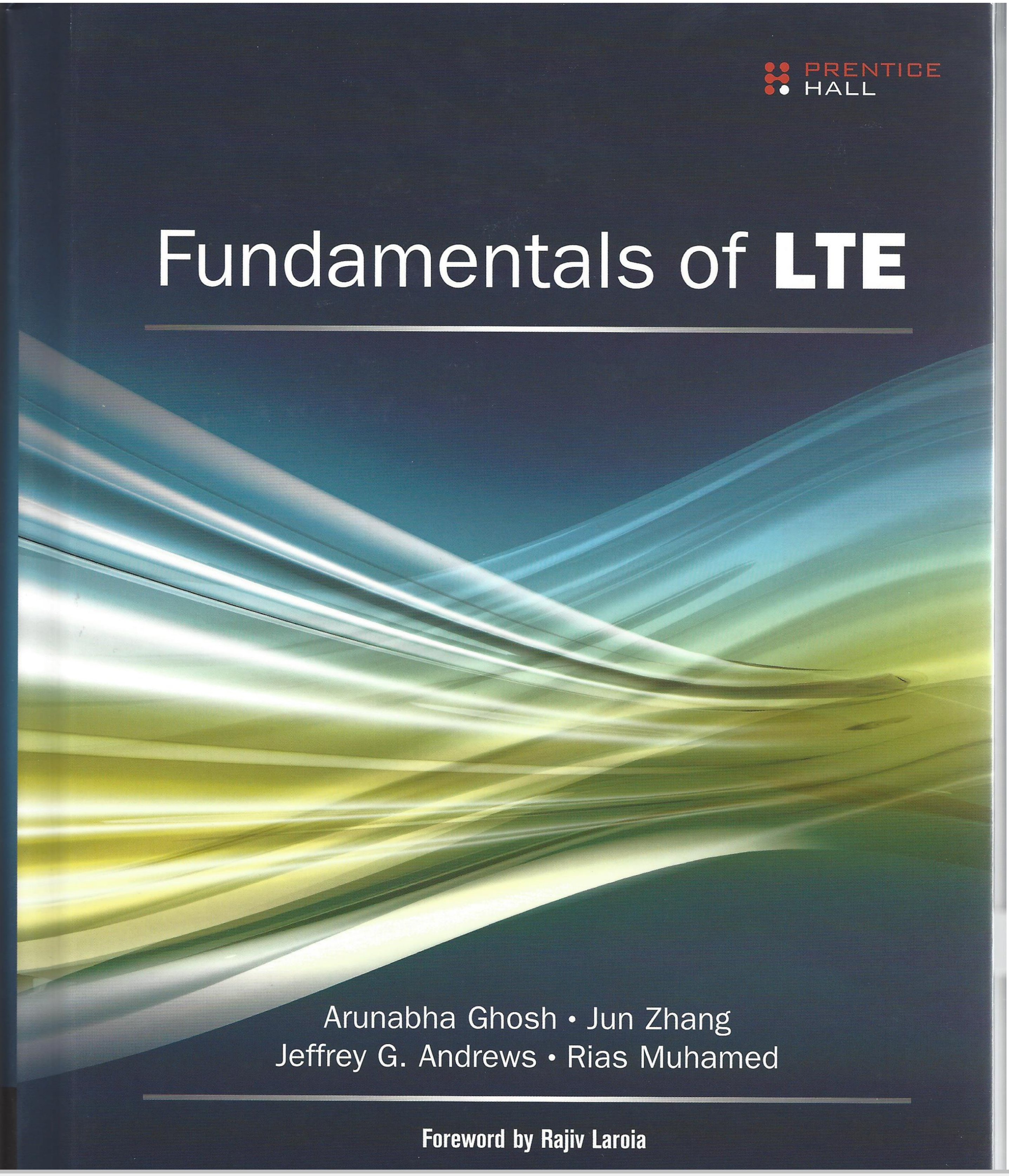

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Fundamentals of **LTE**

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Foreword by Rajiv Laroia

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Table 9.20 The Content of Random Access Response Grant

Information Type	Number of Bits	Purpose
Hopping flat	1	Indicates whether PUSCH frequency hopping is applied in the following step.
Fixed-size resource block assignment	10	Indicates the assigned radio resource for the following transmission.
Truncated modulation and coding scheme	4	Determines the modulation and coding scheme.
TPC command for scheduled PUSCH	3	Adjusts the transit power of PUSCH.
UL delay	1	Adjusts the uplink transmission timing.
CQI request	1	Used in non-contention-based random access procedure to determine whether an aperiodic CQI report is included in the corresponding PUSCH transmission.

resource use different preambles, different UEs can be identified by the eNode-B and there is no collision. However, it is possible that multiple UEs select the same preamble, which causes a collision. To resolve the contention for access, the UE that detects a random access preamble transmits a message containing a terminal identity. If the UE is connected to a cell, Cell Radio Network Temporary Identifier (C-RNTI) will be used, which is a unique UE ID at the cell level; otherwise, a core network identifier is used. In step 3, the H-ARQ protocol is supported to improve the transmission reliability.

Step 4: Contention Resolution Contention resolution is the key feature of the random access channel. In this step, the eNode-B transmits the contention-resolution message on the DL-SCH, which contains the identity of the winning UE. The UE that observes a match between this identity and the identity transmitted in step 3 declares a success and completes its random access procedure. If this UE has not been assigned a C-RNTI, the temporary identity is then set as its C-RNTI. The H-ARQ protocol is supported in this step, and the UE with successful access will transmit an H-ARQ acknowledgment.

9.10 Power Control in Uplink

With SC-FDMA-based transmission in the LTE uplink, orthogonality between intra-cell transmission from multiple UEs is achieved, which removes the intra-cell interference and the near-far issue typical of CDMA-based systems such as W-CDMA/HSPA. This leaves inter-cell interference as the major cause of interference and performance degradation, especially for the cell-edge UEs. In LTE, the power control in the uplink is to control the interference caused by UEs to neighboring cells while maintaining the required SINR at the serving cell. In this section, we describe the power control scheme for the PUSCH transmission in the uplink.

Conventional power control in the uplink is to achieve the same SINR for different efficiency as the common SINR is limited by the cell-edge UEs. LTE specifies Fractional Power Control (FPC) as the open-loop power control scheme, which allows for full or partial compensation of path loss and shadowing [7, 9, 14]. FPC allows the UEs with higher path loss, i.e., cell-edge UEs, to operate with lower SINR requirements so that they generate less interference to other cells, while having a minor impact on the cell-interior UEs so that they are able to transmit at higher data rates. Besides open-loop power control, there is also a closed-loop power control component, which is to further adjust the UE transmission power to optimize the system performance.

We first describe the FPC scheme, based on which the UE adjusts the transmission power according to:

$$P = \min\{P_{max}, 10\log M + P_0 + \alpha \cdot PL\} \text{ [dBm]}, \tag{9.11}$$

where P_{max} is the maximum UE transmission power, M is the number of assigned PRBs, P_0 is a parameter that controls the mean received SINR, α is the cell-specific path loss compensation factor, and PL is the downlink path loss estimate calculated in the UE. Note that the transmit power increases with M, which is to to ensure the same power spectral density irrespective of the number of PRBs.

If we only consider path loss and assume $10\log M + P_0 + \alpha \cdot PL \leq P_{max}$, then the received signal power at the eNode-B is

$$P_r = P - PL = 10\log M + P_0 + (\alpha - 1) \cdot PL \text{ [dBm]}. \tag{9.12}$$

- If $\alpha = 1$, each UE has a constant received power, which corresponds to full compensation, or channel inversion.
- If $\alpha = 0$, each UE has the same transmission power that is independent of the path loss, i.e., no power control.
- For $0 < \alpha < 1$, it is the FPC, and different UEs will have different P_r, depending on their path loss to the serving base station.

We see that reducing the value of α mainly decreases the transmission power of cell-edge UEs, which have large PLs and are likely to cause a high level of interference to neighboring cells. Therefore, by adjusting the path loss compensation factor α, we can reduce inter-cell interference and improve the spectrum efficiency.

Considering both open-loop and closed-loop components, the UE sets its total transmission power using the following formula:

$$P = \min\{P_{max}, 10\log M + P_0(j) + \alpha(j) \cdot PL + \Delta_{MCS} + f(\Delta_i)\} \text{ [dBm]}. \tag{9.13}$$

There are three different PUSCH transmission types, corresponding to $j = 0, 1, 2$:

- For PUSCH (re)transmissions corresponding to a semi-persistent grant, $j = 0$.
- For PUSCH (re)transmissions corresponding to a dynamic scheduled grant, $j = 1$.
- For PUSCH (re)transmissions corresponding to the random access response grant, $j = 2$

The parameters in (9.13) are described as follows:

- For $j = 0$ or 1, P_0 is composed of the sum of a cell-specific nominal component and a UE-specific component, provided by higher layers; for $j = 2$, P_0 is a cell-specific parameter signalled from higher layers.
- For $j = 0$ or 1, $\alpha(j)$ is a 3-bit cell-specific parameter, $\alpha(j) \in \{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$; for $j = 2$, $\alpha(j) = 1$.
- Δ_{MCS} is a UE-specific parameter depending on the chosen modulation and coding scheme (MCS). A large value of Δ_{MCS} corresponds to higher coding rate and/or higher modulation order.
- Δ_i is a UE-specific closed-loop correction value included in the PDCCH, which is also referred to as a Transmit Power Control (TPC) command. This is to compensate the following effects including power amplifier error, path loss estimation error, and inter-cell interference level changes.
- The function $f(\cdot)$ is to perform closed-loop power control based on Δ_i. It is UE specific. There are two types of closed-loop power control defined in LTE:
  - **Accumulated:** The UE applies an offset based on Δ_i using the latest transmission power value as reference:

    $$f(\Delta_i) = f(\Delta_{i-1}) + \Delta_{i-K}. \tag{9.14}$$

    The value of Δ_i is $\Delta_i \in \{-1, 0, 1, 3\}$ [dB]. For the FDD mode, $K = 4$, and for the TDD mode, the value of K depends on the UL/DL configuration [3].
  - **Absolute:** The UE adjusts the transmission power with an absolute value based on Δ_i:

    $$f(\Delta_i) = \Delta_{i-K}. \tag{9.15}$$

    For this case, the value of Δ_i is $\Delta_i \in \{-4, -1, 1, 4\}$ [dB]. For the FDD mode, $K = 4$, and for the TDD mode, the value of K depends on the UL/DL configuration [3].

A similar power control scheme employing FPC is used for sounding reference signals.

9.11 Summary and Conclusions

In this chapter, we specified the physical layer procedures that provide services to upper layers.

- CQI feedback from UEs and channel sounding procedure provide the eNode-B with channel quality information for downlink and uplink channels, respectively, which are then used per UE scheduling and link adaptation. For CQI feedback, to enable frequency-selective scheduling and also to keep the overhead low, various reporting modes are supported, including period and aperiodic reporting, with both wideband and subband reporting. For MIMO modes, RI and PMI feedback are also reported