

LONG TERM EVOLUTION

3GPP LTE Radio and
Cellular Technology



Edited by Borko Furht ■ Syed A. Ahson

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Contents

Preface.....	vii
The Editors.....	ix
Contributors.....	xi
1 Introduction	1
<i>Borko Furht and Syed Ahson</i>	
2 Evolution from TD-SCDMA to FuTURE.....	11
<i>Ping Zhang, Xiaodong Xu, and Lihua Li</i>	
3 Radio-Interface Physical Layer	49
<i>Gerardo Gómez, David Morales-Jiménez, F. Javier López-Martínez, Juan J. Sánchez, and José Tomás Entrambasaguas</i>	
4 Architecture and Protocol Support for Radio Resource Management (RRM)	99
<i>Gábor Fodor, András Rácz, Norbert Reider, and András Temesváry</i>	
5 MIMO OFDM Schemes for 3GPP LTE	155
<i>Gang Wu and Xun Fan</i>	
6 Single-Carrier Transmission for UTRA LTE Uplink.....	181
<i>Basuki E. Priyanto and Troels B. Sorensen</i>	
7 Cooperative Transmission Schemes	213
<i>Wolfgang Zirwas, Wolfgang Mennerich, Martin Schubert, Lars Thiele, Volker Jungnickel, and Egon Schulz</i>	
8 Multihop Extensions to Cellular Networks—the Benefit of Relaying for LTE	265
<i>Rainer Schoenen</i>	

9	User Plane Protocol Design for LTE System with Decode-Forward Type of Relay	305
	<i>Jijun Luo</i>	
10	Radio Access Network VoIP Optimization and Performance on 3GPP HSPA/LTE	319
	<i>Markku Kuusela, Tao Chen, Petteri Lundén, Haiming Wang, Tero Henttonen, Jussi Ojala, and Esa Malkamäki</i>	
11	Early Real-Time Experiments and Field Trial Measurements with 3GPP-LTE Air Interface Implemented on Reconfigurable Hardware Platform.....	365
	<i>A. Forck, Thomas Haustein, Volker Jungnickel, V. Venkatkumar, S. Wahls, T. Wirth, and Egon Schulz</i>	
12	Measuring Performance of 3GPP LTE Terminals and Small Base Stations in Reverberation Chambers.....	413
	<i>M. Andersson, A. Wolfgang, C. Orlenius, and J. Carlsson</i>	
	Index	459

Prefa

This book provides a wide range of information in various directions. The book is intended to be used as a source of information for the 12 chapters authors. The book also includes preface by researchers (faculty) to learn about this book.

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Although the book is for graduate students. Any comments? Many people and foremost of skilled researchers extremely useful.

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Preface

This book provides technical information about all aspects of 3GPP LTE. The areas covered range from basic concepts to research-grade material, including future directions. The book captures the current state of 3GPP LTE technology and serves as a source of comprehensive reference material on this subject. It has a total of 12 chapters authored by 50 experts from around the world. The targeted audience includes professionals who are designers or planners for 3GPP LTE systems, researchers (faculty members and graduate students), and those who would like to learn about this field.

The book has the following objectives:

- to serve as a single comprehensive source of information and as reference material on 3GPP LTE technology;
- to deal with an important and timely topic of emerging technology of today, tomorrow, and beyond;
- to present accurate, up-to-date information on a broad range of topics related to 3GPP LTE technology;
- to present material authored by experts in the field; and
- to present the information in an organized and well-structured manner.

Although the book is not precisely a textbook, it can certainly be used as a textbook for graduate courses and research-oriented courses that deal with 3GPP LTE. Any comments from readers will be highly appreciated.

Many people have contributed to this handbook in their unique ways. The first and foremost group that deserves immense gratitude is the highly talented and skilled researchers who have contributed the 12 chapters. All of them have been extremely cooperative and professional. It has also been a pleasure to work with Rich

scheduling assignment to the UE on the DL control channel (PDCCH). This means that neither the UE nor the eNode B has to do blind decoding. The UE decodes the data received on PDSCH according to the MCS indicated on the PDCCH. In the UL, the eNode B decodes the UE transmission according to the MCS it has assigned to the UE associated with the UL grant.

The power allocation is also under eNode B control, and it is tightly coupled to the MCS selection. A given MCS is optimal only at a given SINR. Therefore, the selection of the MCS is always done with a target SINR in mind. Then it is the responsibility of the power control function to set the transmit power levels such that the target SINR is reached. For the DL transmission, the eNode B distributes its power on the RBs according to the corresponding target SINRs. In the simplest case, the DL power is distributed uniformly over the RBs (i.e., no downlink power control is employed). For a close to optimum power allocation, the so-called *water-filling power allocation* might be used [10,11], whereby higher power is allocated to subcarriers whose fading and interference are in favorable conditions. However, the downlink power allocation is fully controlled by the eNode B, so the power allocation algorithm does not need to be specified in the standard.

However, to control the UL transmission power, the eNode B needs to send power control commands to the UE, which needs to be specified in the standard. Similarly, the behavior of the UE in response to receiving such a power control command also needs to be specified. This means that the UL power control algorithm needs to be specified in the standard. According to this algorithm, the UE transmit power is set as follows:

$$\min(P_{\max}, 10 \log_{10}(M) + P_0 + \alpha \times PL + \Delta_{\text{MCS}} + f(\Delta_i))$$

where

$P_{\max}$ is the maximum allowed power;

M is the number of resource blocks assigned to the UE;

P_0 is a UE-specific parameter;

α is a cell-specific path loss compensation factor;

PL is the downlink path loss calculated in the UE based on reference power measurements;

Δ_{MCS} is a modulation- and coding scheme-specific parameter (the table of Δ_{MCS} values is configured in the UE via RRC signaling; MCS is signaled in the scheduling assignment); and

function $f()$ is also signaled via RRC, while Δ_i is the actual transmit power command signaled in each scheduling assignment.

4.2.4 Handover Control

Handover control is responsible for maintaining the radio link of a UE in active mode as the UE moves within the network from the coverage area of one cell to the coverage

area of another. In LTE, the for mobile communications handover is network controlled from one cell to the other having connectivity to only one cell. This is a multiple access (WCDMA) control and in which the UE

One of the most important the interference sensitivity of the nature of code division transmit power of the UEs, the diversity gain of soft handover is perfect intracell orthogonality the system is not (intracell) system. Moreover, LTE can handle handover, such as multiantenna and channel-dependent channel conditions in the handover solution negligible.

The network-controlled the decision to move the radio is made by the network—mainly by measurement reports received from other information sources. Based on its own measurements, the availability of the radio resource, etc. However, the decision is the UE path gain to ensure that the UE is always in the best cell. This is especially important when moving to a cell other than the best neighbor cells, especially to

Another consequence of the SINR) may change rapidly at the cell edge. The use of ICIC to mitigate interference effects (see Section 4.2.5 for details) can improve the condition of the link quality at the cell edge. However, it is quickly upon the changing link quality that a fast handover execution is required to avoid intercell interference. Moreover, to be reliable and short enough, the handover decision is recognized, the time needed for the handover and the time needed for execution of the handover change of the link quality at



of another. In LTE, the handovers are *hard handovers* (similarly to global system mobile communications [GSM] systems) with preparation at the target cell. The handover is network controlled and UE assisted. Hard handover means that the switch from one cell to the other happens in a “break-before-make” fashion; that is, the UE has connectivity to only one cell at a time. This is in contrast to the 3G wideband code division multiple access (WCDMA) system, which employs soft handover and fast power control and in which the UE can be associated with multiple cells at the same time.

One of the most important reasons why soft handover is used in WCDMA is the interference sensitivity of the system (especially in the uplink), stemming from the nature of code division multiple access. When soft handover is used the transmit power of the UEs, the caused interference can be decreased because the diversity gain of soft handover compensates for the smaller transmit power. In LTE there is perfect intracell orthogonality owing to the OFDM multiple access scheme, so the system is not (intracell) interference sensitive in the same sense as a WCDMA system. Moreover, LTE can exploit diversity in a number of other ways than soft handover, such as multiantenna transmission modes; because of the fast link adaptation and channel-dependent scheduling functions, it can adapt to instantaneous channel conditions in the best possible way, which makes the importance of a soft handover solution negligible.

The network-controlled and UE-assisted property of the handover means that the decision to move the radio link connection of the UE from one cell to the other is made by the network—more specifically, by the eNode B serving the UE, assisted by measurement reports received from the UE. The eNode B can utilize a number of other information sources as well for making the handover decision, including its own measurements, the availability of radio resources in candidate cells, load distribution, etc. However, the most important aspect that should drive the handover decision is the UE path gain measure. In other words, the handover control should ensure that the UE is always connected to the cell with the best average path gain. This is especially important in reuse-1 systems like LTE, where a UE connected to a cell other than the best cell may cause substantial additional interference to neighbor cells, especially to the best cell.

Another consequence of the reuse-1 system is that the link quality (i.e., the SINR) may change rapidly due to intercell interference as the UE moves toward the cell edge. The use of ICIC techniques may mitigate the high cell edge interference effects (see Section 4.2.5 for more details on ICIC). Nevertheless, the fast deterioration of the link quality at the cell edge means that the system needs to act rather quickly upon the changing link conditions before the link gets lost, which requires a fast handover execution and signaling mechanisms that are robust with respect to intercell interference. More specifically, the overall handover procedure time has to be reliable and short enough, including the time elapsed until the handover situation is recognized, the time needed for preparing the handover at the target cell, and the time needed for executing the handover. Another consequence of the fast change of the link quality at the cell edge is that a large hysteresis in the source

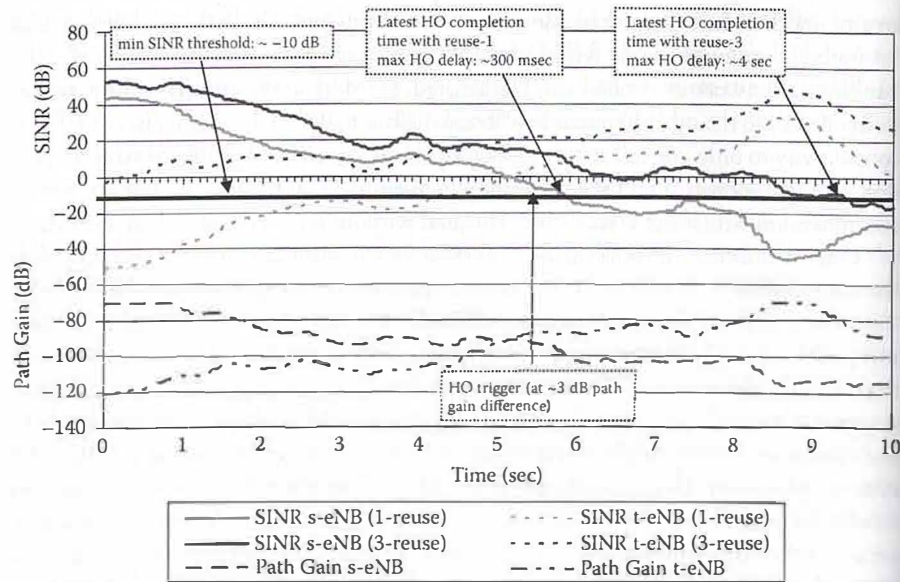


Figure 4.7 Change of SINR at the cell edge for a reuse-1 and a reuse-3 system, simulated with a UE speed of 30 m/s. The time from when the handover is triggered (with 3-dB path gain hysteresis) until the source cell radio link SINR drops below -10 dB (where the radio link is assumed to be lost) is ~300 ms in the reuse-1 case and ~4 s in the reuse-3 case, which gives a maximum delay until the execution of the handover needs to be completed.

and target cell path gain differences, used for the handover decision, may not be allowed. However, a smaller hysteresis may trigger more handovers.

Figure 4.7 shows the change of SINR at the cell edge (obtained from simulations) in the function of time as the UE moves with a speed of 30 m/s from one cell to the other in a reuse-1 and in a reuse-3 system, respectively. As it can be seen in the figure, the SINR deteriorates more rapidly in the reuse-1 system, leaving a shorter time for the execution of the handover (~300 ms in the reuse-1 case and several seconds in the reuse-3 case).

A fast handover execution is not only needed to combat the rapid change of link quality but also is important from the user-perceived performance point of view. This means that, in order to achieve good handover performance from a radio efficiency and also from a user-perceived quality point of view, it is required to have low interruption time and no user data packet losses during the handover. In order to meet these requirements, the following handover procedure is used in LTE, as illustrated in Figure 4.8.

Without discussing all details of the procedure, we would like to point out a few important aspects to observe. After the decision for a handover has been made in the



Figure 4.8

source eNodeB
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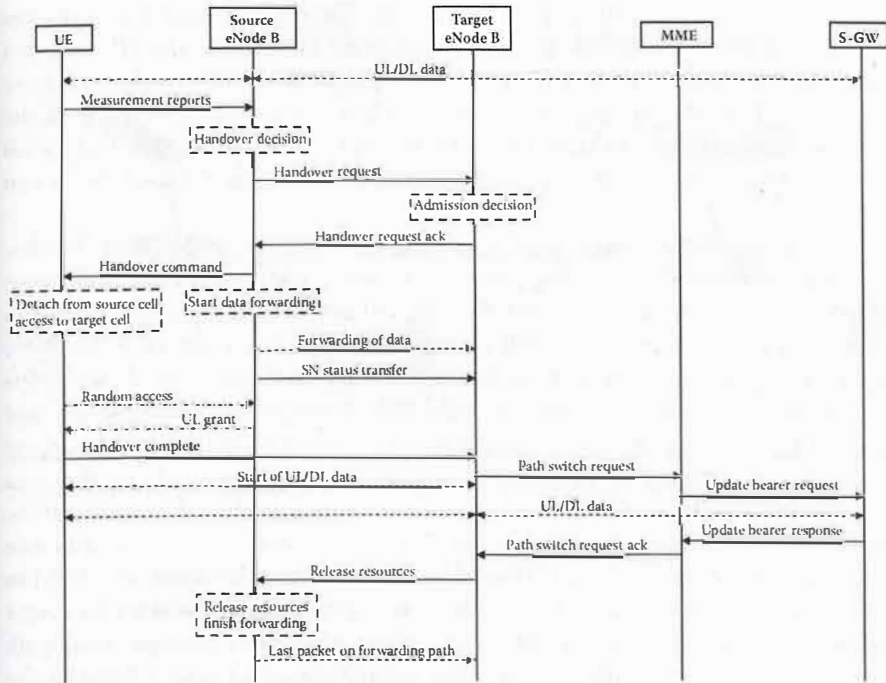


Figure 4.8 Handover message sequence.

source eNode B, it signals to the selected target eNode B and requests the reservation of resources. If the admission decision has passed successfully in the target, the target eNode B prepares a transparent container (which is for interpretation only for the UE, including necessary information for the UE to access the target cell) and sends it back to the source eNode B in the handover request acknowledge message. Next, the source eNode B can command the UE to execute the handover and at the same time start the forwarding of user data. The source eNode B forwards PDCP service data units (SDUs) (i.e., IP packets that could not be successfully sent in the source cell) toward the target eNode B. Note that the L2 protocols including RLC/MAC are reset in the target cell (i.e., no HARQ/ARQ status information is preserved); the header compression engine in the PDCP layer is also reset. For more details on the handover procedure, see 3GPP TS 36.300 [14].

When the UE arrives at the target cell, it accesses the cell via the RACH. However, in order to reduce the interruption time due to potential collisions on the RACH, it is possible to use a dedicated preamble for the access. The term *preamble* refers to the signature sequence that is sent by the UE on the RACH slot, and it is used to identify the access attempt. There are 64 preambles for contention-based access, and a separated set of preambles is used in a contention-free, dedicated manner—for example, for handover access (or for

access to regain uplink time synchronization). The target eNode B can reserve a dedicated preamble for the particular handover instance of the UE and can signal this preamble to the UE via the transparent container in the handover command. Because the preamble is dedicated, no other UEs can use it at the same time, which ensures that the access attempt will be contention free. With the preceding handover scheme, an interruption time in the range of 15 ms can be ensured.

Finally, it is worth mentioning that LTE provides an efficient recovery mechanism for handover failure cases, when the handover could not have been commanded by the network due to the loss of the radio link. Although such radio link losses should be rare events in a well-planned network, their occurrence cannot be completely ruled out, especially due to the potential harsh interference conditions on the cell edge. If the UE loses the radio link, it reselects to a suitable cell and initiates a connection reestablishment. If the UE context is available at the selected eNode B (i.e., if the UE reselects to a cell belonging to the source eNode B or to a cell of an eNode B that has been prepared for a handover), the UE context can be recovered. In such cases, the interruption time and the user-perceived performance will be almost as good as in the nonfailure case. In all other cases, the UE has to reestablish connectivity via an idle to active state transition, which will take a somewhat longer time. Also, if the source eNode B wants to decrease the impact of a potential handover failure, it can prepare multiple target cells; later, after the handover has been successfully completed, it can cancel the preparation in the other cells.

4.2.5 Intercell Interference Coordination (ICIC)

Intercell interference coordination has the task to manage radio resources (notably the radio resource blocks) so that intercell interference is kept under control. The specific ICIC techniques that will be used in LTE are still in some key points that have already been agreed to [46]. ICIC is inherently a multicell RRM function that needs to take into account the resource usage status and traffic load situation of multiple cells. The presingle-antenna, as well as multiple-antenna systems, has been actively studied by the research community (see, for instance, references 24–41). In this chapter we focus on the process.

Within the 3GPP there is a fairly wide consensus that LTE should be a reuse-1 system in which all resource blocks should be used by each cell. In such systems, UEs served by neighboring cells may cause (uplink) interference to eNode Bs, as illustrated in Figure 4.9, while eNode Bs may cause downlink interference to served UEs. However, eNode Bs can employ scheduling strategies that allow them to reduce the probability for causing such intercell interference by carefully selecting the scheduled resource blocks.

A resource block collision between two cells, as described in Figure 4.9, can be reduced either by avoiding scheduling some of the resource blocks in some of the cells (reuse- n , $n > 1$, or fractional reuse; see Figure 4.10) or by coordinating the