCHs. As an example, assuming $T_{on} = T_{off} = 2$ s, the RAT is 0.529 s and the duty cycle is 13.2%, which is much lower than that in the HS-SCCH-less operation (i.e., 100%).

4 Results and conclusions

Some system parameters are selected according to Network Simulator ns-2 and its Enhanced UMTS Radio Access Network Extensions (EURANE) [5]. The path loss (in dB) is given by $137.4 + 35.2\log_{10}(x)$, assuming an urban macro cell. The shadowing is not considered and the cell radius is 300 m. The intra-cell and inter-cell interferences are 30 dBm and -70 dBm, respectively. The antenna gain with cable loss is set to 16 dBi. The durations of the Talkspurt and Silence modes are assumed to be exponentially distributed with the same average duration of 2 s. The multi-path fading is modeled by using various ITU-T channel profiles at velocities of 3 km/h (30%), 15 km/h (30%), 60 km/h (20%) and 120 km/h (20%). UEs are uniformly distributed in the cell. Voice and SID packets are discarded if the transmission delay exceeds 60 ms. The number of HS-PDSCHs is 10, which corresponds to 100 RUs. Among the 100 RUs, 11 RUs are allocated for SID transmissions and 89 RUs for voice transmissions. The downlink transmission power is set to 12.5 W for the 10 HS-PDSCHs. Each UE has an HS-SCCH detection error of 1% [6]. The BS has HS-DPCCH detection errors of Pr(NACK|ACK) = 1%, Pr(ACK|NACK) = 0.01% and Pr(ACK|DTX) = 1% [7, 8].

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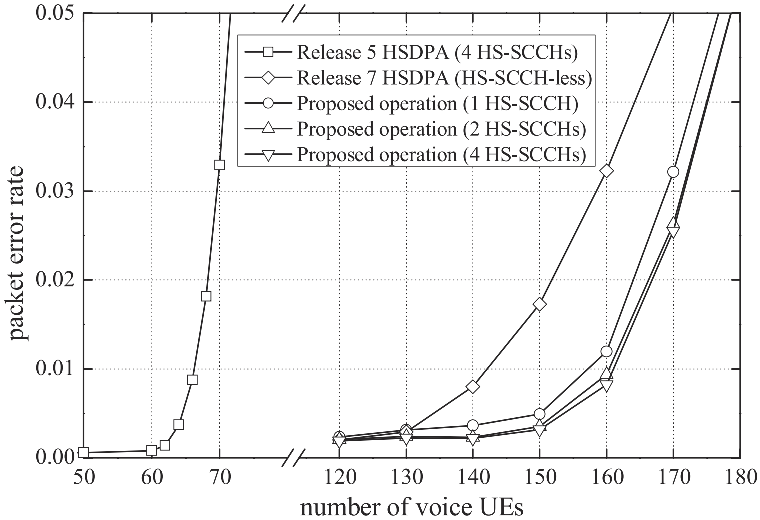

Fig. 3. Voice capacity comparison.

In this paper, the system outage for voice services is defined as the packet error rate (PER) exceeding 1% [9]. Fig. 3 shows the PER of voice services in the various operations. We can see that the proposed operation outperforms the other two HSDPA operations. The Release 5 HSDPA with 4 HS-PDSCHs has the maximum voice capacity of 66 UEs. In the Release 7 HSDPA that supports the HS-SCCH-less operation, the maximum capacity is increased to 142 UEs. In the proposed operation, the maximum voice capacity is further increased by up to 13% (158 and 160 UEs with 1 and 2 HS-SCCHs, respectively) compared to the Release 7 standard. The main reason for improvement is that the proposed operation utilizes the statistical multiplexing over the entire HS-PDSCH resources with minimum HS-SCCH signaling. In the proposed operation, the voice capacity slightly increases as the number of HS-SCCHs increases.

Table I. Average duty cycle of UE receivers (%).

Number of UEs	60	90	120	150	180
Release 5/7 HSDPA	100	100	100	100	100
Proposed operation (1 HS-SCCH)	14.7	14.8	15.0	15.9	21.3
Proposed operation (2 HS-SCCHs)	14.6	14.7	14.9	15.5	20.9
Proposed operation (4 HS-SCCHs)	14.6	14.7	14.8	15.4	20.8

In addition to the capacity improvement, the proposed operation has an important feature with respect to the power consumption at the UE. The UE receiver duty cycle is summarized in Table I. The conventional HSDPA operations have a receiver duty cycle of 100% because they should always monitor the downlink transmissions. The receiver duty cycle in the proposed operation is much lower than that in the conventional operation. For example, the proposed operation has a duty cycle of less than 16% for 150 UEs. Note that the duty cycles in Table I are higher than expected in

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(3) because signaling errors and retransmissions are additionally considered in the simulation. From the results, we can conclude that the proposed operation significantly reduces power consumption at the UE receiver, while offering higher voice capacity.

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