Computer Standards & Interfaces 43 (2016) 30–39

Contents lists available at ScienceDirect

Computer Standards & Interfaces

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

On the impact of mobile node radio architectures on heterogeneous wireless network standards: A performance analysis of LTE–eHRPD mobility

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ARTICLE INFO

Article history:
Received 5 October 2013
Received in revised form 6 June 2015
Accepted 31 July 2015
Available online 8 August 2015

Keywords:
Heterogeneous wireless standards
Multi-radio architecture
LTE
eHRPD
Handover

ABSTRACT

With the availability of various heterogeneous radio access technology standards, how to support multiple heterogeneous radio interfaces in a single device and provide seamless mobility between them is one of key issues in the design and implementation of modern multi-radio mobile devices (like smartphones). The radio architectures of such multi-radio mobile devices can have great impacts on achievable mobility performance. This paper presents a case study that investigates into the impacts of radio architecture design on mobility performance achievable in wireless standard implementation, with a particular focus on heterogeneous radio access mobility between Long Term Evolution (LTE) and enhanced High Rate Packet Data (eHRPD). We present an in-depth overview of handover procedures in standards and their achievable performance enhancements from the perspective of device radio architectures. We consider three radio architectures (single transmission/reception, single transmission dual reception, and dual transmission/reception architectures) and provide a performance analysis to compare the three architectures in terms of handover delay and energy consumption. We also discuss supportability for advanced flow-precision mobility under the different radio architectures, and present a comparison with another vertical handover technology.

1. Introduction

Long Term Evolution (LTE) and LTE-Advanced by the 3rd Generation Partnership Project (3GPP) have become a dominant 4th-generation cellular network standard since major operators world-wide (Telia Sonera, Verizon Wireless, AT&T, SK Telecom, NTT DoCoMo, TMobile, Vodafone, etc.) have launched the initial roll-out of LTE and have nation-wide deployment plans in the coming years [1]. Along with the evolution towards higher spectral efficiency and bit rates in the radio network part (both mobile nodes and base stations), the core network part has been redesigned for radical evolution as well, which is referred to as System Architecture Evolution (SAE) or Evolved Packet Core (EPC) [2,3]. One of the crucial points with the deployment of LTE/SAE as new radio network and core network standards is how they can be seamlessly integrated into the legacy 3rd generation (3G) or 2nd generation (2G) cellular networks without introducing any disruption in service experiences to mobile users. More specifically, for the 3rd Generation Partnership Project 2 (3GPP2) network operators [4], interworking between LTE and eHRPD (or 1xRTT) is of utmost interest [3,5]. Here, eHRPD and 1xRTT are the legacy 3G standards, enhanced High Rate Packet Data and single-carrier Radio Transmission Technology [6]. Meanwhile, for 3GPP network operators, interworking between LTE and UTRAN/GERAN is a key enabler for seamless deployment of the new LTE technology [2,7]. Here, UTRAN is the legacy 3G standard, Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network, and GERAN is the legacy 2G standard, General Packet Radio Service (GPRS) and Enhanced Data Rates for Global Evolution (EDGE) radio access network.

Since the initial deployment of LTE/LTE-Advanced networks and the proliferation of data-consuming mobile user devices (e.g., smartphones and tablets), cellular network operators have met the explosive increase of mobile data traffic [8]. To resolve the challenge, next-generation technologies are envisioned to adopt smaller cell sites [9] and tight integration with non-3GPP technologies like Wi-Fi [10,11], and hence, interworking between different wireless network technologies is expected to more frequently happen in denser heterogeneous wireless networks [12,13]. As the 3GPP technologies will evolve in future, interworking between 3GPP and non-3GPP technologies will need to be newly studied and specified to provide performance experience and seamless operation for mobile users.

In general, interworking between heterogeneous wireless network technologies, e.g., for 4G LTE/LTE-Advanced and the legacy 3G/2G cellular technologies, has many technical aspects to be considered, including system selection, inter-RAT (radio access technology) mobility such as handover and cell reselection, authentication, and quality of service [2,3]. The extant standards and researches on inter-RAT mobility generally tend to focus on message procedures, and functional and performance evaluation from the protocol perspectives [14]. However, we believe that such aspects can be more carefully and thoroughly

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http://dx.doi.org/10.1016/j.csi.2015.07.003
0920-5489/

investigated from the radio architectural points of view for both mobile nodes, i.e., user equipments (UEs) in the 4G terminology, and core network entities. For example, basic interworking procedures for both active-state handover [3,6] and idle-state cell reselection [6,15,16], and possible enhancements to the procedures depend heavily on mobile node radio architectures and the degree of functional support from core network parts. For this reason, from the early stage of specifying interworking standards between heterogeneous wireless technologies, the radio architecture of mobile nodes should be thoroughly considered in the specifications from both functionality and performance points of view.

In this paper, we present a case study to investigate into the impacts of mobile node radio architectures on heterogeneous LTE and eHRPD interworking standards. The standards have a significant importance in that they have recently enabled the successful incremental deployment of the new LTE technology in several countries including the US, South Korea, and Japan. We perform an in-depth analysis, in terms of handover delay and energy consumption, to examine LTE and eHRPD interworking scenarios [5] from the perspectives of mobile node radio architectural design. Particularly, we are interested in the way how mobile node radio architectures can support various LTE and eHRPD handover scenarios and what differences they can potentially make in terms of handover performance per handover scenario.

To provide background information about LTE and eHRPD interworking, we first present, in Section 2, an overview of the network architecture and describe the basic LTE to eHRPD handover procedure from the mobile node radio architectural points, which serves as the baseline for various enhanced handover scenarios. Considering the incremental deployment of LTE cells and possible radio link failure events of deployed LTE cells, handover to more prevalent eHRPD cells of a larger coverage is a key enabler of service continuity to the successful transition from 3G networks to 4G LTE networks. Thus we focus on LTE to eHRPD mobility from the service continuity and performance point of view in this paper although eHRPD to LTE mobility procedure may be important for more advanced data traffic management and load balancing in future. Then in Section 3, we present the details on three different radio architectures that are implementable radio models for state-of-the-art LTE and eHRPD multi-radio mobile devices and how handover enhancements can be realized on top of those radio architectures. Based on the ways of radio architectural design, in Section 4, we conduct performance analysis in terms of handover delay and energy consumption for the combination of radio architectures and handover enhancement scenarios. In Section 5.1, we also discuss supportability of IP flow mobility [17–19], which is a more advanced selective mobility procedure in the precision of individual IP flows rather than the conventional mobility procedure for the whole set of IP flows existing in a mobile node, from the perspectives of mobile node radio architectures. Finally in Section 6, we articulate the main contributions of the paper.

2. Background: LTE and eHRPD interworking

The network architecture for LTE and eHRPD interworking is illustrated in Fig. 1 where LTE is also called evolved UTRAN (E-UTRAN) [3]. The name eHRPD comes from legacy High Rata Packet Data (HRPD) and it enhances 3GPP interworking functions on top of 3GPP2 network of HRPD access networks (ANs). The Packet Data Network Gateway (PDN Gateway or PGW) [2] works as an ingress/egress point between a mobile network and the external public Internet or the mobile network operator's IP Multimedia Subsystem (IMS) network [20]. The Mobility Management Entity (MME) is in charge of keeping track of a UE's current location at different granularity depending on the UE state (either active state or idle state) and plays a key role in the control plane to coordinate data transmission on the user plane or data plane for the UE by executing Non-Access Stratum (NAS) protocol with the UE [21]. The UE, though simplified in Fig. 1, is equipped with multi-radio interfaces (an LTE modem and an eHRPD modem) and thus should be able to access the LTE radio network (eNB: evolved Node B) and the eHRPD radio network (BTS: base transceiver station). We will investigate in detail into how required components in this dual-mode UE are architecturally designed such as baseband chips, radio frequency (RF) chips, RF front-end modules, and antenna for dual bands, and their implications to mobility in the interworking architecture.

An important principle for LTE and eHRPD interworking is that 3GPP and 3GPP2 should share the same 3GPP Authentication Authorization Accounting (AAA) server, Policy and Charging Rule Function (PCRF) [22], and PGW. In this design rationale, a key entity to connect the legacy HRPD network to LTE/EPC is HRPD Serving Gateway (HSGW) which is enhanced from the legacy packet data service network (PDSN) function. An HSGW has reference points (i.e., interfaces defining protocols between network entities) with 3GPP PGW, PCRF, and AAA

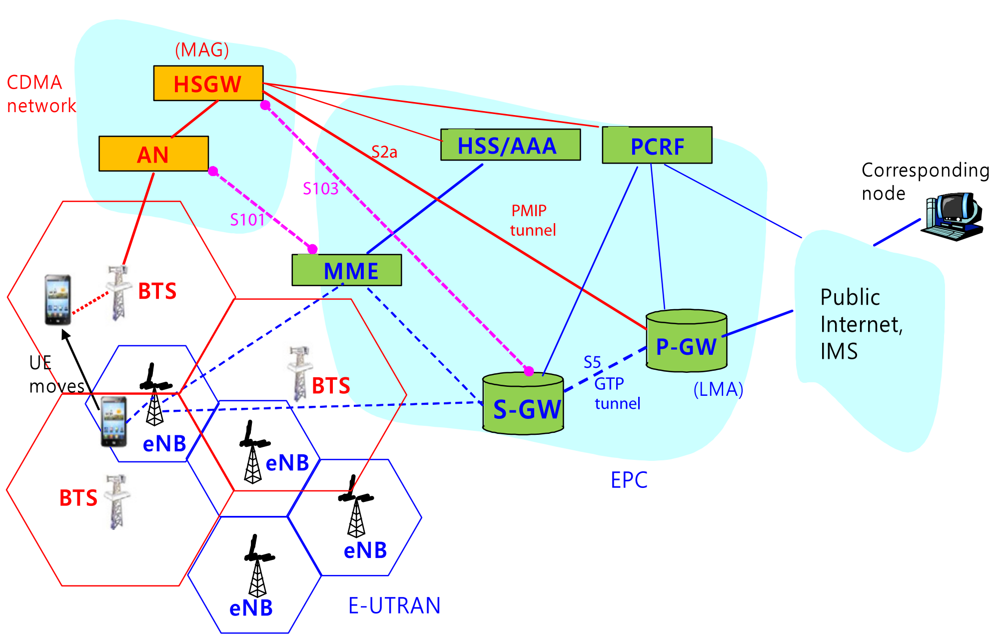

Fig. 1. The network architecture of LTE–eHRPD interworking.