Radio Access Technologies and Signaling Scheme in W-CDMA System

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W-CDMA is a radio interface for IMT-2000 (International Mobile Telecommunications-2000), which was standardized for use as the 3rd generation wireless mobile telephone system. W-CDMA provides a voice service whose quality is comparable with that of a fixed public telephone network and also multimedia mobile communication services with global roaming capability.

This paper introduces the radio access technologies and signaling scheme of the W-CDMA system, which Fujitsu has been working on with the 3GPP community to achieve a competent and feasible system. First, this paper gives a brief description of Layers 3 and 2 of the radio interface protocol. Then, it describes some of the essential aspects of the Layer 1 radio interface in frequency division duplex (FDD) mode, for example, the physical channel structure and transmitting power control method. Finally, this paper gives an overview of the HSDPA (High Speed Downlink Packet Access) scheme, which has been introduced into the latest releases to enable up to 10 Mb/s transmission.

1. Introduction

W-CDMA is a promising radio interface for IMT-2000, which was standardized for use as the 3rd generation wireless mobile telephone system. It provides a variety of services such as voice services and multimedia mobile communication services in a flexible and efficient way with global roaming capability. The standardization organizations in Japan, Europe, USA, and other countries have jointly organized a framework called the 3rd Generation Partnership Project (3GPP) to produce common radio interface specifications for W-CDMA. Commercial services were launched in 2001 in Japan and will soon start in Europe and North America.

After finalizing the first version of specifications as Release 99 (or version 3), further enhancements were made and consecutive releases have been developed as Release 4, Release 5, and beyond.

This paper describes the functions provided by Layer 1 of the radio interface protocol and gives a brief description of Layer 2 and 3, based on the latest specifications for W-CDMA. Then, some of the essential aspects of the Layer 1 functions in W-CDMA Frequency Division Duplex (FDD) mode are summarized. Finally, this paper gives an overview of the HSDPA (High Speed Downlink Packet Access) scheme, which has been introduced into the latest release to enable up to 10 Mb/s transmission.

2. Protocol structure of radio interface

This section outlines the protocol structure of the W-CDMA radio interface (**Figure 1**). To provide radio links between the user equipment (UE) and network side, this structure carries user information to and from the users (U-plane information) and a control signal to maintain and control the radio links (C-plain signaling).

The protocol consists of three layers: the network layer (Layer 3), data link layer (Layer 2), and physical layer (Layer 1). Layer 3 has the Radio Resource Control (RRC) as a sub-layer in the access stratum for C-plain signaling. It provides services to the upper layers of the Call Control (CC) and the Mobility Management (MM) in the non-access stratum. Layer 2 has four sub-layers: the Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP), and Broadcast/Multicast Con-

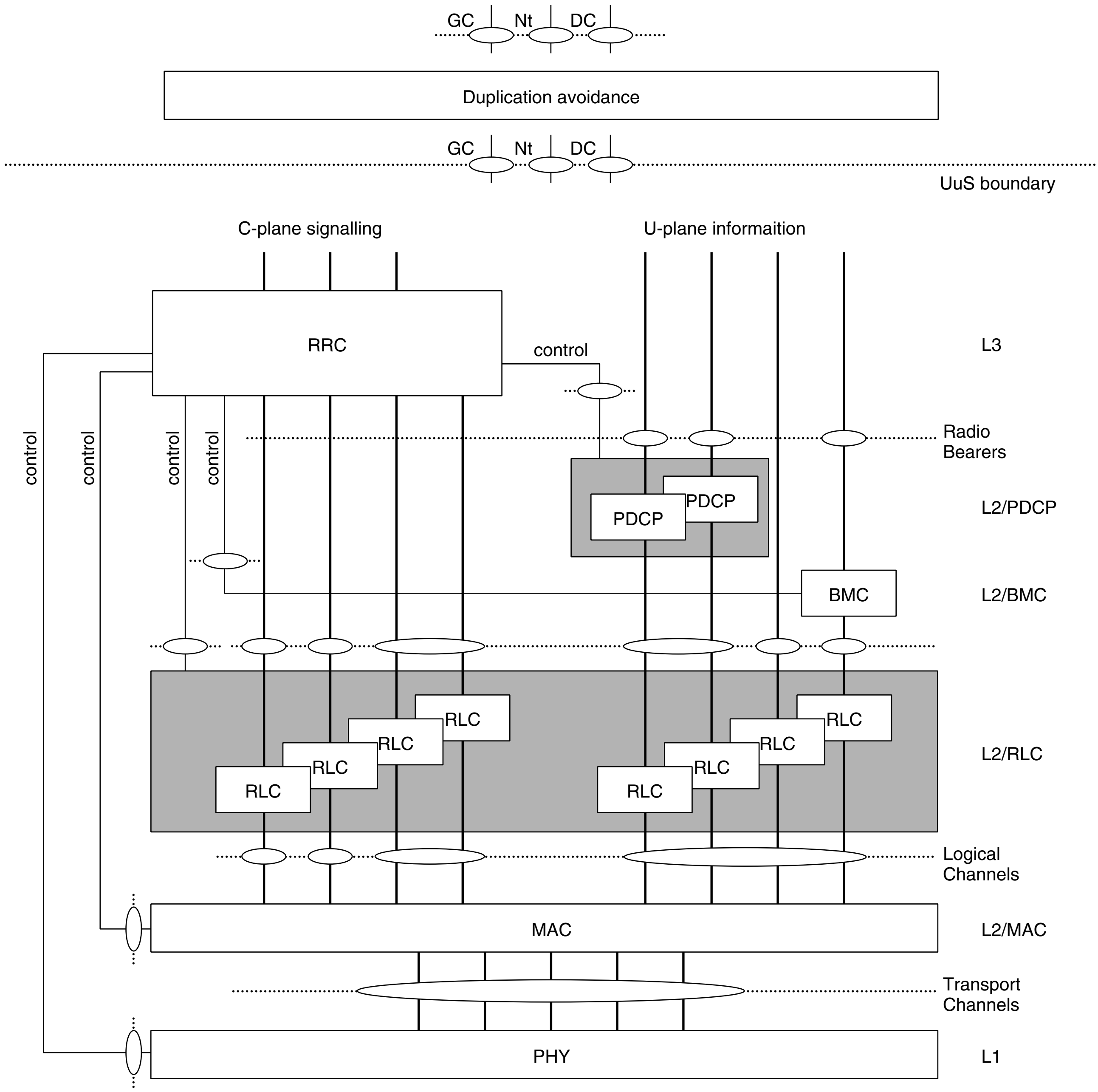

Figure 1
Radio Interface Protocol structure.[1)]

trol (BMC). The RLC and MAC are used both in the U-plane and C-plane, while the PDCP and BMC are only used for U-plain information.

The Service Access Point (SAP) between the MAC and the Physical layer (PHY) provides transport channels, and the SAP between the RLC and MAC sub-layer provides logical channels.

In the following sections, the services provided by each stratum and their functions are briefly summarized.

2.1 Services provided by Layer 3 and its functions

The Radio Resource Control (RRC) layer provides broadcasting, paging, and radio link setup/release. Some of the major functions of the RRC that are used to carry out these services are listed below:

- Broadcast of information
- Establishment, reconfiguration, and release of Radio Bearers
- Paging/notification
- Establishment, re-establishment, maintenance, and release of an RRC connection between the UE and UTRAN
- Control of requested QoS
- Outer loop power control
- Initial cell selection and re-selection in idle mode
- Integrity protection

2.2 Services provided by Layer 2 and its functions

Layer 2 consists of four sub-layers. Overviews of these sub-layers are given below. It should be noted that, as can be seen in Figure 1, some U-plane information may not need either the PDCP or BMC sub-layer.

2.2.1 PDCP sub-layer

The PDCP sub-layer provides PDCP Service Data Unit (SDU) delivery services through the SAP for U-plain packet data. The PDCP has the following functions:

- Header compression and decompression
- Transfer of user data
- Support for lossless SRNS relocation

2.2.2 BMC sub-layer

The BMC provides a broadcast/multicast transmission service in the U-plane. It has functions for storing cell broadcast messages, transmitting BMC messages to the UE, and other functions.

2.2.3 RLC sub-layer

The RLC sub-layer provides a data transfer function with Automatic Repeat Request (ARQ) for C-plain and U-plain transmission. The RLC provides the following services to the upper layers:

- Transparent/Unacknowledged/Acknowledged data transfer
- Maintenance of QoS as defined by the upper layers
- Notification of unrecoverable errors

These services are provided using the following RLC functions:

- Segmentation and reassembly, concatenation, padding
- Transfer of user data with error correction
- In-sequence delivery of upper layer PDUs
- Duplicate detection, flow control, sequence number checking
- Ciphering
- SDU discard

2.2.4 MAC sub-layer and logical channels

The MAC layer offers data transfer services on logical channels, which are defined in the SAP between the MAC and RLC. This section gives a brief description of the MAC functions and an overview of logical channels.

Logical channels are defined at the SAP between the RLCs and the MAC to support a variety of data transfer services. There are two types of logical channels:

- Control channels (for the C plane)

- Traffic channels (for the U plane)

Figure 2 shows the two types of logical channels. Logical channels classified as control channels are used to transfer C-plane signaling, while those classified as traffic channels are for U-plane information. The MAC has a variety of functions to support logical channel transfer:

- Logical channel mapping onto transport channels (**Figure 3**)
- Selection of an appropriate transport format for each transport channel according to the instantaneous source rate
- Priority handling
- Identification of UEs on common transport channels
- Multiplexing/demultiplexing of upper layer PDUs into and from transport blocks that are delivered to and from the physical layer
- Traffic volume measurement and transport channel type switching between common and dedicated transport channels
- Ciphering
- Access service class selection for RACH and CPCH transmission
- HARQ (Hybrid ARQ) functionality for HS-DSCH (High Speed Downlink Shared Channel) transmission

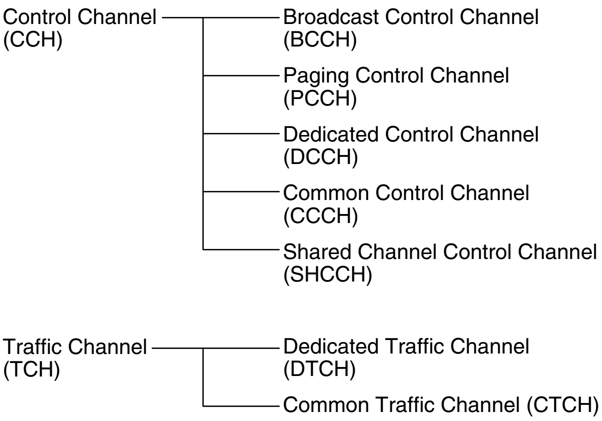

Figure 2
Logical channels.[1)]

2.3 Services provided by Layer 1 and its functions

The physical layer (PHY) offers information transfer services to the MAC and higher layers. To provide a data transfer service to the MAC, transport channels defined at the SAP between the PHY and MAC are used. Transport channels are mapped onto physical channels to carry the information to the other side of the radio link. **Figure 4** shows the mapping from transport channels to physical channels. The major functions in

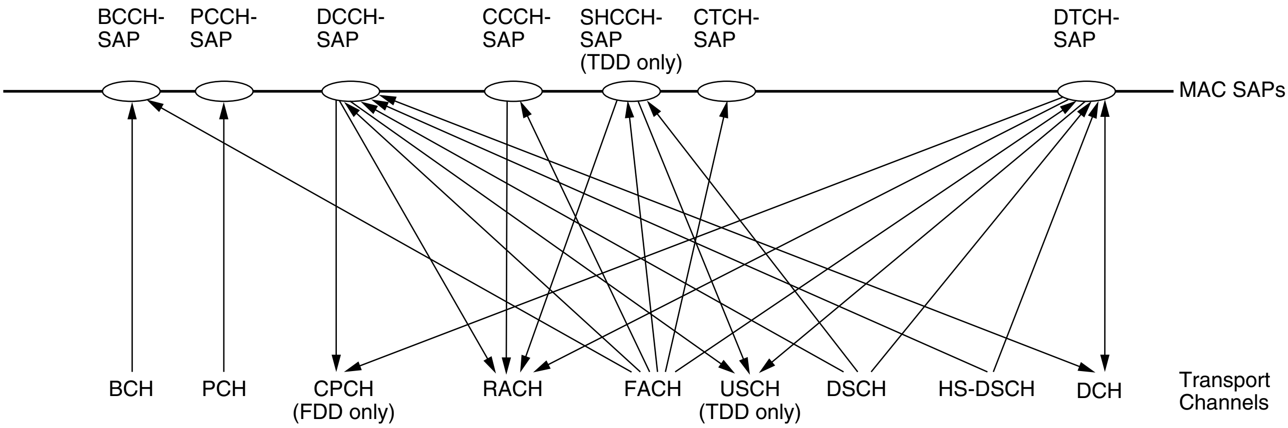

Figure 3
Logical channel mapping onto transport channels (in UE side).[1)]

the physical layer are as follows:

- Macro diversity distribution/combining and soft handover execution
- Error detection on transport channels, forward error correction encoding/decoding, and interleaving/deinterleaving of transport channels
- Multiplexing of transport channels and demultiplexing of coded composite transport channels
- Rate matching
- Mapping of coded composite transport channels on physical channels
- Power weighting and combining of physical channels
- Modulation and spreading/demodulation and despreading of physical channels
- Frequency and time (chip, slot, frame) synchronization
- Measurements and reporting (e.g., BLER [Block Error Ratio], SIR [Signal to Interference Ratio], interference power, and transmit power)
- Closed-loop power control
- RF processing

3. Radio transmission technologies

This section outlines some of the radio transmission technologies of the physical layer (Layer 1) of W-CDMA. It also describes some of the important technologies used in the W-CDMA scheme, for example, transmission power control and variable rate transmission. **Table 1** summarizes the parameters for the radio interface.[3] In the latest version of the W-CDMA radio system, which has evolved from the previous version, the High Speed Downlink Packet Access (HSDPA) scheme pro-

Table 1
Radio interface parameters of W-CDMA (FDD mode).

Access scheme	Direct-sequence CDMA (DS-CDMA)
Duplex method	Frequency division duplex
Chip rate	3.84 Mcps
Information rate	Maximal 10 Mb/s or more
Radio frame	10 ms
Modulation and spreading	QPSK/16 QAM[note)]
Channel coding (FEC)	Convolutional coding/ Turbo coding
Power control algorithm	Open loop TPC Close loop TPC (Inner loop/Outer loop)

note) for HS-DSCH

Transport Channels	Physical Channels
DCH	Dedicated Physical Data Channel (DPDCH)
	Dedicated Physical Control Channel (DPCCH)
RACH	Physical Random Access Channel (PRACH)
CPCH	Physical Common Packet Channel (PCPCH)
	Common Pilot Channel (CPICH)
BCH	Primary Common Control Physical Channel (P-CCPCH)
FACH PCH	Secondary Common Control Physical Channel (S-CCPCH)
	Synchronisation Channel (SCH)
DSCH	Physical Downlink Shared Channel (PDSCH)
	Acquisition Indicator Channel (AICH)
	Access Preamble Acquisition Indicator Channel (AP-AICH)
	Paging Indicator Channel (PICH)
	CPCH Status Indicator Channel (CSICH)
	Collision-Detection/Channel-Assignment Indicator Channel (CD/CA-ICA)
HS-DSCH	High Speed Physical Downlink Shared Channel (HS-PDSCH)
	HS-DSCH-related Shared Control Channel (HS-SCCH)

Figure 4
Transport-channel to physical-channel mapping.[2]

vides a user data rate of 10 Mb/s or more by using 16 QAM (16 Qaudrature Amplitude Modulation) in the downlink with the same 3.84 MHz bandwidth as the previous version. This aspect is described separately in Section 4.

3.1 Frame structure of physical channel in radio link

Figure 5 shows the frame structure for a downlink Dedicated Physical Channel (DPCH). The frame length is 10 ms and consists of 15 slots. Each slot is divided into two sub-channels in the time domain. These two sub-channels are the Dedicated Physical Data Channel (DPDCH) and the Dedicated Physical Control Channel (DPCCH). The DPDCH is used for transferring user information. Depending on the spreading factor, the corresponding physical data rate can vary from 10 to 1280 bits/slot. The DPCCH is used for carrying local control information on the radio link such as Transmit Power Control (TPC) bits, Transport Format Combination Indicator (TFCI) bits, and pilot symbols. These pilot symbols are the points where an SIR measurement is made (the measurement result is used to produce uplink TPC bits). To minimize transmission power control latency, the TPC bits are located at the middle of each slot and the pilot symbols are located at the end of each slot. The detailed frame format and the timing relations are specified in Reference 2).

3.2 Channel coding and modulation

The channel coding function performs error correction and detection, rate matching, and coded transport channel mapping and de-mapping onto and from the physical channels. Forward Error Correction (FEC) for low-speed data such as voice data is done using convolutional coding at 1/3 or 1/2 rate with a constraint length of 9. Turbo coding with a constraint length of 4 is used for higher speed data. Bit repetition or puncturing is done to adjust the size of the data unit to be fitted into the data field of physical channels. When puncturing is done, a pair-wise periodic puncturing is applied only for the parity bits of the Turbo encoder and the systematic coded bits are untouched (**Figure 6**). Compared with simple periodic puncturing, the pair-wise periodic puncturing provides a noticeable performance

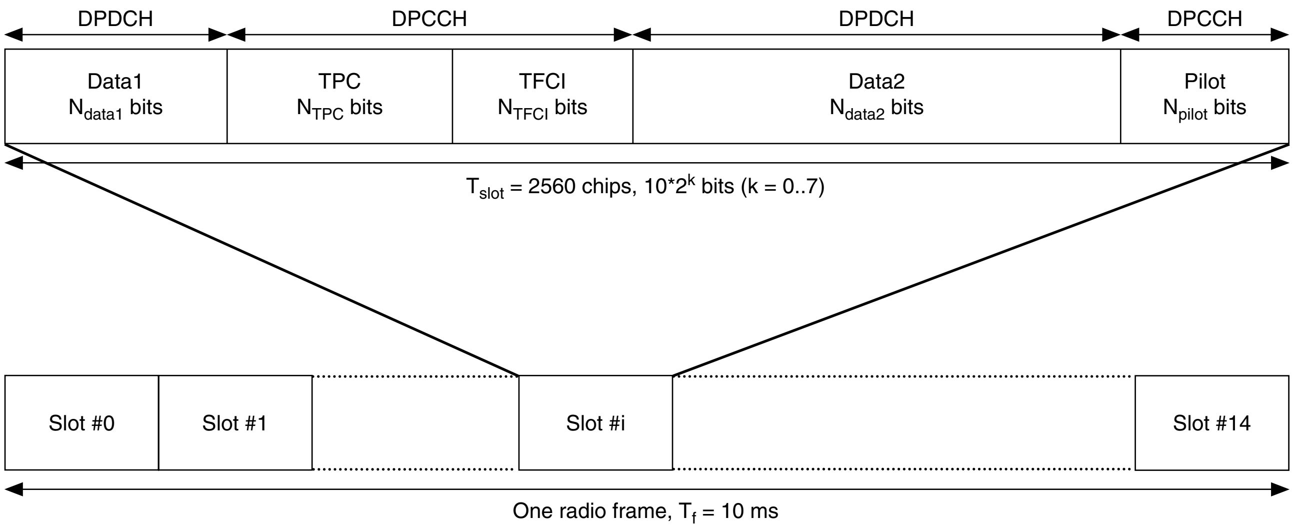

Figure 5
Frame structure for downlink DPCH.[2)]

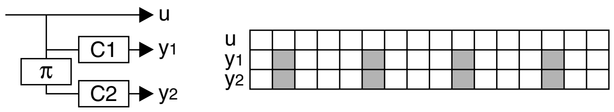

Figure 6
Puncturing pattern with Turbo coding (example).[4)]

improvement in the BER (Bit Error Ratio). This improvement can be seen in **Figure 7**, which shows the results of BER simulations for conventional rate matching and for pair-wise periodic puncturing.[4)] The coding block size N in these simulations was 320 bits or 5120 bits, and the puncturing ratio P was 20%. The simulation was carried out with an AWGN (Additive White Gaussian Noise) channel using a Log-MAP (Maximum a posteriori) Turbo decoder.

Figure 8 shows the spreading and modulation scheme for downlink channels (except SCH). The data stream from the channel coder is split into two signals (the in-phase channel and quadrature channel). The modulation mapper produces the real and imaginary part of the QPSK (Quadrature Phase Shift Keying) signal, or in the case of HS-DSCH transmission, the 16 QAM signal. These signals are spread individually by a channelization code taken from a set of OVSF (Orthogonal Variable Spreading Factor) codes ($C_{ch,SF,m}$). The OVSF code enables code multiplexing of data streams from different users, each of which may have a variety of spreading factors. These signals are then combined as a conjugate signal and spread by a scrambling code ($S_{dl,n}$) that is commonly allocated in the same cell. The scrambling code is a subset of the gold code, and its period is 10 ms, which corresponds to 38400 chips.

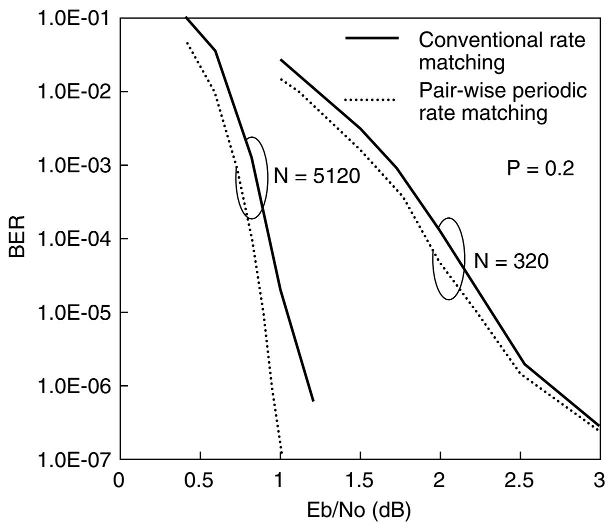

Figure 7
BER performance with pair-wise periodic puncturing.[4)]

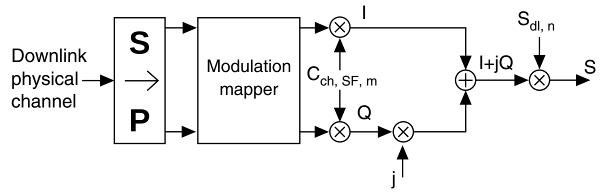

Figure 8
Spreading for all downlink physical channels except SCH.[5)]

3.3 Transmission power control

Generally, in CDMA transmission, the user's signals interference with each other. In W-CDMA, to minimize this interference without degrading the transmission quality, a transmission power control scheme is applied. Different kinds of power control schemes are jointly applied for each physical channel.

The open loop TPC is applied for common channels whose transmit powers cannot be adjusted individually because they may be received by multiple receivers. It is also applied for dedicated channels to determine their initial transmission power of them. In the open loop TPC scheme, the transmit power is determined from an estimated path loss derived from the signal strength as measured at the receiver. This scheme reduces the average amount of unnecessary transmission in FDD duplex operation because there is a rough correspondence between the path losses of the downlink and uplink.

For dedicated channels, the outer loop TPC scheme sets a target BLER. In the receiver side, a target SIR is derived from the target BLER and the measured BLER of the received signal. By comparing the measured SIR with the target SIR, the inner loop TPC scheme produces TPC bits in the DPCCH. The TPC bits transmitted in the DPCCH control the transmission power of the transmitter at the opposite side of the radio link on a slot-by-slot basis to achieve the appropriate received signal quality. One example of how to set a target SIR is described in Reference 6). The example uses the following control algorithm:

$$\mathrm{Sinc} \times \{1 - (1 - \mathrm{BLER})^{T}\} = \mathrm{Sdec} \times (1 - \mathrm{BLER})^{T},$$

where BLER represents the target block error ratio and T is the measurement period of the BLER. In this algorithm, the target SIR is immediately increased by Sinc [dB] when a frame error is detected or decreased by Sdec [dB] when no frame error is detected within a period of T. By properly selecting Sinc, Sdec, and T with respect to the target BLER, the average BLER can be controlled within a certain level of error as shown in **Figure 9.**

In order to minimize additional interference (e.g., from other base stations) in the downlink and maximize the system capacity, SSDT (Site Selection Diversity Transmission) can be applied as an optional feature in soft handovers. In this scheme, a base station in the active set is selected to transmit its downlink signal. Further investigation to improve the performance is reported in Reference 7).

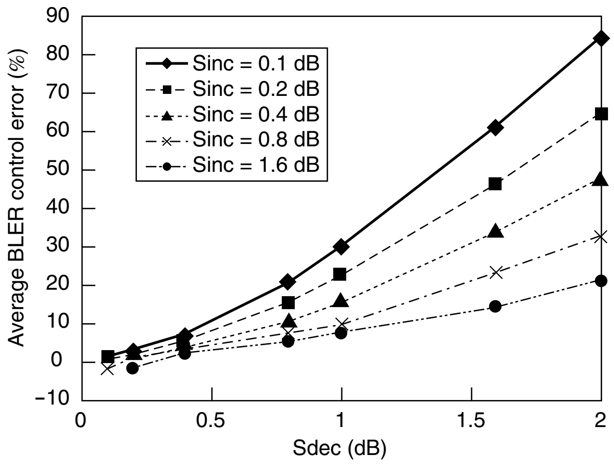

Figure 9
Average BLER control error.[6)]

3.4 Variable rate transmission

Streams of data having a variety of transmission rates can be incorporated into a single radio link. The channelization code obtained from the OVSF code, which may have a range of Spreading Factors (SFs), allows efficient transmission, even when data streams from different users are combined into a single radio link. When this is combined with rate matching and DTX (Discontinuous Transmission), flexible and efficient transmission is achieved. The rate information is transmitted explicitly as a TFCI bits field or implicitly detected at the receiver side by using a CRC (Cyclic Redundancy Check).

4. High-speed downlink packet access (HSDPA)

The latest version of the W-CDMA specification incorporates HSDPA. In the HSDPA scheme, the HS-DSCHs provide data transmission in a physical channel of maximally 10 Mb/s or more by applying 16 QAM with adaptive modulation/coding, hybrid ARQ, and fast scheduling. Instead of high-speed transmission power control as in the DCHs, the transmission power in the HS-DSCHs is determined from a combination of modulation and coding parameters so as to maximize overall throughput. Therefore, the HS-DSCHs may offer improved throughput and reduce transmission latency with a higher peak transmission rate. **Figure 10** shows the protocol termination points for the HS-DSCHs with protocol stacks. As can be seen, the MAC layer is divided into two parts, one of which is implemented in Node B. This enables the scheduler in the MAC to work more efficiently because it can quickly respond to the latest channel conditions. Some of the main features applied for HS-DSCH transmission are described below.

4.1 Hybrid ARQ

Hybrid ARQ (HARQ) is defined as a combined Automatic Repeat Request (ARQ) and Forward Error Correction (FEC) method that saves the information received in previous failed attempts for future joint decoding. **Figure 11** shows the HARQ structure. In terms of the physical layer functionality in the transmitter side, it consists of rate matching functions with buffer functions between them. The first rate matching stage is identical for other channels such as the DCHs; however, the number of bits is adjusted to the available buffer size of each UE instead of the available number of bits in the Transmission Timing Interval (TTI) of the physical channel. The second rate matching stage adjusts the number of bits to match the size available in the TTI of the HS-DSCHs.

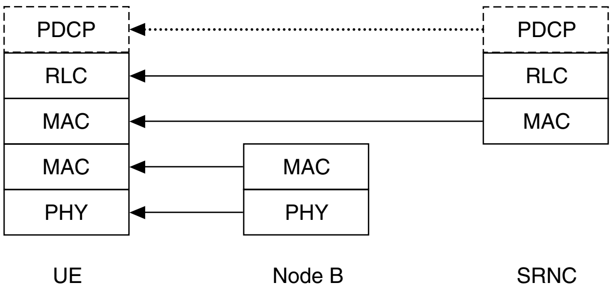

Figure 10
Protocol termination points for HS-DSCH, user plane, Configuration without MAC-c/sh.[1)]

4.2 Adaptive modulation/coding

Several sets of modulation and coding parameters, for example, 16 QAM with a 0.88 coding rate, are available, and one of those modulation/coding sets is adaptively selected according to the radio channel conditions to maximize the overall throughput. **Figure 12** shows an example of an HS-DSCH physical layer structure that includes an adaptive modulation/coding scheme. Turbo

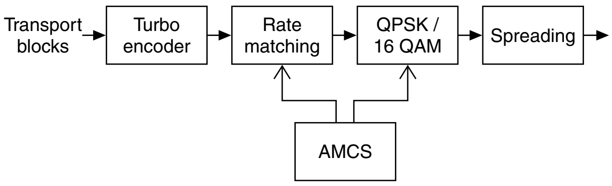

Figure 12
HSDPA physical layer structure.

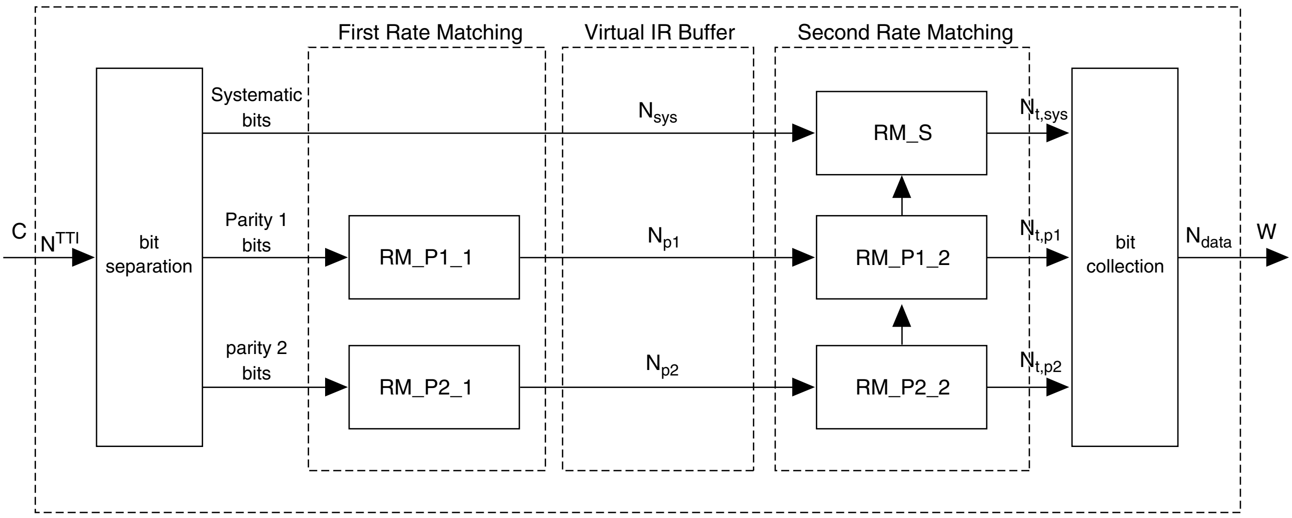

Figure 11
Physical layer Hybrid ARQ functionality.[8)]

coding is performed on the data stream, which is then followed by rate matching and interleaving. Then, the output bits are mapped onto the real and imaginary parts of the QPSK or 16 QAM signal. An adaptive Modulation Control Scheme (AMCS) controls the coding rate and modulation parameters to optimize data transmission for the data rate and radio link conditions.

5. Conclusion

This paper introduced the radio access technologies and signaling scheme of the W-CDMA system. First, it briefly described the Layer 2 and Layer 3 schemes and then described various aspects of the physical layer (Layer 1), especially the radio access technologies used in FDD mode. It described the technologies of the W-CDMA system, which offers a variety of services, and the latest HS-DSCH-related technologies that are used in the HSDPA scheme. By using this latest technology, W-CDMA will efficiently enable more than 10 Mb/s transmission in its radio interface. We have been assisting in the standardization activities of the 3GPP and believe that many of our contributions to the 3GPP have been useful. In order to make the system more suitable for the market, we will continue our investigations and contribute further in cooperation with the mobile communications community.

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