Physical Communication 3 (2010) 217–244

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom

The evolution to 4G cellular systems: LTE-Advanced

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ARTICLE INFO

Keywords:
LTE
LTE-Advanced
4G
Carrier aggregation
CoMP
Relay
MIMO

ABSTRACT

This paper provides an in-depth view on the technologies being considered for Long Term Evolution-Advanced (LTE-Advanced). First, the evolution from third generation (3G) to fourth generation (4G) is described in terms of performance requirements and main characteristics. The new network architecture developed by the Third Generation Partnership Project (3GPP), which supports the integration of current and future radio access technologies, is highlighted. Then, the main technologies for LTE-Advanced are explained, together with possible improvements, their associated challenges, and some approaches that have been considered to tackle those challenges.

1. Introduction

The fourth generation (4G) of wireless cellular systems has been a topic of interest for quite a long time, probably since the formal definition of third generation (3G) systems was officially completed by the International Telecommunications Union Radiocommunication Sector (ITU-R) in 1997. A set of requirements was specified by the ITU-R regarding minimum peak user data rates in different environments through what is known as the International Mobile Telecommunications 2000 project (IMT-2000). The requirements included 2048 kbps for an indoor office, 384 kbps for outdoor to indoor pedestrian environments, 144 kbps for vehicular connections, and 9.6 kbps for satellite connections.

With the target of creating a collaboration entity among different telecommunications associations, the 3rd Generation Partnership Project (3GPP) was established in 1998. It started working on the radio, core network, and service architecture of a globally applicable 3G technology specification. Even though 3G data rates were already real in theory, initial systems like Universal Mobile Telecommunications System (UMTS) did not immediately meet the IMT-2000 requirements in their practical deployments. Hence, the standards needed to be improved to meet or even exceed them. The combination of High Speed Downlink Packet Access (HSDPA) and the subsequent addition of an Enhanced Dedicated Channel, also known as High Speed Uplink Packet Access (HSUPA), led to the development of the technology referred to as High Speed Packet Access (HSPA) or, more informally, 3.5G.

Motivated by the increasing demand for mobile broadband services with higher data rates and Quality of Service (QoS), 3GPP started working on two parallel projects, Long Term Evolution (LTE) and System Architecture Evolution (SAE), which are intended to define both the radio access network (RAN) and the network core of the system, and are included in 3GPP Release 8. LTE/SAE, also known as the Evolved Packet System (EPS), represents a radical step forward for the wireless industry that aims to provide a highly efficient, low-latency, packet-optimized, and more secure service. The main radio access design parameters of this new system include OFDM (Orthogonal Frequency Division Multiplexing) waveforms in order to avoid the inter-symbol interference that typically limits the performance of high-speed systems, and MIMO (Multiple-Input Multiple-Output) techniques to boost the data rates. At the network layer, an all-IP flat architecture supporting QoS has been defined. The world's first publicly available LTE service was opened by TeliaSonera in the two Scandinavian capitals Stockholm and Oslo on December 14, 2009, and the first test measurements are currently being carried out. However, by the time the standard development started,

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doi:10.1016/j.phycom.2010.08.001

the ITU-R framework for 4G systems was not in place, and later research and measurements confirmed that the system did not fully comply with ITU 4G requirements. For this reason, the term 3.9G has been widely used with the expectation of their evolving towards official 4G status in due course.

Before 3GPP started working in the real 4G wireless technology, minor changes were introduced in LTE through Release 9. In particular, femtocells and dual-layer beamforming, predecessors of future LTE-Advanced technologies, have been added to the standard. The formal definition of the fourth generation wireless, known as the International Mobile Telecommunications Advanced (IMT-Advanced) project, was finally published by ITU-R through a Circular Letter in July 2008 with a call for candidate radio interface technologies (RITs) [1]. In October 2009, six technologies were submitted seeking for approval as international 4G communications standard. 3GPP's candidate is LTE-Advanced, the backward-compatible enhancement of LTE Release 8 that will be fully specified in 3GPP Release 10 [2]. By backward compatibility, it is meant that it should be possible to deploy LTE-Advanced in a spectrum already occupied by LTE with no impact on the existing LTE terminals. Other candidate technologies are IEEE 802.16m and China's Ministry of Industry and Information Technology TD-LTE-Advanced (LTE-Advanced TDD specification) [3,4].

The set of IMT-Advanced high-level requirements established by the ITU-R in [5] is as follows.

- A high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost-efficient manner.
- Compatibility of services within IMT and with fixed networks.
- Compatibility of internetworking with other radio access systems.
- High-quality mobile devices.
- User equipment suitable for worldwide use.
- User-friendly applications, services, and equipment.
- Worldwide roaming capability.
- Enhanced peak rates to support advanced services and applications (100 Mbit/s for high mobility and 1 Gbit/s for low mobility were established as targets for research).

All the above requirements, except for the last one, are high level, i.e. they do not quantify the performance requirements; besides, they have largely been pursued by the industry already. When it comes to a detailed description of the IMT-Advanced requirements, explicit targets have been set for average and cell-edge performance in addition to the usual peak data rates. This was a necessary issue to be addressed since they define the experience for the typical user.

The requirements for LTE-Advanced were accordingly set to achieve or even enhance IMT-Advanced. However, as stated in [6], the target for average spectrum efficiency and cell-edge user throughput efficiency should be given a higher priority than the target for peak spectrum efficiency and Voice-over-IP (VoIP) capacity. Therefore, the solution proposals of LTE-Advanced, the main ones of which are covered by this paper, focus on the challenge of raising the average and cell-edge performance. The relationship among the requirements of LTE, LTE-Advanced, and IMT-Advanced are shown in Table 1.

Other important requirements are the already mentioned backward compatibility of LTE-Advanced with LTE and the spectrum flexibility, i.e., the capacity of LTE-Advanced to be deployed in different allocated spectra since each region or country has different regulations. The main issue now is to develop the appropriate technologies that allow LTE-Advanced to meet the proposed targets. From a link performance perspective, LTE already achieves data rates very close to the Shannon limit, which means that the main effort must be made in the direction of improving the Signal-to-Interference-and-Noise Ratio (SINR) experienced by the users and hence provide data rates over a larger portion of the cell.

The remainder of this paper is organized as follows. In Section 2, we provide an overview of the network architecture that will support the LTE and LTE-Advanced air interfaces. Then, we cover the concept and challenges of the four research categories that, according to 3GPP, constitute the pillars of the LTE-Advanced system. In Section 3, we present LTE-Advanced spectrum issues: bandwidth aggregation, a technology that aims at increasing the system bandwidth by aggregating different carriers, and spectrum sharing techniques for heterogeneous networks. The new enhanced MIMO techniques in both the downlink and the uplink for LTE-Advanced are introduced in Section 4. In Section 5, we describe enhanced Node B cooperation techniques in the framework of LTE-Advanced, grouped under the name of coordinated multipoint transmission and reception (CoMP). We present relaying strategies in Section 6. Finally, we conclude the paper with Section 7.

2. Network architecture

3GPP specified in its Release 8 the elements and requirements of the EPS architecture that will serve as a basis for the next-generation networks [7]. The specifications contain two major work items, namely LTE and SAE, that led to the specification of the Evolved Packet Core (EPC), Evolved Universal Terrestrial Radio Access Network (E-UTRAN), and Evolved Universal Terrestrial Radio Access (E-UTRA), each of which corresponds to the core network, radio access network, and air interface of the whole system, respectively. The EPS provides IP connectivity between a User Equipment (UE) and an external packet data network using E-UTRAN. In Fig. 1, we provide an overview of the EPS, other legacy Packet and Circuit Switched elements and 3GPP RANs, along with the most important interfaces. In the services network, only the Policy and Charging Rules Function (PCRF) and the Home Subscriber Server (HSS) are included, for simplicity.

In the context of 4G systems, both the air interface and the radio access network are being enhanced or redefined, but so far the core network architecture, i.e. the EPC, is not undergoing major changes from the already standardized SAE architecture. Therefore, in this section we give an overview of the E-UTRAN architecture and functionalities defined for the LTE-Advanced systems and the main EPC node functionalities, shared by Releases 8, 9, and 10.