國立交通大學

電信工程學系

碩士論文

在以寬頻分碼多工存取為基礎之高速下行鏈路封包存取系統中利用快速重傳來避免封包壅塞之方法進行速率調整及封包排程之研究

A Novel Stall Avoidance Scheduler for Fast Retransmission Strategy in WCDMA systems with High Speed Downlink Packet Access

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中華民國九十五年五月

摘要

隨著高速率多樣化資料傳輸上的需求與日劇增，在無線網路上引發了新的挑戰。為了克服這些挑戰，在這篇論文中提出了一個以成本函數為基礎的速率調適機制針對有著高速率下行鏈路封包存取概念的寬頻分碼多工存取系統進行速率調適以及排程技術的研究。在以寬頻分碼多工存取為基礎之高速下行鏈路封包存取系統中利用快速重傳來避免封包壅塞之方法進行速率調整及封包排程之研究

為了在寬頻分碼多工存取系統(WCDMA)上支援多種類的資料流型態，此機制綜合考量了實體層以及較高層的一些重要參數來增進效能。所提出來的速率調適機制是利用了在媒體存取控制(MAC)層裡面的運輸格式(transport format)選擇程序來實現的。因此，藉由結合實體層資訊(也就是信號雜訊比(SNR))以及媒體存取控制層的資訊(也就是暫存器使用量以及服務優先權)到一個統一化的成本函數，我們發展了一套運輸格式選擇演算法。透過此跨層級的成本函數，此運輸格式選擇程序可以在每個傳送時間區間(transmission time interval)內動態的選出合適的展頻因子，此區間通常是2毫秒到160毫秒。因此，此程序可以達到流通量之增進、功率消耗之節省以及在多個服務之間提供公平性效能改善的目的。

寬頻分碼多工存取系統中之高速率下行鏈路封包存取採用了適應性調變技術、高效率的排程技術以及混合式的自動重送請求技術以達到10 Mbps的高速率傳輸。為了增進系統效能，排程演算法則扮演著重要的角色。一個好的排程演算法目標在於從眾多使用著中，考量到通道的影響、延遲時間以及公平性後進行使用者之傳輸排程。在這篇論文中，我們檢驗現有適合用在此高速率下行鏈路封包存取概念之排程演算法的公平性效能，這些演算法包括最大信號干擾比(maximum C/I) 排程法、知更鳥式循環(round robin)排程法、比例式公平(proportional fair)排程法以及指數型法則(exponential rule)排程法。我們發現現有的排程演算法在此公平性指標上的表現並不是那麼公平。因此，我們提出一個新的排程演算法，稱為避免封包壅塞之方法(stall avoidance + queue-based exponential rule)排程法，來提供比比例式received goodput in upper layer排程法以及指數型法則排程法還要好的效能，並且保持高流通量以及低延遲時間。

A Novel Stall Avoidance Scheduler for Fast Retransmission Strategy in WCDMA Systems with High Speed Downlink Packet Access

A THESIS

Presented to

The Academic Faculty

By

Laina Assane Dimanche

In Partial Fulfillment

of the Requirements for the Degree of

Master in Communication Engineering

Department of Communication Engineering

National Chiao-Tung University

May, 2006

Summary

The objective of this thesis is to propose a *stall avoidance scheduler* for an N-channel $Stop - And - Wait$ (SAW) *Hybrid Automatic Request* or *Retransmission Query* (HARQ) mechanism to improve the end-to-end throughput and reduce total system delay in the WCDMA systems with High Speed Downlink Packet Access (HSDPA).

An increasing demand for both larger system capacity and higher data rates has launched the evolution of the mobile communication market. HSDPA appears as an umbrella of features using key technologies such as Fast Link Adaptation, Fast Scheduling, Adaptive Modulation and Coding (AMC) and Fast Retransmission Strategy (HARQ) whose combination improves the network capacity, increases the peak data rates up to 10 Mbps for downlink packet traffic and decreases the system throughput delay. HSDPA can allow users to enable high peak data rate services with a lower cost per delivered data bit, improve the QoS of already existing services.

In order to satisfy the growing aggressive demand for the wireless packet data services, scheduling algorithms are widely used in WCDMA wireless multimedia networks to provide the guaranteed quality of service. The design of such such algorithms is a challenge due to the mobility and connectivity problems that encountered in Wireless Networks. Among many protocol enhancements designed to maximize downlink throughput, the $N - Channel$ SAW-HARQ is one of the required schemes that can boost the user throughput. The proposed Stall Avoidance (SA+QER) scheduler is to be implemented in MAC layer and its role is to improve the end-to-end throughput and reduce the overall end-to-end delay in the presence of packet stall (or gap) in the receiver reordering buffer in the WCDMA systems with HSDPA.

The overall performance comparison of conventional scheduling policies with *timer* and *window* mechanisms is presented through simulations. Simulations results show that in terms of *received goodput* in upper layer and $head - of - line\ delay$, the proposed stall avoidance scheduler outperforms all the other existing schedulers, including maximum C/I, round robin, proportional fair, queue-based exponential rule. Furthermore, the overall system delay is significantly reduced by the stall avoidance scheduler.

Acknowledgments

I would like to thank GOD Almighty who gave me the strength and the ability to write this thesis. He is the one I pray and I always looked to in the face of trouble and He always makes a way for me out of the critical situation. Thank YOU LORD!!!

I am thankful to my supervisor Prof. Li-Chun Wang for his guidance, support and invaluable advices. This work could not be achieved without his encouragements, comments and suggestions. I am grateful to Prof. Li-Chun Wang not only for reading and correcting this thesis also for his remarkable availability during a difficult period. I would like to thank Prof. Li-Chun Wang who agreed to serve as a member of my oral defense examination committee.

I would like to thank the National Chiao Tung University International Service Center (ISC) particularly Mr. An Hwa-Cheng, Miss Sue Wang, Mr. Li and colleagues for their kindness and sympathy during the last two years in NCTU. Thanks are also extended to my labmates: Chang Chih-Wen, Wang Chung-Wei, Liu Wei-cheng, Jane-Hwa Huang, Yan Kuang-Nan, Cheng Yun-Huai, Hung Hsing Paul, Kimula, W.H. Huang, Vincent Su, Chen Ming Bing and Samer for their good cooperation that kept a wonderful atmosphere in our lab.

A number of people have impacted my studies and my life in Taiwan in general. Alex Wang and Ilona who are my first friends in Taiwan. Daniel Greenhoe and his wife Apple who are my best friends. I am thankful to Dan for his invaluable help and goodness during some critical situations of my life. Kevin and his wife Mona who are my friends in Hsinchu International Church (HIC) Pastor Dale and his family, Pastor Franck and his family and all the HIC brothers and sisters. All my countrymates who are living in Taiwan Nestor, Mouktar, Moulengar, Hisseine, Hakim, Amadaye, Youssouf, Issa, Justin, Khartai, Adoum, Annadif, Khaled, Acyl, Abakar,....for their good cooperation.

I would like to express my deepest gratitude to the Ministry Of Foreign Affairs (MOFA) and the Ministry Of Education (MOE) for their financial supports and for giving me the opportunity to build a successful career. I also express my deepest gratitude to Mr. Lin Ming Shioung (MOFA) and his family for their permanent availability and encouragements. I am grateful to the Republic of Chad Ambassador in Taiwan HE Mr. Hisseine Brahim Taha for his availability and encouragements during my studies in Taiwan and Mr. Masdongar (first Ambassy of the Republic of Chad in ROC).

I would like to thank my Uncle Loum Hinansou Laina, my parents, my brothers and sisters. My parents have been supportive of me throughout my studies by praying. It is the desire to see them happy, that keeps me motivated. Finally, I would like to thank my loving and supportive fiancee Ouedraogo Azarata, She is the person who makes a difference in my life..

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CHAPTER 1

Introduction to WCDMA Systems

1.1 Background on WCDMA

1.1.1 Historical Perspective

The desire to communicate with others dates back to primitive times. Different civilizations found different ways to transmit cultures or messages to their descendants. People used drawing on walls such as cave paintings, engraving signs or words on wood to communicate their way of life to new generations. They early realized that voice had a limited distance, so they created the first long distance communication tool called "drum" whose sound could be heard at a certain distance depending on the wind direction to warn neighbors of imminent danger or to provide them all sort of information.

The invention of telegraph in 1837 by Samuel Morse and the establishment of the first successful and practical radio system by Gugliemo Marconi by the end of the 19th century launched the first roots of cellular communications. Truly speaking the beginning of Code Division Multiple Access (CDMA) dates back to 1949, when John Pierce, Robert Pierce and Claude Shannon first formulated the principles of a new technique for multiple accesses that separates information in the code domain, rather than in the time or frequency domain. The first concept dealt with time hopping spread spectrum, but already in 1950 direct sequence spread spectrum (DSSS) was introduced by De Rosa-Rogoff. DSSS soon attracted much more attention, and became the principal multiple access technique for robust telecommunication systems. At its debut, the new technique of separating information in the code domain was only restricted to military applications for the well-known strategic reasons. The basic idea behind this technique is that at the source the information is spread into a noise-like sequence uncorrelated to all other signals at the destination and the receiver shall de-spread it by using a correlator. This principle gave rise and robustness to communication systems by significantly minimizing the external interferences.

The Wideband CDMA (WCDMA) came under intensive investigation in the 1990's. Because of its better flexibility and its spectrum efficiency, the WCDMA offer better services than the previous CDMA techniques. This is certainly the reason for which in 1995, a coordinated standardization conference including all the major companies in telecommunication and data communication industries was initiated. As an issue, WCDMA was accepted in Europe and Japan as the promising technology for the future Universal Mobile Telecommunication System (UMTS). Also, in the USA a similar standard named CDMA2000 was proposed. The historical data on CDMA development are proposed in reference [1].

Actually, the role of WCDMA in next generation of wireless systems is exponentially growing due to an increasing demand of data service. The efforts toward its standardization completion have escalated. The concern of the standard not only needed to treat the technical details of the system, but also the problem of interoperability of WCDMA with other platforms needed to be dealt with. WCDMA is actually chosen to be one of the three access schemes supported by UMTS. In the TDD bands, the time division CDMA is used instead, and for the USA another scheme dubbed CDMA2000, which is backward compatible with IS-95, was included. At the end of 1999, the standardization process is almost finished, and the next step in the development of a spread spectrum system based on WCDMA has started - optimization. The objective of standardization was to unify key processes in a UMTS system by allowing enough flexibility for individual implementations. One of the key features defined in UMTS Rel 5 is High Speed Downlink Packet Access (HSDPA), which offers significantly higher data capacity and data-user speeds on the downlink. This is possible through the use of a new downlink shared transport channel and a set of smart mechanisms such as very dynamic adaptive modulation and coding, a fast scheduler, and fast retransmissions implemented in the UMTS BTS. This new feature is fully Rel 99 backward compatible and can co-exist on the same RF carrier with R 99 UMTS traffic. Third generation wireless systems are designed to fulfill the communication to *anybody*, *anywhere* and *anytime* vision. Its goal is to support voice, streaming video, high speed data. The features of WCDMA are given in table 1.1 below

Table 1.1: Features of the WCDMA

Features	Explanation/Assumption
Bandwidth	up to 5 MHz
Spreading codes	(OVSF) SF: 4-256
Scrambling codes	DL- Gold sequences (len-18)
	UL- Gold/Kasami sequences (len-41)
Data Modulation	DL - QPSK and UL - BPSK
Data rates	128 kbps, 384 kbps
Duplexing	FDD, TDD

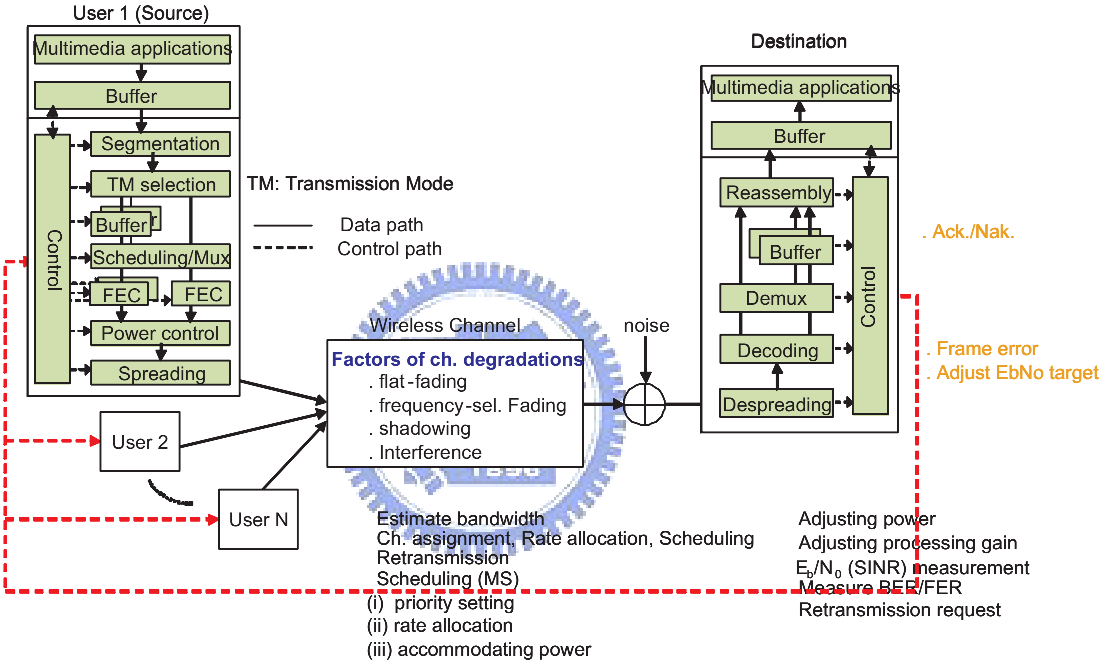

Figure 1.1: CDMA Block Diagram.

1.1.2 Future Promise

With wireless mobile radio communication, there is an endless quest for increased capacity and improved quality of service. As HSDPA is about to launch, new technologies are promising even more bandwidth and new services like High Speed Packet Uplink Access (HSUPA) (Enhanced DCH in 3GPP Release 6), MIMO (Multiple-Input Multiple-Output) and OFDM (Orthogonal Frequency Division Multiplexing) in 3GPP Release 7.

As the name implies, HSUPA is engineered to improve the spectral efficiency (high spectrum efficiency) and low latency for both the uplink and downlink with HSDPA/HSUPA. HSUPA will help improve symmetric applications such as video-conferencing, e-mailing large files back and forth, and transferring files. It is expected that HSUPA will use HSDPA techniques such as adaptive modulation and HARQ to improve both signal speed and quality. The 3GPP objectives with HSUPA or Enhanced-DCHA are to improve the performance of uplink dedicated transport channels by scheduling the Uplink UE data rates depending on the interferences and on the Node B processing resources, while increasing the radio interface robustness with the HARQ protocol. The 3GPP Study has concluded that the use of these mechanisms associated with a shorter TTI of 2 ms can lead to the following enhancements:

1. 50-70 % improvement in UL capacity
2. 20-55 % reduction in end-user packet call delay
3. Around 50 % in user packet call throughput

Obviously, One of the key procedures acting on the efficiency of data transmission is the packet scheduling. It is still the packet scheduling that we focus on in the following work.

1.2 Problem and Solution

The objective of this thesis is to propose a *Novel Stall Avoidance Scheduler* in order to take the "*stall*" or "*gap*" delay in the receiver end into account.

The next generation of WCDMA wireless multimedia networks will be a mixture of different traffic classes, i.e., Real Time (RT) and Non-Real Time (NRT) applications, each has its own QoS requirements such as throughput, delay, delay jitter and loss in terms of packet loss rate or block error rate (BLER). For such heterogeneous traffic, it is important that certain quality of service (QoS) targets be met. Real-time applications specifically require the delivery of information from the source to the destination within a predefined time. In order to satisfy the growing aggressive demand for the wireless packet data services, scheduling algorithms are widely used in WCDMA wireless multimedia networks to provide the guaranteed quality of service.

Most of literatures related to the WCDMA systems with HSDPA and are based on advanced techniques such as fast physical layer retransmission, adaptive modulation, fast link adaptation and efficient scheduling techniques can achieve high throughput up to 10 Mbps and reduce the system delay. However, these discussions did not elucidate the problem of packet stalling in receiving side reordering buffer. Recall, stalling occurs when one or more packets cannot be forwarded up due to missing packet or because of a misinterpretation of NACK-to-ACK or vice versa. Consequently, the overall system throughput may suffer from severe delay. Such delay has a direct impact on user's satisfaction, because it reduces the applications fidelity, which in turn causes the user's frustration. Also, Packet loss in the buffer affects the perceived quality of the application by compromising the integrity of the data to be transmitted or by disrupting the service.

In our approach, we consider the fact that the received packets in the reordering buffer are delayed or stalled (i.e. the process of forwarding packets to the upper layer is delayed) due to a NACK-to-ACK error. We assume that HS-PDSCH BLER is 0.5 for first transmission, the probability that the stall problem occurs is approximately is around 0.01 for HS-DPCCH p_{N-A} (NACK-to-ACK). A variety of packet scheduling algorithms was proposed in literature. However, these algorithms policies are not sufficient because they only take the channel variations and some factors observed from the transmit aspect, e.g. head-of-line delay and queue length, into consideration in WCDMA systems.

In this thesis, we are motivated to propose a *Novel Stall Avoidance Scheme* to take into account the end-to-end delay due to ”*stall*” or ”*gap*” problem in the receiving side reordering buffer by employing an $N - channel\ Stop - and - Wait$ *Hybrid Automatic Repeat Request* or *Retransmission Query* (SAW-HARQ). We compare through simulations the performance of the conventional schedulers based timer and window schemes with the proposed scheduler in the presence of packets stalls within the receiver reordering buffer process. Simulations show that in terms of *received goodput* in upper layer and overall system *delay*, the proposed stall avoidance scheduler (SA+QER) outperforms all the other existing schedulers, including maximum C/I, round robin, proportional fair, queue-based exponential rule. Furthermore, the overall system delay is significantly reduced by the stall avoidance scheduler. Furthermore, the overall system delay is significantly reduced by the stall avoidance scheduler.

1.3 Thesis Outline

The remaining chapters of this thesis are organized as follows. Chapter 2 describes the WCDMA Evolution which is High Speed Downlink Packet Access, in this section, we review the General HSDPA Concept Description, its Architecture through Channel Structure and the different techniques utilized by HSDPA to substitute power control and variable spreading factor such as AMC (Adaptive Modulation and Coding) and Multi-code Transmission and Fast Hybrid ARQ in order to cope with the dynamic range of the EsNo at the UE (User Equipment), HSDPA adapts the modulation, the coding rate and number of channelization codes to the instantaneous radio conditions. In chapter 3, we propose a *Novel Stall Avoidance Scheme* in order to solve the ”*stall*” or ”*gap*” problem in the receiving side reordering buffer and to make a comparative study between the conventional scheduling policies in HSDPA downlink for WCDMA systems employing the Maximum Carrier-to-Interference (MCI), Round Robin (RR), Proportional Fair (PF), queue-based exponential rule (QER), and the proposed Stall Avoidance (SA+QER) scheduling. At last, Chapter 4 gives the concluding remarks and suggestions for future works.

CHAPTER 2

WCDMA Evolution: High Speed Downlink Packet Access

2.1 Introduction

An increasing demand for both larger system capacity and higher data rates has launched the evolution of the mobile communication market. In order to boost the support for the packet switched services, the 3GPP has standardized in the Release 5 a new technology called High Speed Downlink Packet Access (HSDPA) that represents an evolution of the WCDMA radio interface. HSDPA appears as an umbrella of features whose combination improves the network capacity, increases the peak data rates around theoretically 14 Mbps for downlink packet traffic and decreases the system throughput delay. HSDPA can allow users to enable high peak data rate services with a lower cost per delivered data bit, improve the QoS of already existing services. The HSDPA concept relies on a new transport channel, the High Speed Downlink Shared Channel (HS-DSCH), where a large amount of power and code resources are assigned to a single user at a certain TTI in a time and code multiplex fashion. The time-shared nature of the HS-DSCH provides significant trunking benefits over DCH for bursty high data rate traffic [2]. These technological enhancements are possible due to the fact that HSDPA utilizes different techniques such as Adaptive Modulation and Coding (AMC), fast Physical Layer Hybrid ARQ, and fast Packet Scheduling.

These features are tightly coupled and permit a per- TTI adaptation of the transmission parameters to the instantaneous variations of the radio channel quality. The main objective of this chapter is to provide a general overview of HSDPA that is required to achieve a complete comprehension in order to analyze and design Packet Scheduling algorithms. Note that Packet scheduling is an important component of the overall HSDPA concept and the central scope of the next chapter and will, therefore, be detailed there. More overviews information on HSDPA concept can be found in [3–5]

The rest of the thesis is organized as follow:

In Section 2.2, we present a general description of the specific features included and excluded in HSDPA compared to basic WCDMA technology. Section 2.3 gives an overview of the major architectural modifications introduced by HSDPA, while Section 2.4 reviews the HSDPA channel structure. Section 2.5 describes the AMC functionality, while Section 2.6 deals with one of the most important features of HSDPA: the link adaptation functionality. Section 2.7 highlights the powerful HS-DSCH retransmission mechanism: Hybrid ARQ. Finally, Section 2.8 gives the main concluding remarks.

2.2 HSDPA General Concept Description

In WCDMA systems environment, fast power control stabilizes the received signal quality (EsNo) by increasing the transmission power during the fades of the received signal level. This causes peaks in the transmission power and subsequent power rise, which reduces the total network capacity. However, delay tolerant traffic may be served only under favourable radio channel conditions, avoiding the transmission during the inefficient signal fading periods. Moreover, the operation of power control imposes the need of certain headroom in the total Node B transmission power to accommodate its variations. The elimination of power control avoids the aforementioned power rise as well as the cell transmission power headroom. But due to the exclusion of power control, HSDPA requires other link adaptation mechanisms to adapt the transmitted signal parameters to the continuously varying channel conditions. One of these techniques is denominated Adaptive Modulation and Coding (AMC). With it, the modulation and the coding rate are adapted to the instantaneous channel quality instead of adjusting the power. The transmission of multiple Walsh codes is also used in the link adaptation process. Since the combination of these two mechanisms already plays the link adaptation role in HSDPA, the variable spreading factor is deactivated because its long-term adjustment to the average propagation conditions is not required anymore. As closed power control is not present, the channel quality variations must be minimized across the TTI, which it is accomplished by reducing its duration from the minimum 10 ms in WCDMA down to 2 ms. The fast Hybrid ARQ technique is added, which rapidly retransmits the missing transport blocks and combines the soft information from the original transmission with any subsequent retransmission before the decoding process. The network may include additional redundant information that is incrementally transmitted in subsequent retransmissions (i.e. Incremental Redundancy). To obtain recent channel quality information that permits the link adaptation and the Packet Scheduling entities to track the users instantaneous radio conditions, the MAC functionality in charge of the HS-DSCH channel is moved from the RNC to the Node B. The fast channel quality information allows the Packet Scheduler to serve the user only when his conditions are favourable. This fast Packet Scheduling and the time-shared nature of the HS-DSCH enable a form of multiuser selection diversity with important benefits for the cell throughput. The move of the scheduler to the Node B is a major architecture modification compared to the Release 99 architecture.

2.3 HSDPA Architecture

Compared with all the transport channels belonging to the Release 99 architecture, which are terminated at the RNC, the HS-DSCH is directly terminated at the Node B. With the purpose of controlling this channel, the MAC layer controlling the resources of this channel denominated MAC-hs is directly located in the Node B, the Radio Interface Protocol Architecture of HSDPA is depicted in Figure 2.1, thereby allowing the acquisition of recent channel quality reports that enable the tracking of the instantaneous signal quality for low speed mobiles. This location of the MAC-hs in the Node B also enables to execute the HARQ protocol from the physical layer, which permits faster retransmissions. More specifically, the MAC-hs layer is in charge of handling the HARQ functionality of every HSDPA user, distributing the HS-DSCH resources between all the MAC-d flows according to their priority i.e. Packet Scheduling, and selecting the appropriate transport format for every TTI i.e. link adaptation. The radio interface layers above the MAC are not modified from the Release 99 architecture because HSDPA is intended for transport of logical channels. Nonetheless, the RLC can only operate in either acknowledged or unacknowledged mode, but not in transparent mode due to ciphering. This is because for the transparent mode the ciphering is done in the MAC-d, not in the RLC layer, and MAC-c/sh and MAC-hs do not support ciphering. The MAC-hs also stores the user data to be transmitted across the air interface, which imposes some constraints on the minimum buffering capabilities of the Node B. The flow of the data queues to the Node B creates the need of a flow control mechanism called HS-DSCH Frame Protocol that aims at keeping the buffers full. The HS-DSCH FP handles the data transport from the serving RNC to the controlling RNC if the Iur interface is involved and between the controlling RNC and the Node B. The design of such flow control is a challenge, because this functionality in cooperation with the Packet Scheduler is to ultimately regulate the users perceived service, which must fulfil the QoS requirements according to the user's subscription. In other words the guaranteed bit rate or the transfer delay for streaming bearers or the traffic handling priority and the allocation or retention priority for interactive users. Furthermore, the HS-DSCH does not support soft handover due to the complexity of synchronizing the transmission from various cells. The HS-DSCH may optionally provide full or partial coverage in the cell.

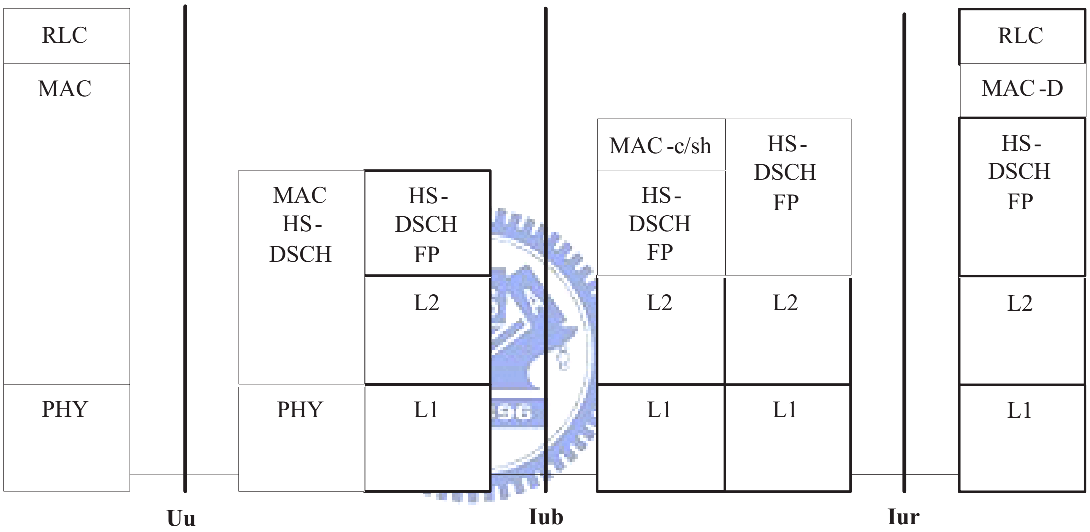

Figure 2.1: Radio Interface Protocol Architecture of HSDPA

2.4 HSDPA Channel Structure

There exists in WCDMA a transport channel particularly suited for downlink packet bursty traffic: the Downlink Shared Channel (DSCH). The DSCH provides common code resources that can be shared by several users in a time multiplex manner. It has the potential to improve the capacity for bursty packet traffic, since the sharing of the resources reduces the potential channelization code shortage that might occur if every user was allocated a DCH. As mentioned above, the HSDPA concept relies on a new transport channel, the HS-DSCH, which can be seen as an evolution of the DSCH channel. The HS-DSCH is mapped onto a pool of physical channels i.e. channelization codes, the figure**??** denominated HS-PDSCHs (High Speed Physical Downlink Shared Channel) to be shared among all the HSDPA users on a time multiplexed manner. The spreading factor of the HS-PDSCHs is fixed to 16, and the MAC-hs can use one or several codes, up to a maximum of 15. Moreover, the scheduler may apply code multiplexing by transmitting separate HS-PDSCHs to different users in the same TTI. The HSDPA concept includes a Shared Control CHannel (HS-SCCH) to signal the users when they are to be served as well as the necessary information for the decoding process. The HS-SCCH carries the following information:

- UE Id Mask: to identify the user to be served in the next TTI.
- Transport Format Related Information: specifies the set of channelization codes, and the modulation. The actual coding rate is derived from the transport block size and other transport format parameters.
- Hybrid ARQ Related Information: such as if the next transmission is a new one or a retransmission and if it should be combined, the associated ARQ process, and information about the redundancy version.

This control information solely applies to the UE to be served in the next TTI, which permits this signalling channel to be a shared one. The RNC can specify the recommended power of the HS-SCCH. The HS-SCCH transmit power may be constant or time varying according to a certain power control strategy though the 3GPP specifications do not set any closed loop power control modes for the HS-SCCH. An uplink High Speed Dedicated Physical Control Channel (HS-DPCCH) carries the necessary control information in the uplink, namely, the ARQ acknowledgements, and the Channel Quality Indicator (CQI) reports. To aid the power control operation of the HS-DPCCH an associated Dedicated Physical Channel (DPCH) is run for every user. The RNC may set the maximum transmission power on all the codes of the HS-DSCH and HS-SCCH channels in the cell. Otherwise, the Node B may utilize all unused Node B transmission power for these two channels, though this option will not be considered in the following chapters. Likewise, the RNC determines the maximum number of channelization codes to be used by the HS-DSCH channel.

2.5 AMC and Multi-code Transmission

As we have mentioned in Section 2.2, HSDPA utilizes other link adaptation techniques to substitute power control and variable spreading factor. To cope with the dynamic range of the EsNo at the UE, HSDPA adapts the modulation, the coding rate and number of channelization codes to the instantaneous radio conditions. The combination of the first two mechanisms is denominated Adaptive Modulation and Coding (AMC). Besides QPSK, HSDPA incorporates the 16QAM modulation to increase the peak data rates for users served under favourable radio conditions. Support for QPSK is mandatory for the mobile, though the support of 16QAM is optional for the network and the UE. The inclusion of this high order modulation introduces some complexity challenges for the receiver terminal, which needs to estimate the relative amplitude of the received symbols, whereas it only requires the detection of the signal phase in the QPSK case. A turbo encoder is in charge of the data protection. The encoder is based on the release 99 turbo encoder with a rate of 1/3, though other effective coding rates within the range from 1/6 to 1/1 can be achieved by means of rate matching, i.e. puncturing and repetition. The combination of a modulation and a coding rate will be denominated here as Modulation and Coding Scheme. Table 2.1 shows the set example of Modulation and Coding Schemes (MCS) used in HSDPA. Besides AMC, multi-code transmission can also be considered as a tool for link adaptation purposes. If the user enjoys good channel conditions, the Node B can exploit the situation by transmitting multiple parallel codes, reaching significant peak throughputs. For example in Figure 2.1, with the MCS 5 and a set of 10 multi-codes, a maximum peak data rate of up to 7 Mbps can be obtained [6]. Such high peak data rates are expected to be used under favourable instantaneous signal quality conditions. With the multi-code transmission, the overall dynamic range of the AMC can be increased by 10.log10(15) $\cong$ 12 dBs. The overall link adaptation dynamic range coped with the combination of the AMC and multi-code transmission is around 30 dB. Note that the dynamic range of the variable spreading factor of WCDMA is around 20 dB, which yields a dynamic range around 10 dB larger in HSDPA. Nonetheless, the dynamic range of HSDPA is slightly shifted upwards, which might indeed have some coverage implications. The most protecting coding rate (1/6) may not be sufficient to serve a user close to the cell edge during a signal level fade with a reasonable BLER.

Table 2.1: Modulation and Coding Schemes in the HSDPA Concept

Modulation and coding schemes (MCS)	Modulation	Effective code rate
MCS 1	QPSK	1/4
MCS 2	QPSK	1/2
MCS 3	QPSK	3/4
MCS 4	16-QAM	1/2
MCS 5	16-QAM	3/4

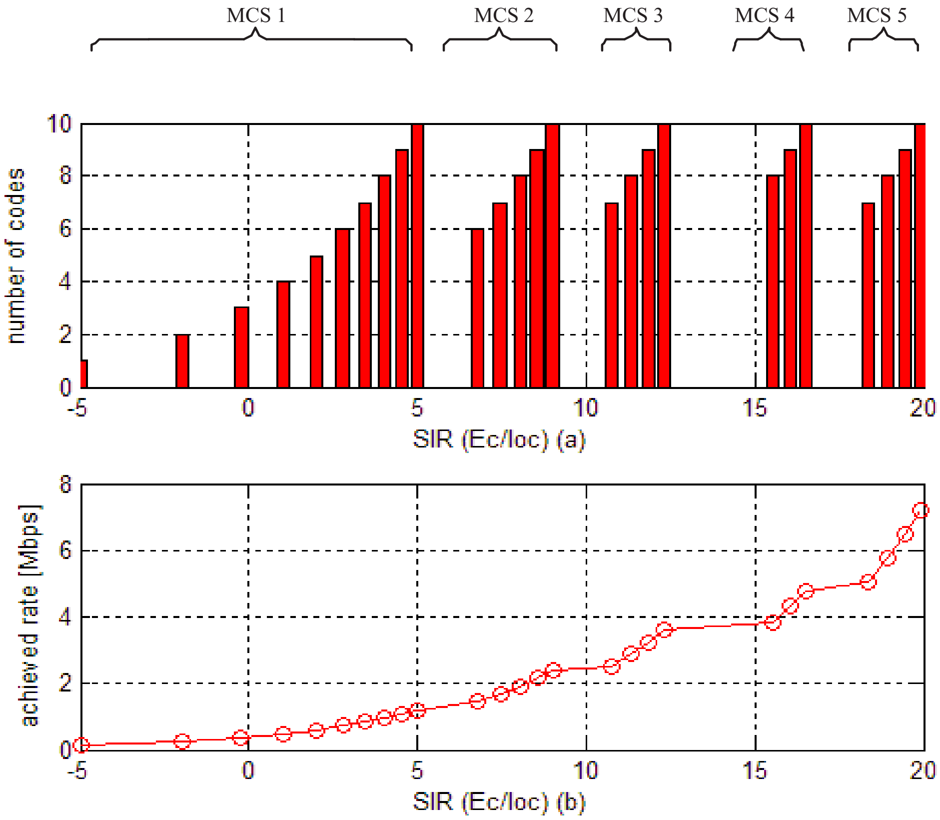

Figure 2.2: The hull curve with five modulation and coding schemes and the multi-code operation of maximum 10 codes.

2.6 Link Adaptation

Link adaptation is the process of modifying transmission parameters to adapt to the current channel parameters. Higher modulation, in conjunction with channel coding, optimizes the use of a fading radio channel. By transmitting at constant power, the modulation and coding schemes (MCS) can be selected to maximize throughput on the downlink. The media access control (MAC) in the Node B selects the MCS that match the instantaneous radio conditions depending on the shortened HSDPA transmission time interval (TTI). In other terms, the link adaptation functionality of the Node B is in charge of adapting the modulation, the coding format, and the number of multi-codes to the instantaneous radio conditions.

Fast link adaptation enables the use of more spectrally efficient modulation when channel conditions permit. Favorable channel conditions use 16 Quadrature Amplitude Modulation (QAM), while unfavorable channel conditions use Quadrature Phase Shift Keying (QPSK).

In Table2.1, for example, a coding rate of 1/4 means that error correction takes 75 percent of the bandwidth and the user data rate is only 25 percent of the maximum. Likewise, a coding rate of 3/4 means that the user achieves the maximum data rate, but there is no error correction, and therefore there will be many errors in the received data.

2.7 Link Adaptation Methods

The link adaptation functionality is to select the MCS and the number of multi-codes to adapt them to the instantaneous EbNo. However, The MCS selection criterion depends on:

- Channel Quality Indicator (CQI): the UE sends in the uplink a report denominated

CQI that provides implicit information about the instantaneous signal quality received by the user. The CQI specifies the transport block size, number of codes and modulation from a set of reference ones that the UE is capable of supporting with a detection error no higher than 10 in the first transmission for a reference HSPDSCH power. The RNC commands the UE to report the CQI with a certain periodicity from the timing set [2, 4, 8, 10, 20, 40, 80, 160] ms can be found in [7], and can possibly disable the report.

- Power Measurements on the Associated DPCH: every user to be mapped on to HSDSCH runs a parallel DPCH for signalling purposes, whose transmission power can be used to gain knowledge about the instantaneous status of the users channel quality. This information may be employed for link adaptation as well as Packet Scheduling. With this solution, the Node B requires a table with the relative EbNo offset between the DPCH and the HS-DSCH for the different MCSs for a given BLER target. The advantages of utilizing this information are that no additional signalling is required, and that it is available on a slot basis. However, it is limited to the case when the HS-DSCH and the DPCH apply the same type of detector e.g. a conventional Rake, and can not be used when the associated DPCH enters soft handover.
- Hybrid ARQ Acknowledgements: The acknowledgement corresponding to the H-ARQ protocol may provide an estimation of the users channel quality too, although this information is expected to be less frequent than previous ones because it is only received when the user is served. Hence, it does not provide instantaneous channel quality information. Note that it also lacks the channel quality resolution provided by the two previous metrics since a single information bit is reported.
- Buffer Size: the amount of data in the MAC-hs buffer could also be applied in combination with previous information to select the transmission parameters.

In order to optimize the implementation of the link adaptation functionality, a combination of all the previous information sources is needed. However, if only one of them is to be selected, the CQI report possibly appears as the most attractive solution due to its simplicity for the network, its accuracy and its frequent report.

2.8 Fast Hybrid ARQ

HSDPA incorporates a physical layer retransmission functionality that significantly improves the performance and adds robustness against link adaptation errors. Since the Hybrid ARQ functionality is located in the MAC-hs entity of the Node B, the transport block retransmission process is considerable faster than RLC layer retransmissions because the RNC or the Iub are not involved. This benefit is directly reflected on a lower UTRAN transfer delay (both in terms of average and standard deviation), which has obvious pay offs at end-to-end level. The retransmission protocol selected in HSDPA is the Stop And Wait (SAW) due to the simplicity of this form of ARQ. In SAW, the transmitter persists on the transmission of the current transport block until it has been successfully received before initiating the transmission of the next one. Since the continuous transmission to a certain UE should be possible, N SAW-ARQ processes may be set for the UE in parallel, so that different processes transmit in separate TTIs. The maximum number of processes for a single UE is 8. According to L1 round trip time estimates, the delay between transmission and first retransmission is around 12 ms, which requires 6 SAW processes for continuous transmission to a single UE. The SAW protocol is based on an asynchronous downlink and synchronous uplink. That implies that in downlink, the HS-SCCH must specify the HARQ process that is transmitting on the HS-DSCH, while in uplink the SAW process acknowledgements are tied to the timing. The Hybrid ARQ technique is fundamentally different from the WCDMA retransmissions because the UE decoder combines the soft information of multiple transmissions of a transport block at bit level. Note that this technique imposes some memory requirements on the mobile terminal, which must store the soft information of unsuccessfully decoded transmissions. There exist different Hybrid ARQ strategies:

- Chase Combining (CC): in this scheme, every retransmission is simply a replica of the coded word employed for the first transmission. The decoder at the receiver combines these multiple copies of the transmitted packet weighted by the received SNR prior to decoding. This type of combining provides time diversity and soft combining gain at a low complexity cost and imposes the least demanding UE memory requirements of all Hybrid ARQ strategies. The combination process incurs a minor combining loss to be around 0.2-0.3 dB per retransmission.

- Incremental Redundancy (IR): The retransmissions include additional redundant information that is incrementally transmitted if the decoding fails on the first attempt. That causes that the effective coding rate increases with the number of retransmissions. Incremental Redundancy can be further classified in Partial IR and Full IR. Partial IR includes the systematic bits in every coded word, which implies that every retransmission is self-decodable, whereas Full IR only includes parity bits, and therefore its retransmissions are not self-decodable. IR, and particularly Full IR, imposes demanding requirements on the UE memory capabilities, and the standard only compels the UE soft memory to support the needs for Chase Combining. Full IR only provides a significant coding gain for effective coding rates higher than 0.4-0.5, because for lower coding rates the additional coding rate is negligible since the coding scheme is based on a 1/3 coding structure. On the other hand, for higher effective coding rates the coding gain can be significant, for example a coding rate of 0.8 provides around 2 dB gain in Vehicular A, 3km/h, QPSK modulation.

Due to its simplicity and its straightforward modelling, the Chase Combining method only requires the addition of the signal qualities of the multiple retransmissions and the subtraction of the combining loss.

2.9 Summary

This chapter described a general overview of the technologies used in the HSDPA concept. Although each of these technologies by itself provides a significant network performance enhancement, however their combination in terms of complementary characteristics makes HSDPA a key step in the evolution of WCDMA. The introduction of the AMC technique allows to exploit the high throughput available for users under favorable instantaneous signal quality conditions. The multi-code operation combined with the AMC extends the operating signal dynamic range up to around 30 dB. However, this range is still smaller than the one given by the combination of power control and variable spreading factor. The most protective effective coding rate (around 1/6) already yields a data rate of 80 kbps, which might be not sufficiently robust to serve a user close to the cell edge during a signal fade with a reasonable BLER. According to the link adaptation operation, the multi-code allocation is more spectrally efficient than the usage of a less robust Modulation and Coding Scheme in power limited conditions. With a fine resolution of the coding rate in the set of available MCSs, the assignment of a less protecting Modulation and Coding Scheme should be restricted to code shortage situations. The Hybrid ARQ represents a fast and efficient mechanism that reduces the average retransmission delay in UTRAN. Hybrid ARQ provides protection against measurement errors and delays that can induce link adaptation errors. In Hybrid ARQ, the soft combining of the multiple transmissions of a certain packet provides time diversity and soft combining gain, which reduces the average number of transmissions for successfully decoding with obvious benefits in terms of spectral efficiency. With Incremental Redundancy, the retransmissions can decrease the effective coding rate and increase the soft combining gain, though this is expected to be significant only for high coding rates in the first transmission. The architectural modifications of HSDPA are introduced to take advantage of the knowledge of the instantaneous signal quality in the radio interface. It enables to modify the classical CDMA concept of maintaining a certain channel bit rate and vary the transmission power to compensate for the channel fades, towards adaptation of the users data rate while keeping the transmission power about constant. From a complexity point of view, the deployment of HSDPA requires a Node B software update and possibly a hardware upgrade to increase the processing power of the base station. This extra processing power will allow the Node B to execute the new HSDPA functionalities (e.g. Packet Scheduling and link adaptation). Additionally, HSDPA imposes some new requirements on the mobile terminal. HSDPA capable terminals have to incorporate functionalities for the Hybrid ARQ soft combining, multi-code reception, 16QAM detection (optional), etc. The migration from WCDMA to HSDPA may initially be done only in certain areas of the network such as hot spots (indoor offices, airports, etc). As the traffic demand increases, operators may gradually upgrade the rest of the network.

CHAPTER 3

A Novel Stall Avoidance Scheduler

3.1 Introduction

The next generation of WCDMA wireless multimedia networks will be a mixture of different traffic classes, i.e., Real Time (RT) and Non-Real Time (NRT) applications, each has its own QoS requirements such as throughput, delay, delay jitter and loss in terms of packet loss rate or block error rate (BLER). For such heterogeneous traffic, it is important that certain quality of service (QoS) targets be met. Real-time applications specifically require the delivery of information from the source to the destination within a predefined time. In order to satisfy the growing aggressive demand for the wireless packet data services, scheduling algorithms are widely used in WCDMA wireless multimedia networks to provide the guaranteed quality of service.

High speed downlink packet access (HSDPA) has become an important technique in the wideband code division multiple access (WCDMA) systems. The goal of HSDPA is to provide high data transmission rates up to 10 Mbits/sec [8]. To achieve this goal, some key techniques are applied in HSDPA, including the physical layer fast adaptive modulation and coding, fast packet scheduling in the medium access control (MAC) layer, fast cell selection, multiple input multiple output (MIMO) antenna, and buffer overflow control.

However, the stall problem in HSDPA can terminate forwarding the media access control (MAC) layer packets to the upper layer [9]. In order to fully utilize the channel capacity, the HSDPA adopts the multi-process stop-and-wait (SAW) hybrid automatic repeat request (HARQ) to implement the concept of ”keeping the pipe full”, the multi-process SAW-HARQ is depicted in fig. 3.1. In the multi-process SAW HARQ protocol, the receiver sends back an acknowledge (ACK) or a negative acknowledge (NACK) to inform the transmitter whether a packet should be retransmitted or not. Nevertheless, when a NACK signal becomes an ACK signal due to the transmission errors in the control channel, the transmitter mistakenly believes that the packet has successfully reached the destination while the receiver keeps waiting for the retransmission. More seriously, the process of forwarding the already received packets in the reordering buffer of the MAC layer to the upper layer can be held up. We call this dilemma the stall problem.

Most of literatures related to the WCDMA systems with HSDPA [10], [11], [12], [13] and [14] are based on advanced techniques such as fast physical layer retransmission, adaptive modulation, fast link adaptation [6] [15] and efficient scheduling techniques can achieve high throughput up to 10 Mbps [10], [12] and reduce the system delay [6]. However, these discussions did not elucidate the problem of packet stalling in receiving side reordering buffer, a single device block diagram is depicted in Fig. 3.1.

A variety of packet scheduling algorithms was proposed in literature [13], [16], [17], [18], [15], [19] , and [20]. However, these algorithms are not sufficient and cannot deal with stalling incurred in the receiver side buffer. The design of scheduling algorithms for wireless communication networks is a challenge because of the heavy traffic, the high variable link error rates, the system capacity, and mobility. Also, the connectivity specifically encountered in such networks.

In this thesis, we are motivated to propose a novel scheduler namely called Novel Stall Avoidance Scheduler and we compare the performance between the conventional schedulers - Maximum Carrier-to-Interference (MCI), Round Robin (RR), Proportional Fair (PF), queue-based exponential rule (QER), and the proposed Stall Avoidance scheduling (SA+QER) each associated with timer and window size in the presence of "*stalls*" or "*gaps*" within the receiver buffer due to the reordering process. The novel scheduler is to be implemented in the MAC layer for CDMA systems. Its goal is to solve the "*stall*" or "*gap*" problem once it occurs during the process of forwarding packets to upper layers according to their delay requirements. Therefore, the throughput is maximized by reordering packet transmissions according to traffic classes and by scheduling the packet transmissions at the mobile terminal's maximum possible transmission rate. Furthermore, packet losses are minimized by using a Stop-and-Wait Hybrid Automatic Request (SAW HARQ) protocol. An analytic evaluation of the performance of the Send and Wait Protocol can be found in [21].

The remainder of this paper is organized as follows. In section II, we present the gap problem. In Section III, we propose HARQ protocol and the different packet scheduling algorithms (MCI, RR, PF, QER and the proposed Stall Avoidance (SA) scheduler). In Section IV, we propose the system model. In Section IV, we state our assumptions and compare the performance of these schedulers and analyze the results. Finally, in Section VI we conclude the paper by highlighting our contribution.

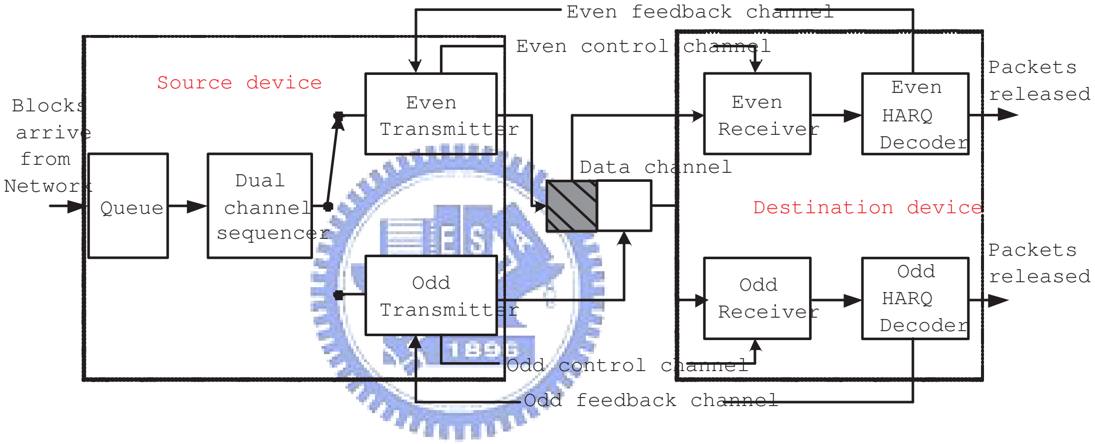

Figure 3.1: single device block diagram.

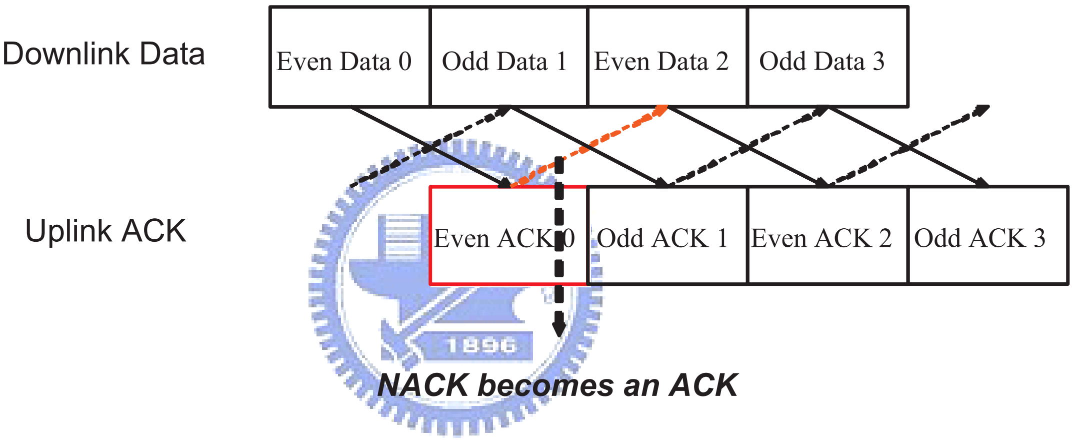

Figure 3.2: A NACK becomes an ACK.

3.2 Problem Statement and solutions

Stalling occurs when one or more packets cannot be forwarded up due to missing packet or because of a misinterpretation of an NACK-to-ACK or vice versa. The fig. 3.2 is an illustration of this problem. A well-known drawback of this problem is that the whole system throughput may suffer from severe delay. Such delay has a direct impact on user's satisfaction, because it reduces the applications fidelity, which in turn causes the user's frustration. Also, packet loss in the buffer affects the perceived quality of the application by compromising the integrity of the data to be transmitted or by disrupting the service.

In other words, when the stall problem happens, the performance of the end-to-end packet delivery delay and the system goodput can be seriously degraded, especially when a scheduler is applied to allocate resources to a large number of users. In HSDPA, a system scheduler is applied to assign the transmission time interval (TTI) to users [22]. To achieve the fairness and transmission efficiency, users are supposed to own similar amount of TTIs and transmit signals in a discontinuous fashion according to the channel conditions. Thus, in the stall situation, the received packets will be reluctantly accumulated in the reordering buffer of the MAC layer for a long time until the stall problem has been solved. Note that the stall problem can be solved when a predefined timer expires [23] or a detection window is overbooked by the newly received packets [24]. Although the stall problem can be eventually solved, how to accelerate the detection window to be overbooked and increase the amount of packets to be forwarded to the upper layer as the timer expires becomes a new and important issue to smooth the impact of the stall problem on HSDPA.

By adopting the fast retransmission strategy based N-channel SAW HARQ, our proposed scheme recovers from packet loss by significantly increasing the aggregated overall received packet in upper layer also the delay induced by whatever gap is reduced. In addition, the overall system delay is significantly reduced. In an N-channel ARQ, a new Transmission Sequence Number (TSN), in increasing order, is appended to each new packet transmission in the N-channels. With N-channel ARQ, packets may arrive at the receiver out of their original order. This may happen because the packets sent in different HARQ processes are sent at different times (in order), controlled by the scheduler, these processes are depicted in Fig. 3.3. However, due to the retransmissions process, these different HARQ processes are received successfully in random time. This is due to the fact that different HARQ processes may require different numbers of retransmissions. Since packets must be delivered to higher layers in their original order, a packet cannot be delivered to a higher layer if a packet with a lower sequence number has yet to be received. The effects of the out-of-sequence packets on the higher layer would depend on the operating mode configured at the next layer such as Radio Link Control (RLC) for a particular service.

In this thesis, we proposed a novel stall avoidance (SA) scheduling for HSDPA to increase the amount of MAC layer packets ready to be forwarded to the upper layer and trigger this packets forwarding process earlier. The goal of the proposed novel scheduler is to improve the goodput and reduce the end-to-end packet delivery delay. In the proposed novel stall avoidance scheduling policy, the transmitter allocates more TTIs to the user in the two situations: (1) packets are already stored in the reordering buffer of the MAC layer for a longer period of time; (2) more packets are accumulated in the reordering buffer of the MAC layer. To support this idea, the receiver has to periodically feedback the counting of the timer and the number of packets accumulated in the MAC layer via the feedback control channel.

With the aid of the SA scheduler, the amount of available MAC layer packets to be forwarded to the upper layer as the timer expires can be largely increased in the above first situation. As a result, the degraded goodput can be recovered quickly. In the above second situation, the SA scheduler makes the detection window be overbooked much earlier by receiving more packets. Then, the end-to-end packet delivery delay can be reduced. Comparing with the conventional schedulers, not only the head-of-line delay, the proposed SA scheduled also takes the goodput and the end-to-end packet delivery delay into consideration. The simulation results show that the proposed stall avoidance scheduler can outperform the conventional schedulers in terms of the goodput and packet delivery delay.

In this paper, we first investigate through simulation the effect of stall problem assuming a single user in the cell. Secondly, we compare the performance between the conventional schedulers - Maximum Carrier-to-Interference (MCI), Round Robin (RR), Proportional Fair (PF), queue-based exponential rule (QER), and the proposed Stall Avoidance scheduling (SA+QER) each associated with timer and window size in the presence of ”*stalls*” or ”*gaps*” within the receiver buffer in a multiuser environment.

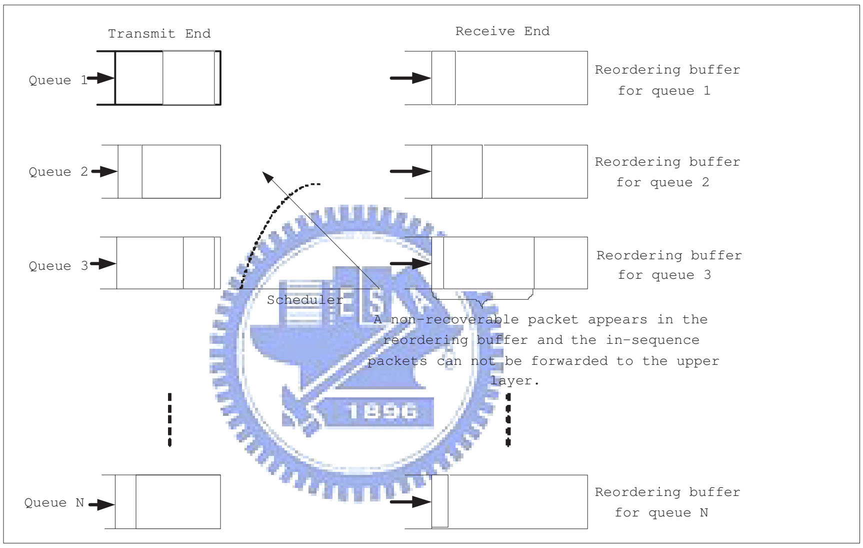

Figure 3.3: Packets are sent in different HARQ processes via the scheduler.

3.3 Hybrid Automatic Request HARQ

HSDPA incorporates a physical layer retransmission functionality that can significantly increase user throughput over independent ARQ. Therefore, it improves the performance and adds robustness against link adaptation errorsbecause it does not rely on channel estimates to provide the correct code rate, but instead relies on the errors signalled by the ARQ protocol. The Hybrid ARQ functionality is located in the MAC-hs entity of the Node B, the transport block retransmission process is considerable faster than RLC layer retransmissions because the RNC or the Iub are not involved. This benefit is directly reflected on a lower UTRAN transfer delay in terms of average and standard deviation.

The drawback of using Hybrid ARQ is that HARQ requires additional receiver memory to store unsuccessful attempts. As a result, Hybrid ARQ can significantly increase UE complexity depending on the ARQ protocol design and the network configuration. However the choice of H-ARQ mechanism is important. According to [6] there are two main ARQ mechanisms:

- $Selective\ Repeat\ (SR)$
- $Stop - And - Wait\ (SAW)$ is of special interest

In SR, only erroneous blocks are re-transmitted. A sequence number is required to identify the block. In order to fully utilize the available channel capacity the SR ARQ transmitter needs to send a number of blocks while awaiting a response or lack of it. Thus mobile memory requirements can be huge. More importantly, H-ARQ requires that the receiver must know the sequence number prior to combining separate re-transmissions.

Stop-and-wait (SAW) due to its simplest form is the selected retransmission protocol in HSDPA because it requires very little overhead. In this scheme, the transmitter persists on the transmission of the current transport block until it has been successfully received before initiating the transmission of the next one. Protocol correctness is ensured with a simple one-bit sequence number that identifies the current or the next block. Hence, the control overhead is minimized a technical detail SAW HARQ is given in. Furthermore, because only a single block is in transit at a time, memory requirements at the UE are also minimized. Therefore, HARQ using a stop-and-wait mechanism offers significant improvements by reducing the overall bandwidth required for signalling and the UE memory. However, it is important to notice a major drawback of this protocol: acknowledgements are not instantaneous and therefore after every transmission, the transmitter must wait to receive the acknowledgement prior to transmitting the next block. Furthermore, the channel remains idle and system capacity goes wasted. In a slotted system, the feedback delay will waste at least half the system capacity while the transmitter is waiting for acknowledgments. So, at least every other timeslot must go idle even on an error free channel. Therefore, an ARQ method for Hybrid ARQ with the minimal complexity of stop-and-wait but with the throughput efficiency is desired. Since the continuous transmission to a certain UE should be possible, N SAW-ARQ processes may be set for the UE in parallel, so that different processes transmit in separate TTIs. The maximum number of processes for a single UE is 8. According to L1 round trip time estimates, the delay between transmission and first retransmission is around 12 ms, which requires 6 SAW processes for continuous transmission to a single UE. The SAW protocol is based on an asynchronous downlink and synchronous uplink. That implies that in downlink, the HS-SCCH must specify the HARQ process that is transmitting on the HS-DSCH, while in uplink the SAW process acknowledgements are tied to the timing. In our simulation, we propose a 6-channel SAW-HARQ implementation. This scheme offers a solution by parallelising the stop-and-wait protocol and in effect running a separate instantiation of the Hybrid ARQ protocol when the first channel is idle. As a result the system capacity is well-used since one instance of the algorithm communicates a data block on the forward link at the same time that the other communicates an acknowledgment on the reverse link [6].

3.3.1 Packet Scheduling Algorithms

Packet Scheduling Algorithms are divided in two main groups: *fast scheduling* and *slow scheduling* methods. Let us first define the different parameters that will be used in the following equations:

- $a_i > 0$ where $i = 1...N$: are selected weights to characterize the desired quality of service.
- k: the index of the k^{th} transmission time interval (TTI).
- $\gamma_i(k)$: the short-term SIR of user i averaged in the $(k-1)^{th}$ TTI.
- $\overline{\gamma_i(k)}$: the long-term average SIR of user i observed in $[(k-T), k]$, where T is the length of sliding window in terms of the number of TTIs.
- $d_i(k)$: the delay time for the packet waiting in the head of line (HOL) TTI before getting the service for user i.
- $q_i(k)$: the queue length of user i at the beginning of the k^{th} TTI.

Fast Scheduling makes scheduling decisions on recent UE channel quality measurements i.e. executed on a TTI basis that allow to track the instantaneous variations of the user's supportable data rate. These algorithms have to be executed in the Node B in order to acquire the recent channel quality information. These methods can exploit the multiuser selection diversity, which can provide a significant capacity gain when the number of time multiplexed users is sufficient.

(a) $Maximum\,Carrier-to-Interference$ (MCI): This scheduling algorithm serves in every TTI the user with largest instantaneous supportable data rate. This serving principle has obvious benefits in terms of cell throughput, although it is at the cost of lacking throughput fairness because users under worse average radio conditions are allocated lower amount of radio resources. Nonetheless, since the fast fading dynamics have a larger range than the average radio propagation conditions, users with poor average radio conditions can still access the channel. Specifically, the maximum C/I scheduler will select the user j in the k-th TTI if

$$j = \arg\{\max_i \gamma_i(k)\}. \tag{3.1}$$

(b) *Proportional Fair* (PF): the Proportional Fair scheduler serves the user with largest relative channel quality. This algorithm intends to serve users under very favourable instantaneous radio channel conditions relative to their average ones, thus taking advantage of the temporal variations of the fast fading channel. Specifically, the proportional fair scheduler will schedule user j in the k-th TTI if

$$j = \arg\{\max_i \frac{\gamma_i(k)}{\overline{\gamma_i(k)}}\}. \tag{3.2}$$

Based on the above criterion, the $\overline{\gamma_i(k)}$ is the average SIR measured over a sliding window as follows,

$$\overline{\gamma_i(k+1)} = \begin{cases} (1-\frac{1}{T})\overline{\gamma_i(k)} + \frac{1}{T}\gamma_i(k) \\ \text{if user } i \text{ is scheduled,} \\ (1-\frac{1}{T})\overline{\gamma_i(k)} \\ \text{if user } i \text{ is not scheduled.} \end{cases}$$

Slow Scheduling method basically allows scheduling decisions on the average user's signal quality or that do not use any user's performance metric at all.

(a) Round Robin (RR): In this scheme, the users are served in a cyclic order ignoring the channel quality conditions. This method outstands due to its simplicity, and ensures a fair resource distribution among the users in the cell. It is interesting to observe that the Round Robin scheduling method satisfies the proportional fairness criterion described by Kelly in. The Round Robin scheduler schedules user j in the k-th TTI if

$$j = mod((k-1), N) + 1, \tag{3.3}$$

where $mod(\cdot)$ denotes the modulus operator and the N is the number of active users in the system.

(b) Queue-Based Exponential Rule Scheduler:

Let us first define what Fairness Index (FI)

For any time interval $[t_1, t_2]$, the channel capacity allocated to flow i, denoted as $W_i(t_1, t_2)$, should satisfy the following condition:

$$\left| \frac{W_i(t_1, t_2)}{r_i} - \frac{W_j(t_1, t_2)}{r_j} \right| = 0, \ \forall i, j \in B(t_1, t_2), \tag{3.4}$$

where r_i and r_j are the weights of flows i and j, respectively, and $B(t_1, t_2)$ is the set of backlogged flows during (t_1, t_2). However, this condition in terms of bits can not be maintained in a practical packet switched network. The goal of the packetized fair queueing algorithm is to minimize the difference of $|W_i(t_1, t_2)/r_i - W_j(t_1, t_2)/r_j|$. Therefore, we define a fairness index as follows,

$$FI = \frac{1}{l} \left| \frac{W_i(t_1, t_2)}{r_i} - \frac{W_j(t_1, t_2)}{r_j} \right|, \tag{3.5}$$

where l is a normalization factor of the packet size.

The exponential rule scheduler considers the effect of the delay time in the head of line (HOL) TTI. However, it does not *explicitly* incorporate the factor of queue length into the scheduling policy. By observing (3.5), we note that to achieve fairness not only the HOL delay is required to be considered, but also the queue length. Consequently, we are motivated to propose a queue-based exponential rule scheduler as follows. In the k^{th} TTI, the proposed scheduler will choose user j if

$$\begin{aligned} j \;&= \arg\{\max_i a_i \tfrac{\gamma_i(k)}{\overline{\gamma_i(k)}} \exp\left(\tfrac{a_i d_i(k) - \overline{ad(k)}}{1+\sqrt{\overline{ad(k)}}}\right) \cdot \\ &\exp\left(\tfrac{q_i(k)-\overline{q(k)}}{1+\overline{q(k)}}\right)\}, \end{aligned} \tag{3.6}$$

where

$$\overline{ad(k)} = \frac{1}{N}\sum_{i=1}^{N} a_i d_i(k), \tag{3.7}$$

and

$$\overline{q(k)} = \frac{1}{N}\sum_{i=1}^{N} q_i(k). \tag{3.8}$$

The basic idea of second exponent term in is to balance the service queue length among multiple users. Moreover, in order to prevent the second exponent term from exceeding that of first exponent term, the denominator of the second exponent term does not take the square root as that of the first exponent term.

(c) *Stall Avoidance Schemes:*

Currently, two basic stall avoidance mechanisms are defined to reduce the number of gaps in the re-ordering buffer due to out-of-sequence packet delivery. These are commonly known as the timer-based and window-based mechanisms.

- $Timer-based\ mechanism$: A timer is triggered when a packet cannot be delivered to higher layers due to the non-arrival of a packet with a lower sequence number. Upon timer expiration, the gap is flushed and the recovery of the lost packet must be accomplished via the higher RLC layer, thereby introducing increased latency.

$$j \;\;=\;\; arg\left\{\max_i a_i \frac{\gamma_i(k)}{\overline{\gamma_i(k)}}\right.$$

$$exp\left(\frac{a_i d_i^{(tx)}(k) - \overline{ad^{(tx)}(k)}}{1+\sqrt{\overline{ad^{(tx)}(k)}}}\right)$$

$$exp\left(\frac{q_i^{(tx)}(k) - \overline{q^{(tx)}(k)}}{1+\sqrt{\overline{q^{(tx)}(k)}}}\right)$$

$$exp\left(\frac{b_i d_i^{(rx)}(k) - \overline{bd^{(rx)}(k)}}{1+\sqrt{\overline{bd^{(rx)}(k)}}}\right)\Bigg\}$$

Where

$$\overline{ad^{(tx)}(k)} = \frac{1}{N}\sum_{i=1}^{N} a_i d_i^{(tx)}(k), \tag{3.9}$$

$$\overline{bd^{(rx)}(k)} = \frac{1}{N}\sum_{i=1}^{N} b_i d_i^{(rx)}(k), \tag{3.10}$$

and

$$\overline{q^{(tx)}} = \frac{1}{N}\sum_{i=1}^{N} q_i^{(tx)}(k) \tag{3.11}$$

- *Window − based mechanism*: the transmitter operates under simple rules derived from the modular nature of the packet sequence numbers to remove stalling in the receiver re-ordering buffer. The window size defines the range of expected sequence numbers at the receiver, and in order to avoid modular ambiguity the window size cannot be larger than half the TSN space. A coherent example that elucidates a gap processing is given in [25], suppose the TSN is allotted 3 bits and thus has a sequence number range of $0, 1, 2, .., 7$. The transmitter can only transmit packets within a TSN window of 4 packets (or less). Suppose TSNs 1, 2 and 3 are received and 0 is not received. The transmitter may either re-transmit 0 or transmit a new packet 4. Transmitting 4 "advances the window" and thus communicates to the receiver that 0 will not be re-transmitted. This ends the stall caused by packet 0 on the higher numbered packets that cannot be delivered to the higher layer. Due to the complexity of the MAC-hs protocol, various factors must be taken into account in any analysis of stall avoidance performance. These factors are summarized in:

$$\begin{aligned} j \;=\; arg\Bigg\{ & \max_i a_i \frac{\gamma_i(k)}{\overline{\gamma_i(k)}} \\ & exp\left(\frac{a_i d_i^{(tx)}(k) - \overline{ad^{(tx)}(k)}}{1+\sqrt{\overline{ad^{(tx)}(k)}}}\right) \\ & exp\left(\frac{q_i^{(tx)}(k) - \overline{q^{(tx)}(k)}}{1+\sqrt{\overline{q^{(tx)}(k)}}}\right) \\ & exp\left(\frac{q_i^{(rx)}(k) - \overline{q^{(rx)}(k)}}{1+\sqrt{\overline{q^{(rx)}(k)}}}\right)\Bigg\} \end{aligned}$$

Where

$$\overline{ad^{(tx)}(k)} = \frac{1}{N}\sum_{i=1}^{N} a_i d_i^{(tx)}(k), \tag{3.12}$$

$$\overline{q^{(tx)}} = \frac{1}{N}\sum_{i=1}^{N} q_i^{(tx)}(k), \tag{3.13}$$

and

$$\overline{q^{(rx)}} = \frac{1}{N}\sum_{i=1}^{N} q_i^{(rx)}(k) \tag{3.14}$$

3.4 System model

We consider a multi-cell CDMA system with 30 users in the center cell of interest. The downlink traffic is transmitted using multi-code transmission with base spreading factor in the shared channel denoted by the transport channel HS-DSCH. An HARQ scheme using SAW-HARQ is simulated in this study. The spreading factor is 16 and a 1/3 Turbo Code forms the base code. Modulation with QPSK and 16 QAM are the only allowed. We evaluated by system simulation the effect of gap using the fast packet scheduling algorithms associated with the timer and window based on the achievable throughput performance, assuming a 6-channel SAW- HARQ protocol evaluated. A three-sectored 7-hexagonal cell model was used. the major simulation parameters and explanation are given in Table 1 in annex. We assume that HS-PDSCH BLER is 0.5 for first transmission, the probability that the stall problem occurs is approximately is around 0.01 for HS-DPCCH p_{N-A} (NACK-to-ACK).

3.5 Simulation Results

We first investigate the stall effect on single user throughput.This effect on upper layer throughput is depicted in fig. 3.4. The figure shows that without timer and window stall avoidance schemes, the user throughput decreases significantly. When the timer and window schemes are respectively coupled with packet scheduling algorithms, the user throughput is maintained at a high level and the system transmission continuity is ensured as long as there are packets to be sent in the buffer.

Secondly we compare the performance of the five schedulers with different timer settings in the presence of stall in terms of aggregated received throughput in upper layer during interval T when multiple users request packet transmission. We employed a 6-channel SAW HARQ to achieve high-speed packet transmission beyond 3 Mbps. The Figs. 3.5, 3.6 and 3.7 show the cumulative distribution of different schedulers associated with Timer T=1sec, T=2sec and T=3sec. we observe that in term of the upper layer received goodput versus user throughput, the proposed SA+QER outperforms all the other conventional schedulers.

Thirdly, we compare the cumulative distribution of different schedulers associated with window settings i.e., W=16, W=32, and W=64 are respectively depicted in Figs. 3.8, 3.9 and 3.10. We observe that users with SA+QER based window schemes can obtain throughput up to 3 Mbps and have higher throughput than those with other schemes. Furthermore, the end-to-end received goodput delay is reduced to around 10% Fig. 3.11. As result, the overall system delay based on SA+QER is also reduced.

3.6 Conclusion

we propose a *Novel Stall Avoidance Scheduler* take into account the end-to-end delay incurred ”*stall*” or ”*gap*” problem in the receiving side packet reordering buffer. We compare the performance between the conventional schedulers including - Maximum Carrier-to-Interference (MCI), Round Robin (RR), Proportional Fair (PF), queue-based exponential rule (QER), and the proposed Stall Avoidance scheduling (SA+QER) based Timer and Window mechanisms in the presence of ”*stalls*” or ”*gaps*” in the receiver reordering buffer.

We employ the fast packet scheduling based 6-channel SAW HARQ to achieve high-speed packet transmission up to 3 Mbps in a packet stalling environment for HSDPA in the W-CDMA systems. The simulation results elucidate that the received goodput in upper layer with window mechanism is higher than that with timer mechanism in a slow mobility environment such as the average vehicular speed of 3 km/h. However, the effect of employing the proposed (SA+QER) based Timer and window schemes maintains user throughput at high level. In other hand, it significantly improves the user aggregated throughput for all the 30 accessing users. In summary, our simulation results show that the proposed scheme deliver higher throughput than all the other schedulers for different timers setting and window. In addition, the end-to-end received delay is also reduced to around 10%. As result, the overall system delay based on SA+QER is also reduced.

Table 3.1: Simulation Parameters

Parameters	Explanation/Assumption
Cell layout	7 hexagonal cells
Cell radius	1.6 km
User location	Uniform distribution
Num. of retransmissions	unlimited
Num. of SAW HARQ channel	6
HS-PDSCH BLER	0.5
HS-DPCCH p_{N-A} (NACK-to-ACK)	0.01
Antenna pattern	Omni-direction
Propagation model	L = 128.1 + 37.6 Log10(R)
HS-DSCH power budget/the total Node-B power	60 %
Shadowing Std. deviation	8 dB
Correlation distance of shadowing fading	50 m
Carrier frequency	2 GHz
Base station total transmit power	44 dBm
Fast fading model	Jakes spectrum
Number of HS-DSCH multi-codes	10
Transmission time interval (TTI)	2 msec
Simulation duration	6000 TTIs

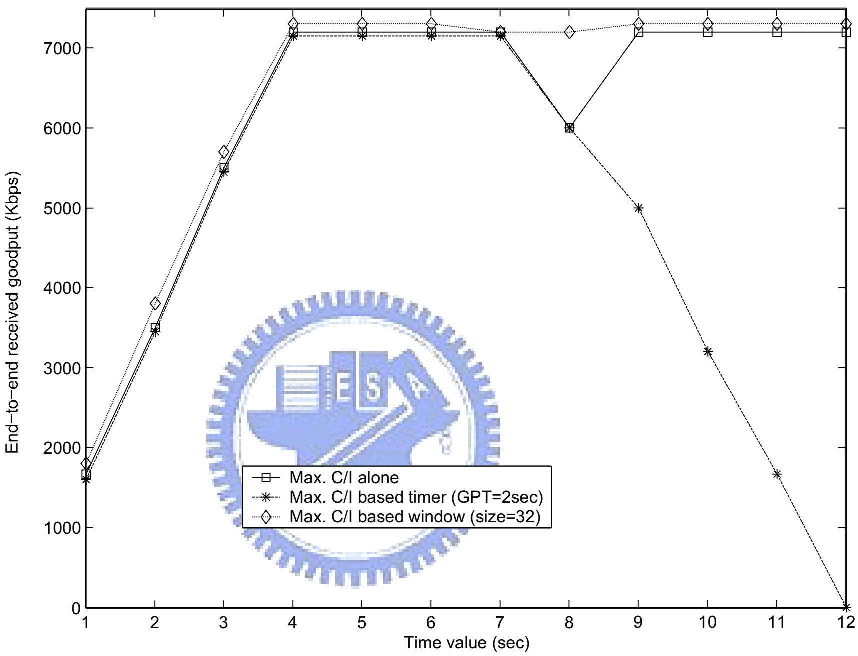

Figure 3.4: End-to-end received goodput with MCI, respectively without/with timer(T_1=2s) and window (W=32), versus user throughput, Nu=30.

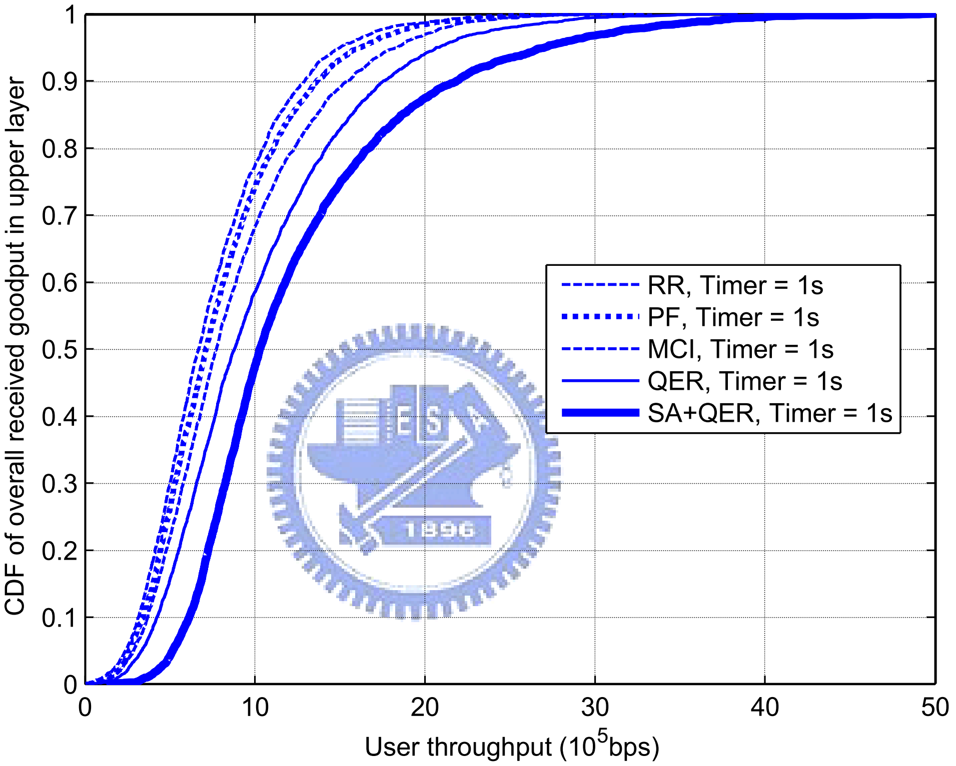

Figure 3.5: CDF of the total received goodput with 5 schedulers, T_1=1s, versus user throughput, Nu=30.

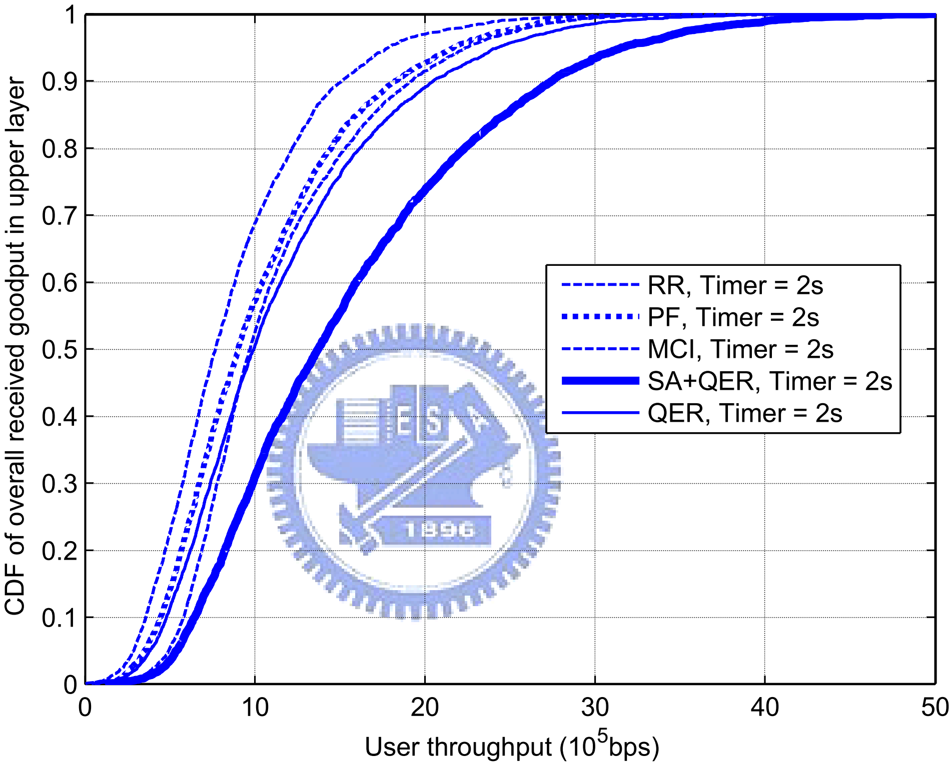

Figure 3.6: CDF of the total received goodput with 5 schedulers, T_1=2s versus user throughput, Nu=30.

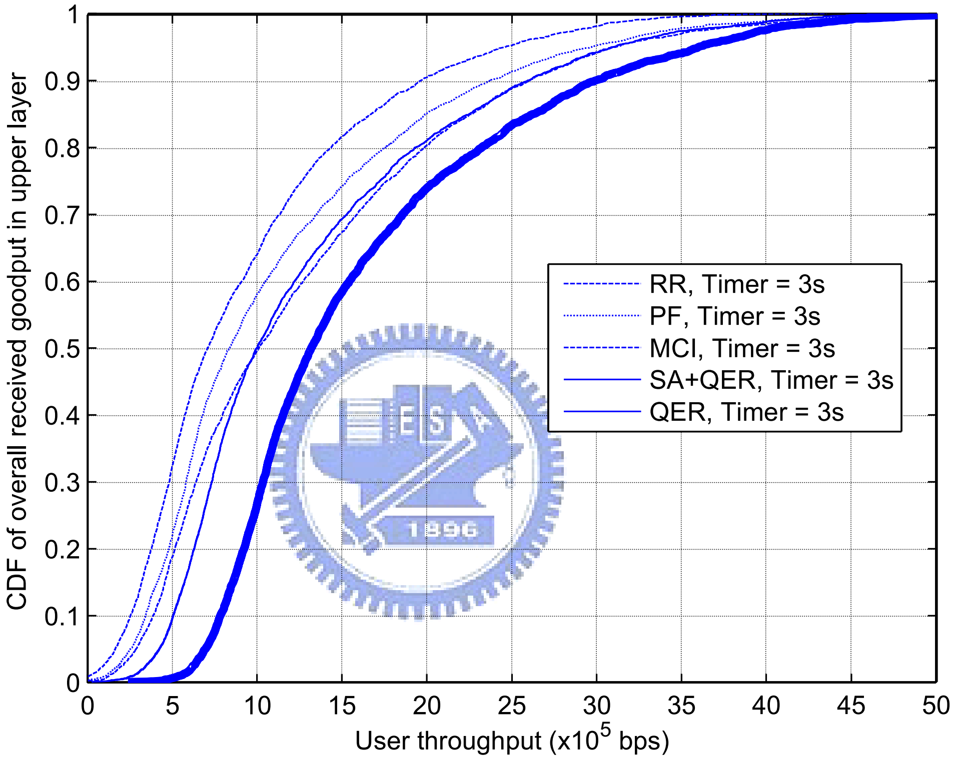

Figure 3.7: CDF of the total received goodput with 5 schedulers, T_1=3s versus user throughput, Nu=30.

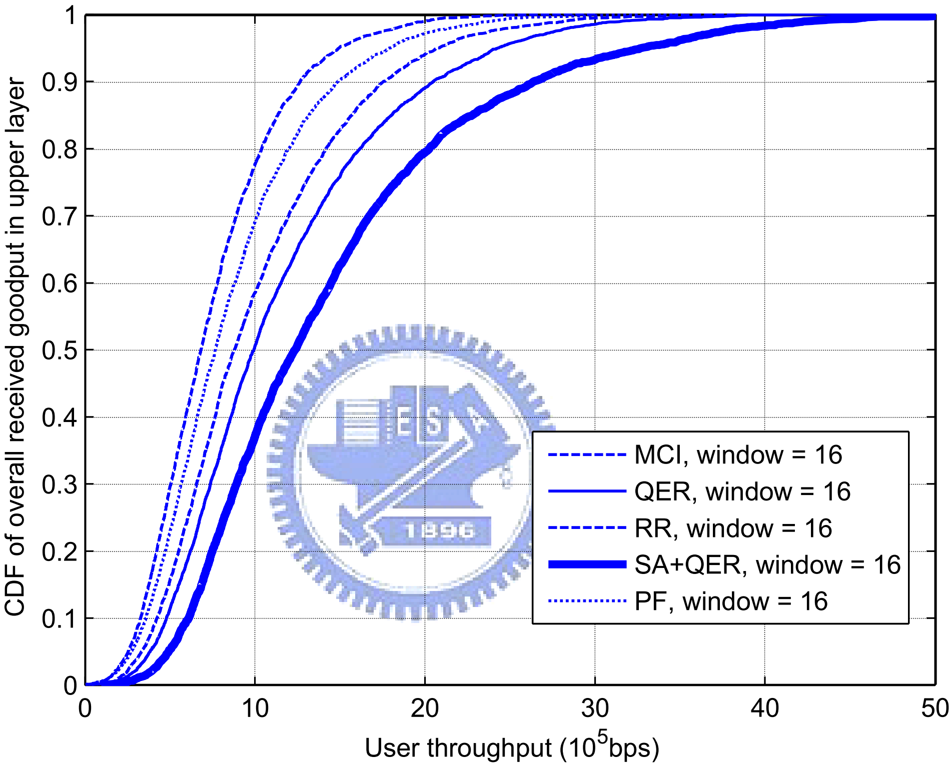

Figure 3.8: CDF of the total received goodput with 5 schedulers, *window*=16 versus user throughput, Nu=30.

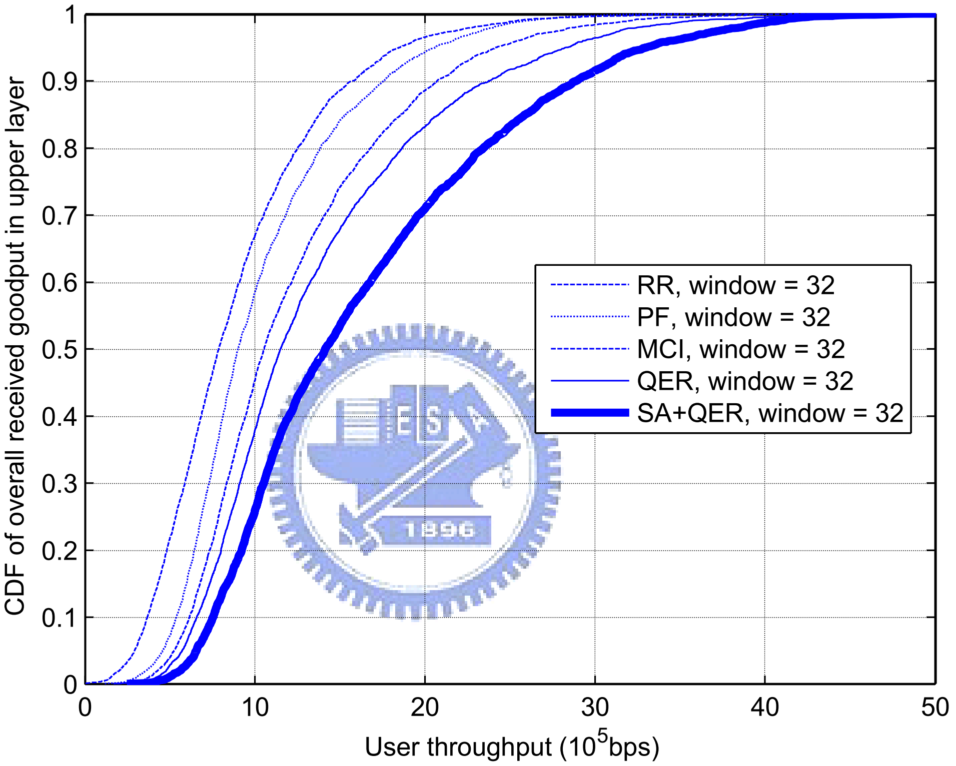

Figure 3.9: CDF of the total received goodput with 5 schedulers, *window*=32 versus user throughput, Nu=30.

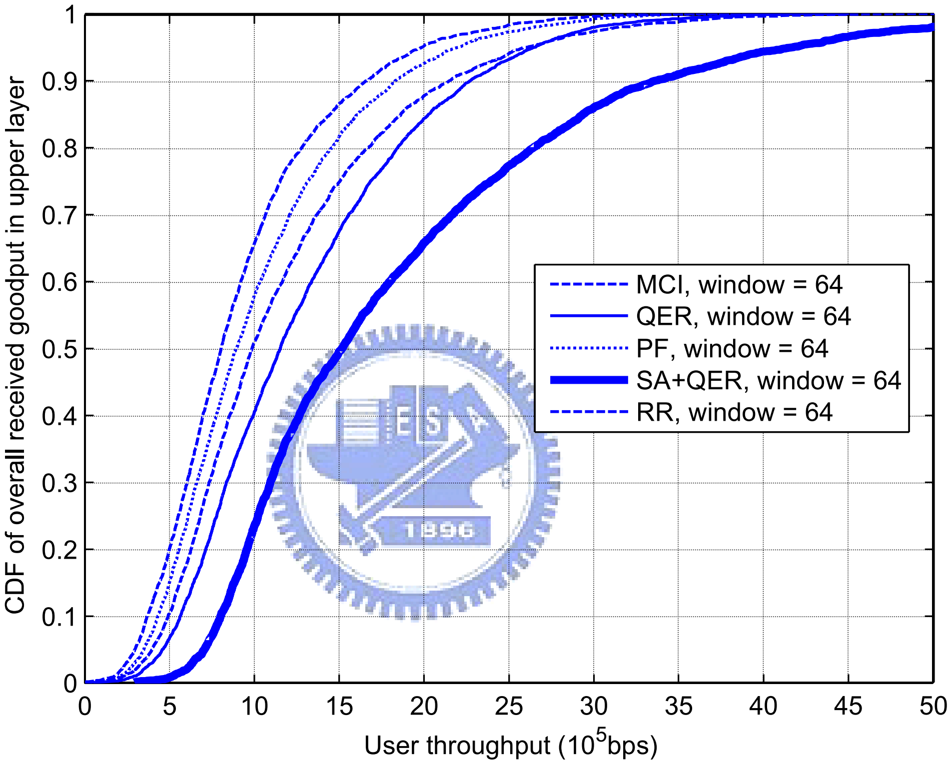

Figure 3.10: CDF of the total received goodput with 5 schedulers, *window*=64 versus user throughput, Nu=30.

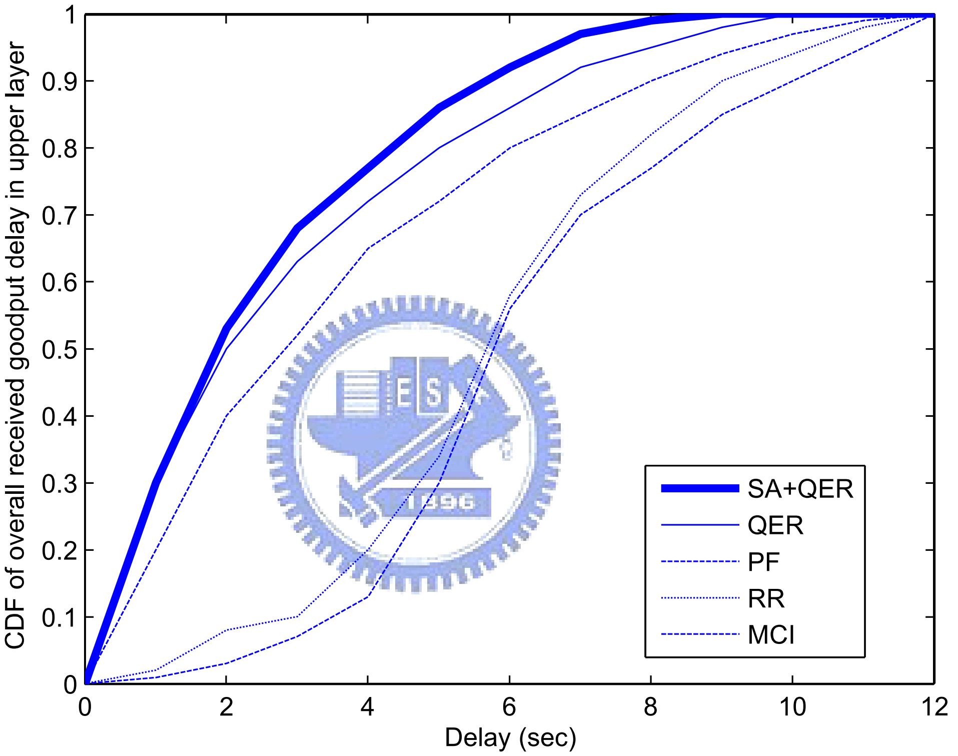

Figure 3.11: CDF of the overall goodput delay with 5 schedulers, Nu=30.

CHAPTER 4

Concluding Remarks

First of all, we introduce the WCDMA sytem by giving an overview of historical perspective and WCDMA promising future. The invention of telegraph in 1837 by Samuel Morse and the establishment of the first successful and practical radio system by Gugliemo Marconi by the end of the 19th century launched the first roots of cellular communications. The beginning of Code Division Multiple Access (CDMA) dates back to 1949, when John Pierce, Robert Pierce and Claude Shannon first formulated the principles of a new technique for multiple accesses that separates information in the code domain, rather than in the time or frequency domain. In wireless mobile radio communication, there is an endless quest for increased capacity and improved quality of service. As today, HSDPA is about to launch, new technologies are promising even more bandwidth and new services like High Speed Packet Uplink Access (HSUPA) (Enhanced DCH in 3GPP Release 6), MIMO (Multiple-Input Multiple-Output) and OFDM (Orthogonal Frequency Division Multiplexing) in 3GPP Release 7.

4.1 WCDMA Evolution: High Speed Downlink Packet Access

The chapter 2 has given a general overview of the technologies comprised by the HSDPA concept. Though every technology by itself provides a significant network performance enhancement, it is their complementary characteristics that make HSDPA a key step in the evolution of WCDMA.

- The introduction of the AMC technique permits to exploit the high throughput available for users under favourable instantaneous signal quality conditions. The multi-code operation combined with the AMC extends the operating signal dynamic range up to around 30 dB.
- Under the link adaptation operation, the multi-code allocation is more spectrally efficient than the usage of a less robust Modulation and Coding Scheme in power limited conditions.
- The Hybrid ARQ represents a fast and efficient mechanism that reduces the average retransmission delay in UTRAN. Hybrid ARQ provides protection against measurement errors and delays that can induce link adaptation errors. there are two schemes:
  - The soft combining of the multiple transmissions of a certain packet provides time diversity and soft combining gain, which reduces the average number of transmissions for successfully decoding with obvious benefits in terms of spectral efficiency.
  - With Incremental Redundancy, the retransmissions can decrease the effective coding rate and increase the soft combining gain, though this is expected to be significant only for high coding rates in the first transmission.

- The architectural modifications of HSDPA are advantageous in the point of view of the knowledge of the instantaneous signal quality in the radio interface. It enables to modify the classical CDMA concept of maintaining a certain channel bit rate and vary the transmission power to compensate for the channel fades, towards adaptation of the users data rate while keeping the transmission power about constant.

- As drawback, the deployment of HSDPA requires a Node B software update and possibly a hardware upgrade to increase the processing power of the base station. This extra processing power will allow the Node B to execute the new HSDPA functionalities (e.g. Packet Scheduling and link adaptation). Furthermore, HSDPA imposes some new requirements on the mobile terminal. HSDPA capable terminals have to incorporate functionalities for the Hybrid ARQ soft combining, multi-code reception, etc. The migration from WCDMA to HSDPA may initially be done only in certain areas of the network such as hot spots indoor offices, airports, etc). As the traffic demand increases, operators may gradually upgrade the rest of the network.

4.2 A Novel Stall Avoidance Scheduler

This part is our major contribution in the thesis. In this Chapter we propose a *Novel Stall Avoidance Scheduler* take into account the end-to-end delay incurred "*stall*" or "*gap*" problem in the receiving side packet reordering buffer. We compare the performance between the conventional schedulers including - Maximum Carrier-to-Interference (MCI), Round Robin (RR), Proportional Fair (PF), queue-based exponential rule (QER), and the proposed Stall Avoidance scheduling (SA+QER) based Timer and Window mechanisms in the presence of "*stalls*" or "*gaps*" in the receiver reordering buffer.

We employ the fast packet scheduling based 6-channel SAW HARQ to achieve high-speed packet transmission up to 3 Mbps in a packet stalling environment for HSDPA in the W-CDMA systems. The simulation results elucidate that the received goodput in upper layer with window mechanism is higher than that with timer mechanism in a slow mobility environment such as the average vehicular speed of 3 km/h. However, the effect of employing the proposed (SA+QER) based Timer and window schemes significantly improves the user aggregated throughput for all the 30 accessing users. Furthermore, we observe that with SA+QER based Timer and window schemes, whole of accessing users can obtain a user throughput up to 3 Mbps. In summary, our simulation results show that the proposed scheme deliver higher throughput than all the other schedulers for different timers setting and window. In addition, the end-to-end received delay is also reduced to around 10%. As result, the overall system delay based on SA+QER is also reduced.

4.3 Suggestion for Future Work

High Speed Uplink Packet Access (HSUPA) or Enhanced-Dedicated Channel (E-DCH) is a new radio interface for the Uplink communication. Its overall goal is to improve the coverage and throughput as well as to reduce the delay of the uplink dedicated transport channels.

Enhanced uplink transmission is an upcoming key topic in the on-going evolution of 3G radio systems. It is currently being standardized for the 3GPP standard Release 6, but the concept of HSUPA is not yet sufficiently understood in all details and their consequences for the achievable performance efficiency. From technical point of view, the first set of standards was approved in December 2004, but performance aspects were finalized by RAN No.4 at RAN No. 28 in June 2005. A major driver for the HSUPA development is the operators strong interest in the cost-efficient provision of delay-sensitive packet services such as Voice over IP (VoIP) or gaming applications.

Similar to HSDPA in the downlink, HSUPA aims at increasing throughput and reducing delays for packet data services and employs similar techniques (fast adaptive scheduling, Hybrid ARQ and short TTI).

As future work, there exists significant differences between the two types of transmission that need to be deeply investigated:

- Fast adaptive scheduling schemes as they are applied in HSDPA and envisaged for HSUPA generally have to solve a tradeoff between the requirements of reduced delay by serving each user as fast as possible and increased throughput by waiting for favorable transmission conditions.
- For bi-directional realtime services (like VoIP or gaming), the decisive QoS parameter often is not the one-way delay in uplink or downlink direction, but the overall roundtrip time. This obviously leads to a common optimization problem of the uplink and downlink scheduling, which can best be solved by a coordinated approach. As both, HSDPA and HSUPA scheduling take place in special MAC-entities in the Node B, a coordination between the two does not even require additional signaling between network elements.
- Another open issue is to investigate the impact of scheduling schemes and strategies on the system performance.

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