HSDPA: An Overview

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Abstract

High Speed Downlink Packet Access (HSDPA) is a packet-based data service in W-CDMA downlink over a 5 MHz bandwidth. It is intended to provide higher capacity, reduced delay and significantly higher data rates. This article first describes its physical layer and then discusses four important implementations of HSDPA. They are: Adaptive Modulation and Coding (AMC), Hybrid Automatic Request (HARQ), Fast Scheduling and Fast Cell Selection (FCS).

Sommaire

HSDPA est un service de données qui est basé sur la transmission de paquets en downlink W-CDMA sur bande passante de 5 MHz. Ce service a pour objectifs d'offrir une plus grande capacité, une réduction des délais et des taux de transmission des données plus élevés. Cet article décrit les couches physiques et les quatre importantes implantations du HSDPA. Les implantations du HSDPA sont les suivantes: modulation adaptative et code (AMC), demande automatique hybride (HARQ), ordonnancement rapide et sélection cellulaire rapide (FCS).

1.0 Introduction

The requirements for future wireless communication systems are rapidly evolving as applications increase in complexity. Many users require access to real-time applications, the internet, and high speed file transfer on a regular basis. To meet the demanding throughput and delay requirements of these services, the 3rd Generation Partnership Project (3GPP) has developed a new high speed data transfer protocol named High-Speed Downlink Packet Access (HSDPA).

In the 3GPP standards, Release 4 specifications of this protocol provide efficient IP support enabling provision of services through an all-IP core network. Release 5 specifications focus on HSDPA to provide data rates to support packet-based multimedia services. HSDPA is evolved from and is backward compatible with Release 99 WCDMA systems. Following feasibility studies in 2002, the wireless industry is in trial mode to implement HSDPA in the near future.

HSDPA is expected to provide a significant performance increase over the 2 Mbps data transfer capabilities of WCDMA. Throughput is expected in excess of 10 Mbps, increasing to nearly 20 Mbps when combined with a Multiple-Input Multiple-Output (MIMO) antenna structure. The substantial increase in throughput is realized by means of a fast link adaptation scheme that will utilize Adaptive Modulation and Coding (AMC). This protocol operates by transmitting with a constant power, while the Modulation and Coding Scheme (MCS) is altered to match the instantaneous channel conditions experienced by the User Equipment (UE). If errors occur in the transmission process, Hybrid Automatic Repeat reQuest (HARQ) is employed to quickly retransmit packets at the link layer. Finally, fast scheduling is used to quickly schedule users when experiencing a constructive fade, maximizing throughput and reliability to these users.

2.0 Physical Layer

To facilitate operation of HSDPA, three new channels have been added to the WCDMA platform. These channels include the High-Speed Downlink Shared Channel (HS-DSCH), High-Speed Shared Control Channel (HS-SCCH) and the Uplink Dedicated Physical Control Channel (DPCCH). The following sections discuss these channels in detail.

2.1 High Speed Downlink Shared Channel (HS-DSCH)

The HS-DSCH is the primary radio bearer for this technology. As the name suggests, this channel is provisioned as a shared resource for all users in a particular sector. During each transmission slot, users are assigned an MCS level that will maximize throughput, while maintaining a low probability of retransmissions.

Primary channel multiplexing occurs in the time domain, where each Transmission Time Interval (TTI) consists of three timeslots, totaling 2 ms. The selection of a 2 ms TTI has resulted in several benefits over the 10 ms TTI used for data transfer with WCDMA. This includes reduced round trip delay and higher validity of the channel estimation mechanism. For instance, if a longer TTI is combined with AMC, more channel variations will occur during the transmission, possibly corrupting the data packet.

Within each 2 ms TTI, a constant spreading factor of 16 is used for code multiplexing, providing a maximum of 15 parallel channels for the HS-DSCH. These channels may all be assigned to one user during the TTI, or may be split amongst several users. The number of parallel channels allocated to each user depends on cell loading, QoS (Quality of Service) requirements, and the capabilities of the UE.

2.2 High Speed Shared Control Channel (HS-SCCH)

The HS-SCCH is used to signal a variety of information to the UE before the beginning of each scheduled TTI. This includes the channelization-code set, modulation scheme, transport block size, and HARQ protocol information. Although all of this information is required to successfully decode the data on the HS-DSCH, the channelization-code set and the modulation scheme are time critical parameters. These identify which parallel codes on the HS-DSCH contain data for the UE, and whether QPSK or 16-QAM is used in the upcoming transmission. If this data is not received before the beginning of the HS-DSCH TTI, the data will be buffered until the UE is aware of these parameters. This increases the delay and buffering requirements considerably. One might imagine that this could be solved simply by sending all this information prior to the TTI. This, however, will increase the delay between the channel quality feedback and the transmission, reducing the validity of

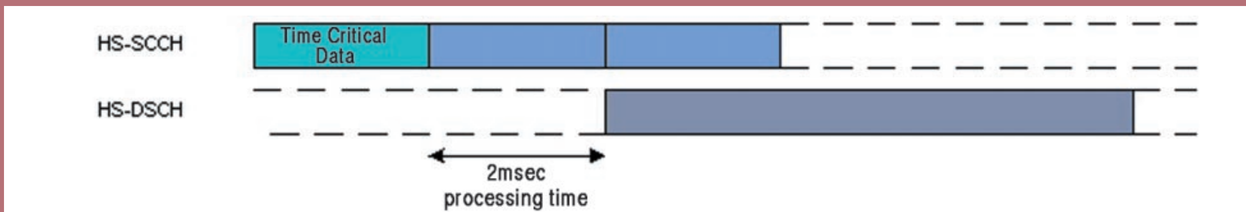

Figure 1: Timing Relation

the channel estimation process. As a result, the 3GPP has elected to separately interleave the time critical data, and send it in the first 0.667 ms slot of the HS-SCCH. Figure 1 shows this timing relation.

Since this channel is only required prior to the HS-DSCH TTI, it is favorable to provide a shared resource for this purpose. For this reason, the UE must monitor between one and four HS-SCCH channels simultaneously. An HS-DSCH Indicator (HI) is then sent on the users Dedicated Channel (DCH) to indicate the control channel that contains data for the UE. By sharing this resource, less power is required for signaling, increasing the system's efficiency considerably.

2.3 Uplink Dedicated Physical Control Channel (DPCCH)

The third new channel required to implement HSDPA is the Uplink DPCCH. This channel is responsible for uplink signaling of Acknowledgements (ACK) and Negative Acknowledgements (NACK) to indicate the status of the previous packet. The Channel Quality Information (CQI) is also sent on this channel. A five bit value is used to indicate which modulation and coding schemes are suitable for the upcoming transmission. Different codes indicate MCS levels ranging from QPSK using R = ¼ turbo coding, to 16-QAM with R = ¾ turbo coding. One state is also reserved to indicate that no transmission should be made in the event of extremely poor channel conditions.

3.0 Adaptive Modulation and Coding

Adaptive Modulation and Coding is the fundamental technology that allows HSDPA to surpass the data rates of its predecessors. Traditionally, systems that utilize Code Division Multiple Access (CDMA) have used a constant modulation scheme (usually M-PSK), with fast power control to adapt to changes in channel conditions. Instead, AMC transmits with a constant power while the Modulation and Coding Scheme is altered to adapt to these variations. This results in higher average throughput because higher order MCS levels are assigned to users experiencing favorable conditions. Spectral efficiency is also increased because the highest possible MCS level is utilized during each transmission.

The selection of the MCS level is done to maximize throughput, while maintaining a low probability of retransmission. In effect, if a user is experiencing favorable channel conditions, a high order modulation scheme such as 16-QAM with R = ¾ turbo coding may be used to maximize throughput for this user. Conversely, if the channel conditions are poor, QPSK with R = ¼ turbo coding can be used to provide higher reliability in the transmission. Further granularity is accomplished by using code rates from ¼ to ¾ with the previously mentioned modulation schemes.

The MCS level used in the upcoming transmission is selected based upon the power measured on the Common Pilot Channel (CPICH). The UE then encodes the data and transmits this CQI on the DPCCH. The UE is then scheduled by the Node B (base station controller), where the final selection of the MCS level and channelization-code set is performed. This functionality is located at the Node B to ensure that fairness is retained between users, and the majority of QoS requirements can be satisfied.

4.0 Hybrid Automatic Repeat Request

Although the MCS level is selected to ensure a reasonable probability of a successful transmission, errors do occur in any wireless system. This is a result of highly variable channel conditions caused by interference from other users and base stations. Under normal circumstances, approximately 10 - 30% of first transmissions must be resent to be successful. For this reason, the choice of the retransmission protocol is vital to the performance of any wireless communication system.

The 3GPP selected HARQ for retransmissions because of its ability to quickly retransmit packets. HARQ functionality is implemented at the MAC (Media Access Control) layer, as an alternative to the RLC (Radio Link Control) layer used for many other data transfer protocols. This decreases delay considerably because this entity is located at the radio interface. In normal instances, a negative acknowledgement may require less than 10 ms at the MAC layer, while this process may take between 80 and 100 ms at the RLC layer while the information is sent over the network interfaces [4].

By decreasing the delay associated with retransmissions, protocols such as TCP/IP can be easily implemented into higher layers of the system. This will allow support for a variety of applications, such as the internet and file transfers, which already rely on TCP/IP for higher layer error correction and flow control.

To limit the complexity of the retransmission process, the 3GPP has selected the Stop-and-Wait (SAW) protocol. This operates by transmitting one packet and awaiting a response from the UE. The problem, however, is that the system is idle while awaiting acknowledgements. To reduce this inefficiency, the 3GPP has selected an N-Channel SAW protocol. While one channel is awaiting an ACK or NACK, the other (N - 1) channels continue to transmit. Although the value for N is still being evaluated for performance and complexity, it is expected to be between two and four.

Another benefit of HARQ is that it uses a three stage virtual buffer to store a soft copy of the previously transmitted packet. When a retransmission occurs, the data is combined with data stored in the soft buffer to effectively increase the coding gain. This enables the retransmission process to require fewer transmissions, and increases the average throughput as a result.

The method of combining packets with those stored in the soft buffer is very important to the performance and complexity of the retransmission process. Two fundamental schemes have been proposed to accomplish this task. These include Chase Combining (CC) and Incremental Redundancy (IR).

Chase Combining is the least complex combining scheme; however, it provides a lower coding gain than IR. The Node B simply retransmits the original packet, and the UE combines this with data stored in the soft buffer.

The IR schemes, however, provide additional coding gain by transmitting parity bits in the retransmission. The result is that fewer retransmissions are necessary to successfully retransmit packets. This is especially true under poor channel conditions, or when the user is traveling at a high velocity.

5.0 Fast Scheduling

The fast scheduling entity is also very important in the operation of HSDPA. One primary change from the previous implementations is that the scheduler is located at the Node B. This enables the scheduler to quickly respond the changes in the channel conditions, and ensures that the UE is served while on a constructive fade. There are three main types of schedulers that have been proposed for HSDPA. These include Round Robin (RR), Maximum C/I, and Proportional Fair (PF).

The RR scheduler operates by scheduling users based upon their position in a first-in first-out queue. Although this scheduler provides the least complex operation and the most fairness between users, the UE's channel conditions are not taken into consideration. As a result, users may be scheduled when experiencing a destructive fade, causing the packet to be corrupted.

As an alternative, the Maximum C/I algorithm schedules users when their instantaneous SIR is the highest amongst all users at the respective base station. This scheduling algorithm ensures that all users are served on a constructive fade, and as a result, has a higher percentage of successful transmissions. Also, the throughput and spectral efficiency is maximized because the highest possible MCS level is used during each transmission. The disadvantage, however, is the lack of fairness between users in the sector. In normal circumstances, the geometry of radio propagation causes nearly 50% of users to be located near the cell border. This indicates that nearly half of the users may receive inadequate service as a result.

A compromise between these two schedulers is the Proportional Fair algorithm. This schedules users based on the offset between the long term average SIR and the instantaneous SIR. The result is that each user is served while on a constructive fade, while fairness is maintained because instantaneous channel conditions will exceed the long term average at some instant. Figure 2 shows the operation of the previously discussed scheduling schemes.

6.0 Fast Cell Selection

In any cellular communication system, handoffs are necessary to accommodate users that are in motion, or those located near the cell border. Traditionally, CDMA systems have utilized a soft handoff procedure to seamlessly switch between base stations. The scheduled nature of the HS-DSCH, however, makes it impossible to use a soft handoff mechanism with HSDPA. Instead, a fast, hard handoff algo-

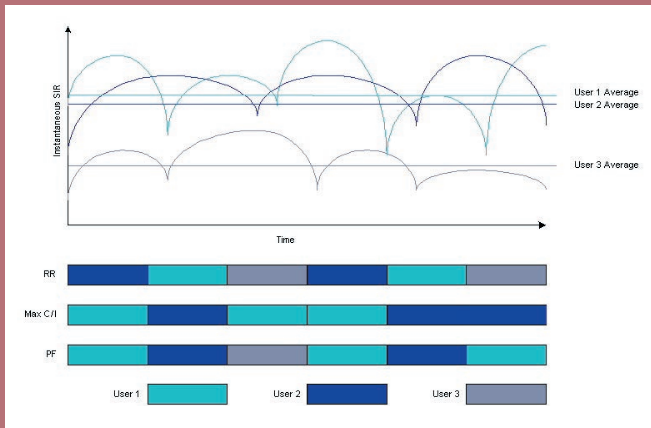

Figure 2: Scheduling Schemes and Operations (Adapted from [7]

rithm has been proposed to quickly switch between base stations.

This technology, named Fast Cell Selection (FCS), operates by monitoring the SIR level of all the base stations in the UE's active set. When a different base station in this set can provide a higher SIR (higher CPICH power), the user is transferred to the respective base station.

Both Internode and Intranode handoffs can be supported with FCS. When utilizing Intranode B FCS, the fast handoff mechanism is restricted to base stations that are a subset of the current Node B. If a sector outside of the current Node B can provide better channel conditions, the RNC (Radio Network Controller) is responsible for the handoff procedure. This increases the handoff delay considerably, and may result in QoS requirements that cannot be satisfied. The alternative to this restriction is to utilize Internode handoffs. Internode B FCS allows the UE to quickly change base stations regardless of the respective Node B. This decreases the delay in the handoff procedure; however, complexity is increased considerably. When a handoff occurs, the UE must use over-the-air signaling to quickly signal its status to the new Node B.

This technology has proven to be beneficial in providing seamless coverage to mobile users. It also increases performance to users located near the cell border, especially when combined with the RR scheduler. Less benefit is realized, however, when implemented with a Maximum C/I scheduler because users located near the cell border are rarely serviced.

7.0 Conclusion

The future of cellular communication is an ever expanding marketplace. As applications increase in complexity, the resources that support these applications will need to evolve as well. The 3GPP's evolution in high speed data transmission will definitely be a good candidate in providing users with the increased data rates and minimal delay necessary to support these applications. Only time will show the actual benefit of HSDPA, but at the present time, it appears to be a viable protocol for the future of cellular communications.

8.0 Read more about it:

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[3]. T.E. Kolding, F. Frederiksen, and P.E. Mogensen. "Performance Aspects of WCDMA Systems with High Speed Downlink Packet Access (HSDPA)", Proc. of 56th IEEE VTC, September 2002. pp 477 - 481

[4]. M. Chatterjee, G.D. Mandyam, S.K. Das. "Fast ARQ in High Speed Downlink Packet Access for WCDMA Systems", Proc. of European Wireless. February 2002. pp 451 - 457.

[5]. A. Das, F Khan, A. Sampath, and H. Jung Su. "Design and Performance of Downlink Shared Control Channel for HSDPA", Proc. of 13th IEEE PIMRC, Sept. 2002. pp 1088 - 1091.

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[7]. Y. Ofuji, A. Morimoto, S. Abeta, and M. Sawahashi. "Comparison of Packet Scheduling Algorithms Focusing on User Throughput in High Speed Downlink Packet Access", The 13th annual symposium on Personal, Indoor and Mobile Radio Communications, 2002. Sept. 2002. pp 1462 - 1466

9.0 Acknowledgement

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10.0 Acronyms

3G	-	Third Generation
3GPP	-	Third Generation Partnership Project
ACK	-	Acknowledgement
AMC	-	Adaptive Modulation and Coding
CDMA	-	Code Division Multiple Access
CPICH	-	Common Pilot Channel
DPCCH	-	Dedicated Physical Control Channel
FCS	-	Fast Cell Selection
HARQ	-	Hybrid Automatic Repeat Request
HSDPA	-	High Speed Downlink Packet Access
HS-DSCH	-	High Speed Downlink Shared Channel
HS-SCCH	-	High Speed Shared Control Channel
MAC	-	Media Access Control
MCS	-	Modulation and Coding Scheme
NACK	-	Negative Acknowledgement
PSK	-	Phase Shifting Key
QAM	-	Quadrature Amplitude Modulation
RLC	-	Radio Link Control
RNC	-	Radio Network Controller
TTI	-	Transmission Time Interval
UE	-	User Equipment
WCDMA	-	Wideband Code Division Multiple Access

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