PRENTICE HALL

Fundamentals of **LTE**

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Foreword by Rajiv Laroia

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9.6 Scheduling and Resource Allocation

The main purpose of scheduling and resource allocation is to efficiently allocate the available radio resources to UEs to optimize a certain performance metric with QoS requirement constraints. Scheduling algorithms for LTE can be divided into two categories:

- **Channel-dependent scheduling:** The allocation of resource blocks to a UE is based on the channel condition, e.g., proportional fairness scheduler, max CI (Carrier to Interference) scheduler, etc.

- **Channel-independent scheduling:** The allocation of resource blocks to a UE is random and not based on channel condition, e.g., round-robin scheduler.

In a multicarrier system such as LTE, channel-dependent scheduling can be further divided into two categories:

- **Frequency diverse scheduling:** The UE selection is based on wideband CQI. However, the PRB allocation in the frequency domain is random. It can exploit time selectivity and frequency diversity of the channel.

- **Frequency selective scheduling:** The UE selection is based on both wideband and subband CQI, and the PRB allocation is based on the subband CQI. This can exploit both time and frequency selectivity of the channel.

In this section, we mainly focus on the frequency selective scheduling.

Dynamic channel-dependent scheduling is one of the key features to provide high spectrum efficiency in LTE. To better exploit the channel selectivity, the packet scheduler is located in the eNode-B, which allocates physical layer resources for both the DL-SCH and UL-SCH transport channels every TTI. Resource assignment consists of PRBs and MCS. Such scheduling depends heavily on the channel information available at the eNode-B, which is provided by the uplink CQI reporting for the downlink channel and by channel sounding for the uplink channel, as discussed in Section 9.2 and Section 9.4, respectively. The scheduler should also take account of the traffic volume and the QoS requirement of each UE and associated radio bearers. Due to the implementation of OFDMA/SC-FDMA, LTE is able to exploit the channel variation in both the time and frequency domain, which is a major advantage compared to HSPA, which is able to exploit channel variation only in the time domain.

The objective of channel-dependent scheduling, as discussed in Chapter 4, is to exploit multiuser diversity to improve the spectrum efficiency. Meanwhile, it should also consider such issues as fairness and QoS requirements. In addition, scheduling is tightly integrated with link adaptation and the H-ARQ process. The scheduling algorithm is not standardized and is eNode-B vendor specific. See [10–13] for the investigation of different scheduling schemes in LTE, and refer to Chapter 4 for related discussion. In this section, we focus on the signaling for both downlink and uplink scheduling. Dynamic scheduling is mainly applied on the data traffic, which is the focus in this section. The scheduling of VoIP services will be discussed in Section 9.7.

9.6.1 Signaling for Scheduling in Downlink and Uplink

For both downlink and uplink, the eNode-B scheduler dynamically controls which time-frequency resources are allocated to a certain UE. The resource assignments, including the assigned time/frequency resources and respective transmission formats, are conveyed through downlink control signaling. The minimum size of radio resource that can be allocated to a UE corresponds to two resource blocks, which is 1 ms duration in the time domain and 180kHz in the frequency domain. Both downlink and uplink employ orthogonal transmission, so each resource block is allocated to a single UE except in the MU-MIMO mode. Both localized and distributed resource allocations are supported in the downlink, while in the uplink UEs are always assigned contiguous resources, i.e., only localized allocation is supported. In addition, there is a strict constraint on the UE transmit power in the uplink, which is subject to the uplink power control that will be discussed in Section 9.10.

Signaling for Downlink Scheduling

The channel state information at the eNode-B for the downlink scheduling is obtained through CQI reporting from UEs, as discussed in Section 9.2. To enable frequency selective scheduling, subband CQI reporting is required. The eNode-B dynamically allocates resources to UEs at each TTI. A UE always monitors the PDCCH for possible allocations. For dynamically scheduled data traffic, the UE is configured by the higher layers to decode the PDCCH with CRC scrambled by the C-RNTI.[2] The UE shall decode the PDCCH and any corresponding PDSCH according to the respective combinations defined in Table 9.16. For example, when a UE configured in transmission mode 3 or 4 (OL and CL spatial multiplexing) receives a DCI format 1A assignment, it shall assume that the PDSCH transmission is associated with transport block 1 and that transport block 2 is disabled, and transmit diversity is applied. The DCI carries the downlink scheduling assignment and other information necessary to decode and demodulate data symbols. The transport channel processing of DCI was described in Section 7.3.

As shown in Section 6.3.3, in the downlink, while the two distributed allocation types (resource allocation type 0 and type 1) provide better performance with a high overhead, the localized allocation type (resource allocation type 2) provides a low overhead alternative at the cost of limited scheduling flexibility. The UE shall interpret the resource allocation field depending on the PDCCH DCI format detected. PDCCH DCI formats 1, 2, and 2A with type 0 and with type 1 resource allocation have the same format and are distinguished via the single bit resource allocation header field, where type 0 is indicated by 0 value and type 1 is indicated otherwise. PDCCH with DCI format 1A, 1B, 1C, and 1D have a type 2 resource allocation while PDCCH with DCI format 1, 2, and 2A have type 0 or type 1 resource allocation. The details of the resource assignment can be interpreted from DCI for different formats.

To determine the modulation order and transport block size, the UE shall first read the 5-bit "modulation and coding scheme" field (I_{MCS}) in the DCI, based on which a Transport Block Size (TBS) index can also be determined. The mapping between the MCS index I_{MCS}, the modulation order, and TBS index I_{TBS} for PDSCH is shown in

2 This is the unique identification used for identifying RRC connection and scheduling.

Table 9.16 PDCCH and PDSCH Configured by C-RNTI

UE DL Transmission Mode	DCI Format	Transmission Scheme of PDSCH
Mode 1	DCI format 1A	Single-antenna port, port 0
	DCI format 1	Single-antenna port, port 0
Mode 2	DCI format 1A	Transmit diversity
	DCI format 1	Transmit diversity
Mode 3	DCI format 1A	Transmit diversity
	DCI format 2A	OL spatial multiplexing or transmit diversity
Mode 4	DCI format 1A	Transmit diversity
	DCI format 2	CL spatial multiplexing or transmit diversity
Mode 5	DCI format 1A	Transmit diversity
	DCI format 1D	Multiuser MIMO
Mode 6	DCI format 1A	Transmit diversity
	DCI format 1B	Closed-loop Rank = 1 precoding
Mode 7	DCI format 1A	If the number of PBCH antenna ports is one, single-antenna port (port 0); otherwise, transmit diversity
	DCI format 1	Single-antenna port, port 5

Table 9.17. The TBS can then be determined based on I_{TBS} and the total number of allocated PRBs. Note that in Table 9.17 different MCS indices may be mapped to the same TBS, e.g., $I_{MCS} = 9, 10$ are mapped to $I_{TBS} = 9$, resulting in the same data rate. Such modulation overlap is adopted to improve the performance around the modulation switching points, as different combinations of modulation and coding with the same rate may provide different performance in different scenarios. For $29 \leq I_{MCS} \leq 31$, the TBS is determined from the previous scheduling grant for the same transport block using $0 \leq I_{MCS} \leq 28$.

Signaling for Uplink Scheduling

In the uplink, the channel state information is estimated at the eNode-B with the help of sounding reference signals, as discussed in Section 9.4. A UE always monitors the PDCCH in order to find possible allocation for uplink transmission. Only contiguous resource blocks can be allocated to a UE due to the SCFDMA nature of the UL transmission'. Frequency hopping can be applied to provide additional diversity. The UE obtains the uplink resource allocation as well as frequency hopping information from the uplink scheduling grant received four subframes earlier, i.e., if the UE detects a PDCCH with DCI format 0 in subframe n intended for this UE, it will adjust the corresponding PUSCH transmission in subframe $n + 4$ accordingly.

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