ISSN 1881-803X

ICIC Express Letters

An International Journal of Research and Surveys

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Volume 7, Number 1, January 2013 ISSN 1881-803X

International

ICIC Express Letters

An International Journal of Research and Surveys

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Volume 8, Number 5, May 2014 ISSN 1881-803X

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ICIC EXPRESS LETTERS

AN INTERNATIONAL JOURNAL OF RESEARCH AND SURVEYS

VOLUME 8, NUMBER 5, May 2014

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 ISSN 1881-803X PRINTED IN JAPAN

ICIC Express Letters
Volume **8**, Number **5**, May **2014**

ICIC International ©2014 ISSN 1881-803X
pp. 1519–1526

DESIGN OF MULTI-RAT VIRTUALIZATION ARCHITECTURES IN LTE-ADVANCED WIRELESS NETWORK

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Received July 2013; accepted September 2013

Abstract. *Long Term Evolution-Advanced (LTE-A) standard is one of the competing heads of access network technology in 4G wireless networks. Long Term Evolution (LTE) and LTE-A are developed by Third Generation Partnership Project (3GPP) which are organized by telecommunication vendors and operators. Moreover, both LTE and LTE-A are backward compatible with previous 3GPP standards such as Universal Mobile Telecommunications System (UMTS), General Packet Radio Service (GPRS) and Global System for Mobile Communications (GSM) cellular systems. To improve radio resource utilization, telecommunication vendors could simultaneously deploy Multiple Radio Access Technologies (Multi-RATs) in a given coverage area and carry the complete offered user traffic with varied wireless services in a single radio device. If LTE-A base station can support Multi-RATs including UMTS, Wireless Fidelity (Wi-Fi) and Worldwide Interoperability for Microwave Access (WiMAX) by virtualization system, the LTE-A system would provide more flexible network services than before. However, the virtualization system architecture for Multi-RATs support is still under development. This paper focuses on designing virtualization architecture by which Donor Evolved Node B (DeNB) can provide services for both UMTS User Equipments (UEs) and LTE UEs. Two novel architectures (Arch_A and Arch_B) are presented in this paper. As shown in the Multi-RAT Virtualization architecture, our proposed structure can integrate the services of 3G UMTS and 4G LTE-A wireless networks. Thus, the migration between 3G and 4G is more easily achieved by our proposed two architectures.*
Keywords: LTE, Virtualization, Multi-RAT, UMTS, 4G

1. **Introduction.** The telecom manufacturers and vendors have begun to provide traditional network communication services on mobile phones in recent years. The new technology is called *Long Term Evolution (LTE)* [1] which is a competing access network technology in 4G wireless networks with *Worldwide Interoperability for Microwave Access (WiMAX)* [3,4]. *Third Generation Partnership Project (3GPP)* formally approved LTE to be the standard technology for the wireless communication. Since LTE standard is defined by telecom vendors and is backward compatible with *Global System for Mobile Communications (GSM)*/*Universal Mobile Telecommunications System (UMTS)* cellular systems, this makes LTE deployment much easier than WiMAX. In the enhanced LTE version, *Long Term Evolution-Advanced (LTE-A)* [2], the transmission bandwidth has been upgraded. The transmission rate can reach up to 1Gbps when UEs are in low mobility state. Even UEs in high mobility state, the transmission rate can still provide up to 100Mbps. The major difference between 3GPP Release 10 LTE-A [1] and original LTE is a new entity called *relay node* (*RN*) introduced in LTE-A. The base station, called *Donor Evolved Node B* (*DeNB*) [5], can extend its serving coverage by using RN.

Moreover, DeNB and RN can also offer higher data rates and better spectral efficiencies, in combination with the necessity of retaining the traditional technologies for as long as possible (in order not only to satisfy the previous 3GPP version users who do not switch to the new technologies, but also to obtain the maximum benefits from the already constructed infrastructure). The Multi-RATs [6-8] simultaneously co-exist in a given wireless area and can reduce the cost of physical devices construction and increase the previous 3GPP technologies coverage. However, the Multi-RAT supporting in DeNB is still under development in 3GPP, there is no suitable architecture proposed in 3GPP standards, and furthermore, there is also no virtualization implementation system in LTE-A networks. So we will first propose a novel virtualization architecture design by which DeNB is able to provide services for both *UMTS UEs* and *LTE UEs*. The proposed *Multi-RAT Virtualization architecture in DeNB* should not only support *Evolved Node B* (*eNB*), *Node B (NB)* and *Radio Network Controller (RNC)* functionalities and corresponding link interfaces, but also add a virtual tunnel link between *Evolved Packet Core* (*EPC*) and UMTS domain in order to provide connection between UMTS UEs and UMTS core network. As we know, UMTS UE must attach to an RNC before receiving service, and *Evolved-UTRAN (E-UTRAN)* and EPC have to provide connection between UMTS UE and RNC with two alternatives, *Arch_A and Arch_B*. For UMTS UEs and LTE UEs, the novel Multi-RAT Virtualization architecture DeNB can provide seamless wireless services without extra UMTS NB deployment. Thus, the company's construction cost can be reduced by our proposed novel Multi-RAT Virtualization architecture. The performance analysis has shown that our proposed Multi-RAT Virtualization architectures are workable and the Arch_B might have better performance in handover delay and signal.

The remainder of this paper is organized as follows. Section 2 briefly introduces 3GPP UMTS, LTE/LTE-A technologies while the virtualization technique is also presented. Section 3 will present the Multi-RAT Virtualization architectures. Performance analysis between proposed architectures is shown in Section 4. Finally, we conclude this paper in Section 5.

2. Related Works.

2.1. 3GPP.

UMTS. GSM is already the primary business mobile phone system in more than 170 countries and is rapidly evolving to 3G and beyond. 3GPP UMTS, one of the 3G cellular telephone systems, provides higher transmission bandwidth and varied multimedia applications. The transmission rate can reach up to 2 Mbps when UEs are motionless. The transmission rate can reach up to 384 Kbps if UEs are in low mobility status. Even when UEs are in high mobility status, the transmission rates can still reach 144 Kbps. Thus, the UMTS can satisfy voice communication demand and also meet the requirements for Internet access via varied hand-held UEs. The radio access network in UMTS is called *UMTS Terrestrial Radio Access Network (UTRAN)* in [9]. The core network contains entities such as *Mobile Switching Center (MSC) and Serving GPRS Support Node (SGSN)*. NB uses *Iub* interface connecting RNC in Figure 1. RNCs are inter-connected with *Iur* Interfaces and connecting core network with *Iu* interfaces.

LTE. LTE standard inherits 3GPP developed versions from current telecommunication network architecture and is backward compatible with GSM or UMTS cellular systems. So operators only need to upgrade the traditional UMTS base station NB, to the enhanced version eNB in order to support LTE mobile devices in the lower left corner of Figure 2. The radio access system is called *Evolved Universal Terrestrial Radio Access Network (E-UTRAN)* in LTE network. User devices such as mobile phones, iPads or hand-held devices are named UEs while the base stations are called eNBs. LTE standard is designed

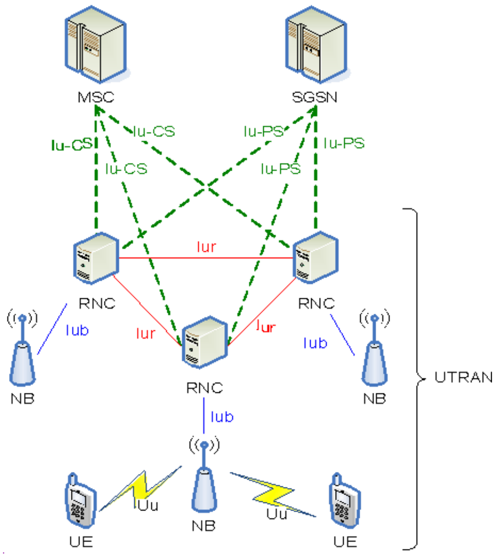

FIGURE 1. UMTS network architecture

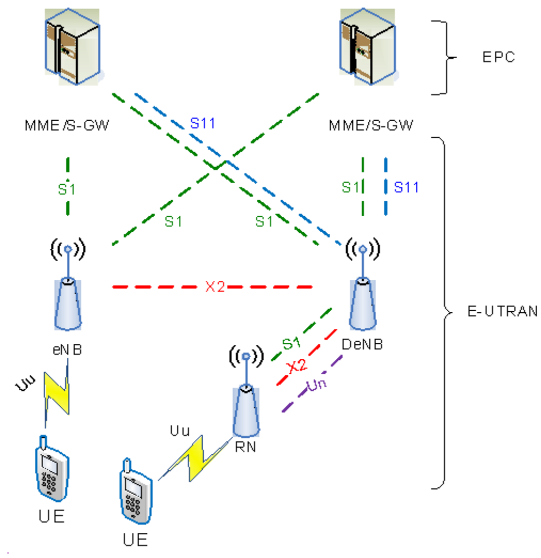

FIGURE 2. LTE-A network architecture

to support multiple radio access technologies including 3GPP and non-3GPP technologies. Basically, the LTE connects 3GPP-related technologies such as UMTS by connecting *Mobility Management Entity (MME)/Serving-Gateway (S-GW)* and SGSN while the LTE connects non-3GPP technologies such as Wi-Fi and WiMAX by passing through *PDN Gateway (P-GW)* and Internet.

LTE-A. Each eNB has a limited serving area. However, it is more difficult to deploy a new eNB since residents of developed countries have more health concerns in regards to the *Electromagnetic radiation (EMR)* emitted. So the idea of signal relay by a smaller entity called RN has been proposed and becomes an LTE-A specification. As illustrated in the lower right corner of Figure 2, a DeNB can expand its serving area by using RN to relay radio signal coverage. RN firstly connects to an eNB in order to enlarge an eNB's serving area. The eNB that is connected with RN is called DeNB since it needs to provide more functionality for serving both UE and RN. The interface used between RN and DeNB is called *Un* as shown in the lower right corner of Figure 2.

2.2. **Virtualization.** "*Virtualization*" is a new and important key concept in enabling the "computing-as-a-service" vision of computing solutions. Virtual machine related features such as flexible resource providing, and mobility of computing machine state have improved efficiency of resource usage and dynamic resource allocation. A virtualization machine is a virtual, user-friendly computer that runs on a complex platform, hiding the

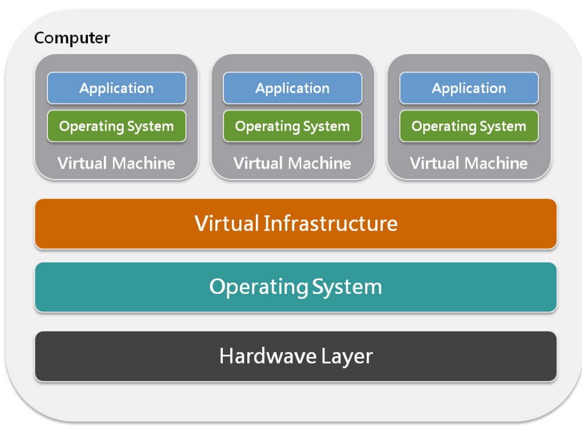

FIGURE 3. Virtualization system framework

complicated physical process of computing resources from the user. The virtual machine can be carried out on a given hardware platform by the host software – an example is a control program such as *Virtual Infrastructure* that produces a simulated computer environment or a virtual machine for the supporting software. The concept of the framework is shown in Figure 3. In recent years, the virtualization system or platform has had many software applications such as *VirtualBox* [10], *VMWare* [11] and *Xen* [12].

3. Proposed Multi-RAT Virtualization Architecture in LTE-A Base Station. Since the LTE is designed to support previous 3GPP standard versions such as GSM and UMTS, the architecture for inter-working with LTE and different access technologies simply requires the connection of their cores networks by *IP Multimedia Core Network Subsystem (IMS)*. This Multi-RAT Virtualization architecture might be workable but how to deliver packets or find a route path for the data traffic is still a discussion issue. Moreover, to build up Network Virtualization in LTE core network with Multi-RAT is also an ongoing problem. If the DeNB can simultaneously support not only LTE UEs but also previous 3GPP end users such as *UMTS UEs*, *GPRS MSs* and *GSM MSs*, the LTE or LTE-A deployment cost will be decreased significantly. Some articles discuss these important and currently trending issues, such as Network Virtualization in WLAN [13], mobile network [14], LTE network [15], and Multi-RAT supporting in mobile users [16] respectively. As we know, cellular base station is the interface between UEs and EPC in LTE-A network; if a Multi-RAT Virtualization base station (called *Multi-RAT Virtualization DeNB*) is able to deal with different radio signals from different access technologies, then packets from UEs with different technologies are routed and encrypted via DeNB with special tunnel passing through the corresponding core networks, and the deployment cost could be reduced. The proposed architecture as indicated in Figure 4 shows the virtualization architecture for supporting Multi-RAT including UMTS, LTE and LTE-A, and an example of the intra-virtual nodes connection is shown in Figure 5.

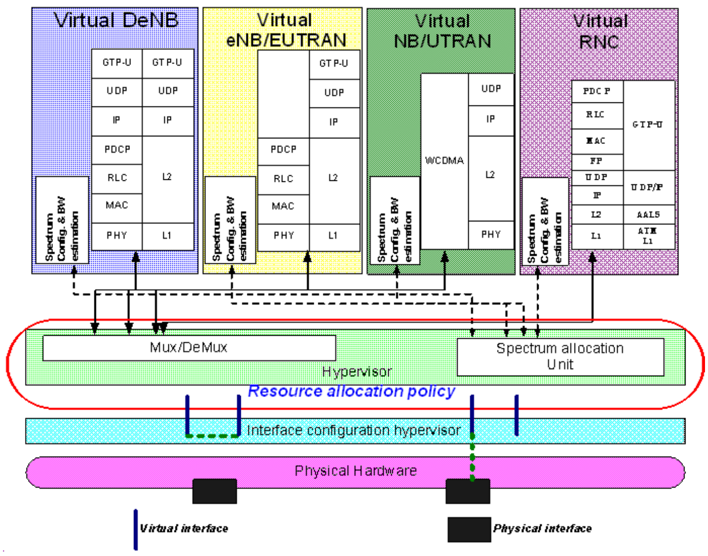

FIGURE 4. Multi-RAT Virtualization DeNB architecture

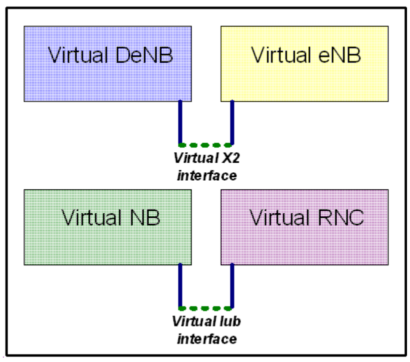

FIGURE 5. Example of virtual nodes connection

Architecture design. There are many popular 3GPP radio access technologies in the world, and this paper only focuses on the design of the supported system among LTE, LTE-A and UMTS. There are two kinds of approaches for LTE domain (*E-UTRAN, EPC*) to provide connection between UMTS UEs and UMTS domain (*UTRAN, UMTS core network*) for the Multi-RAT Virtualization DeNB. For air radio interface, Multi-RAT Virtualization DeNB must apply both original LTE UE and UMTS UE radio connection.

Moreover, if the UMTS UEs have connected to DeNB as a UMTS NB via RN, the RN would be like a repeater device for *Virtual NB* under *Virtual UTRAN* area. So RN backhaul link *Un* interface is also a WCDMA PHY layer tunnel for *Virtual NB* as shown in the lower left corners of Figure 6 and Figure 7. For wired core network interface, the first one is to add tunnel connectivity between EPC and UMTS domain, which is named as *Arch_A* (Figure 6). The other one is to add *Virtual RNC in DeNB* and connectivity from DeNB backhaul link to UMTS domain, which is named as *Arch_B* (Figure 7).

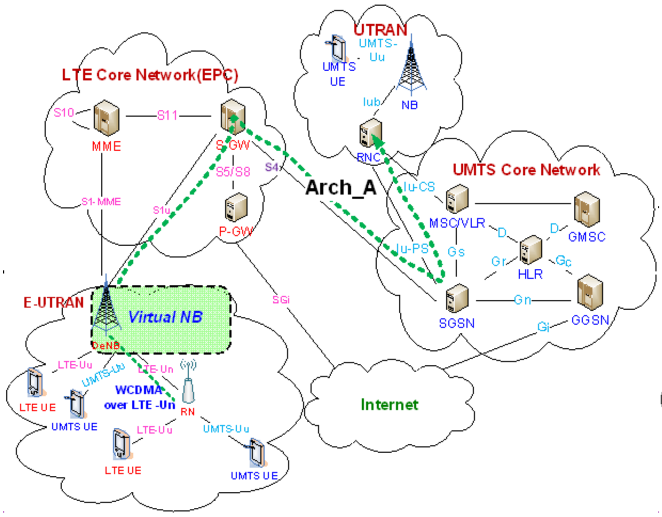

FIGURE 6. Arch_A architecture

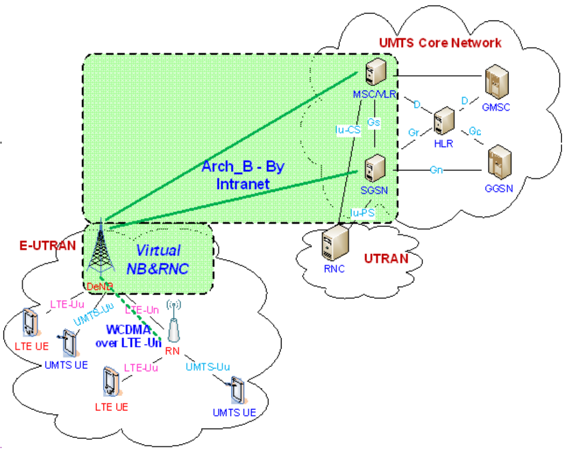

FIGURE 7. Arch_B architecture

4. **Performance Analysis.** The two proposed architectures, Arch_A, and Arch_B, have different advantages and disadvantages. Table 1 shows the qualitative comparison between Arch_A, and Arch_B. There are some differences in criteria UMTS RNC Complexity, DeNB Complexity, LTE/UMTS CN Complexity, UMTS UE Transmission Efficiency and Security Concern. Arch_A presents less complexity of DeNB at the expense of increased complexity of UMTS RNC in comparison with those in Arch_B. Generally speaking, transmission path (include passing through EPC) for UMTS UE in Arch_A is higher than Arch_B, and the transmission latency will be increased obviously. Arch_B might have higher security concerns among network transmission than Arch_A, since its connectivity is going through an Intranet connection as new connection in the standard. Furthermore, the quantitative analysis can provide advanced comparisons, the numerical analysis parameters can be found in Table 2 and the analysis scenario during *Handover (HO)* can be illustrated by Figure 8. The analysis of handover latency can be identified by Formula (1) with several parts such as *radio link*, *wired link* and *processing time*. In the lower left corner of Figure 8, there are two types of handover, *Intra-NB handover and Inter-NB handover*. In Figure 9, it can figure out the *HO latency* by extension of Formula (1), the handover procedure flow can show the detail information (e.g., an Inter-NB example in Arch_A as Figure 10), the estimated time for finishing HO is the summation of (A) the transmission time of sending *HO* signals via the radio link and wired link are the arrowhead symbols ($N_{Radio-link} = 4$, $N_{Wired-link} = 18$), and (B) the bearer configuration time in HO procedure are the *Step 3* and *Step 11* ($N_{Bearerconfiguration} = 2$), and (C) the processing time in HO procedure comes from each square symbol and the sending arrowhead device ($N_{Device} = 3 + 22 = 25$). All kinds of HO latency are listed in Figure 9; moreover, the *number of HO signal* can be calculated from the part (A) of HO procedure. Table 3 has shown the quantitative comparison in criteria of *HO latency* and *Number of HO signal*. Based on results of Table 1 and Table 3, our proposed Arch_B has better performance. However, to apply Arch_A for different purposes is also an alternative solution

for Multi-RAT Virtualization supporting in LTE-A network.

$$\begin{aligned} Handover\ latency = {} & T_{Radio\text{-}link} \times N_{Radio\text{-}link} + T_{Wired\text{-}link} \times N_{Wired\text{-}link} \\ & + T_{Bearer\ configuration} \times N_{Bearer\ configuration} + T_{CP\text{-}processing} \times N_{Device} \end{aligned} \quad (1)$$

Table 1. Qualitative comparison between Arch_A and Arch_B

Metric	Arch_A	Arch_B
UMTS RNC Complexity	Serving UMTS-UE via EPC tunneling	IuPS (backhaul link) via Intranet
RN Complexity	UMTS-Uu (access link) and WCDMA tunnel (backhaul link)	UMTS-Uu (access link) and WCDMA tunnel (backhaul link)
DeNB Complexity	Bearer management + NB Virtualization	Virtualization (NB and RNC)
LTE/UMTS CN Complexity	Bearer management S4 btw S-GW and SGSN	No impact
UMTS-UE Transmission Efficiency	Low	High
Security Concern	Low	Middle

Table 2. Analysis parameters

Parameter	Description	Value
$T_{Radio\text{-}link}$	Transmission time via radio link	2 ms
$T_{Wired\text{-}link}$	Transmission time via wired link	2 ms
$T_{Bearer\ configuration}$	Transport bearer setup/release time	5 ms
$T_{CP\text{-}processing}$	Control-plane processing time	5 ms

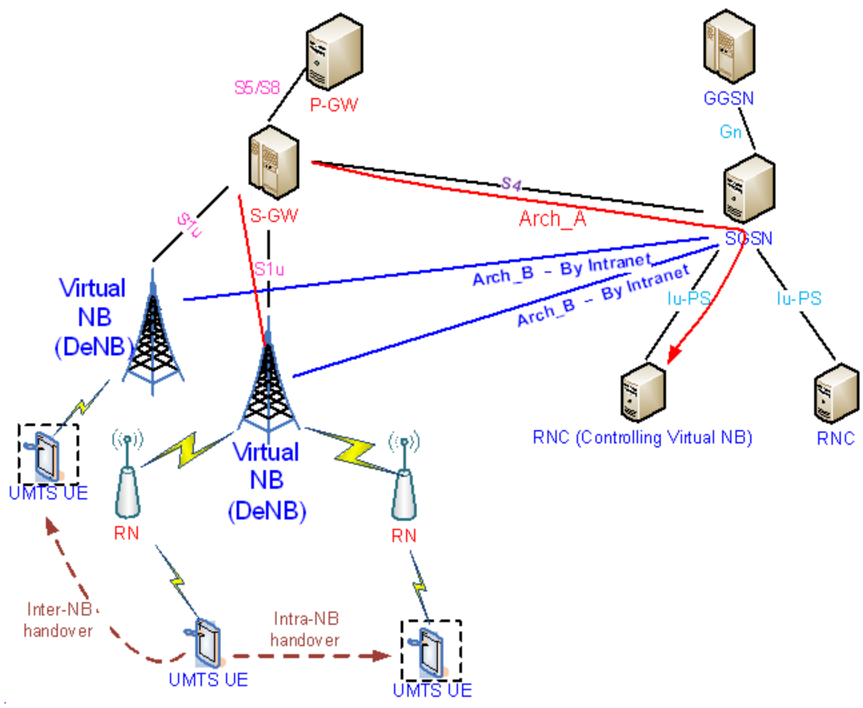

Figure 8. Analysis scenario

5. **Conclusions.** Both LTE and LTE-Advanced are backward compatible with 3G UMTS and 2G GSM, GPRS cellular networks. Considering wireless coverage and upgrade deployment cost, the LTE-Advanced adds a new entity RN to enlarge service coverage. This paper has designed two workable Multi-RAT Virtualization architectures by which DeNB

$$\begin{aligned}
&\textit{Intra-NB HO latency}_{Arch_A} = T_{Radio\text{-}link} \times 2 \\
&\quad + T_{Wired\text{-}link} \times 6 + T_{CP\text{-}processing} \times 7 = 51 \\
&\textit{Intra-NB HO latency}_{Arch_B} = T_{Radio\text{-}link} \times 2 \\
&\quad + T_{CP\text{-}processing} \times 1 = 9 \\
&\textit{Inter-NB HO latency}_{Arch_A} = T_{Radio\text{-}link} \times 4 \\
&\quad + T_{Wired\text{-}link} \times 18 + T_{Bearer\ configuration} \times 2 \\
&\quad + T_{CP\text{-}processing} \times 25 = 179 \\
&\textit{Inter-NB HO latency}_{Arch_B} = T_{Radio\text{-}link} \times 4 \\
&\quad + T_{Wired\text{-}link} \times 12 + T_{Bearer\ configuration} \times 2 \\
&\quad + T_{CP\text{-}processing} \times 13 = 107
\end{aligned}$$

Figure 9. Handover latency calculation

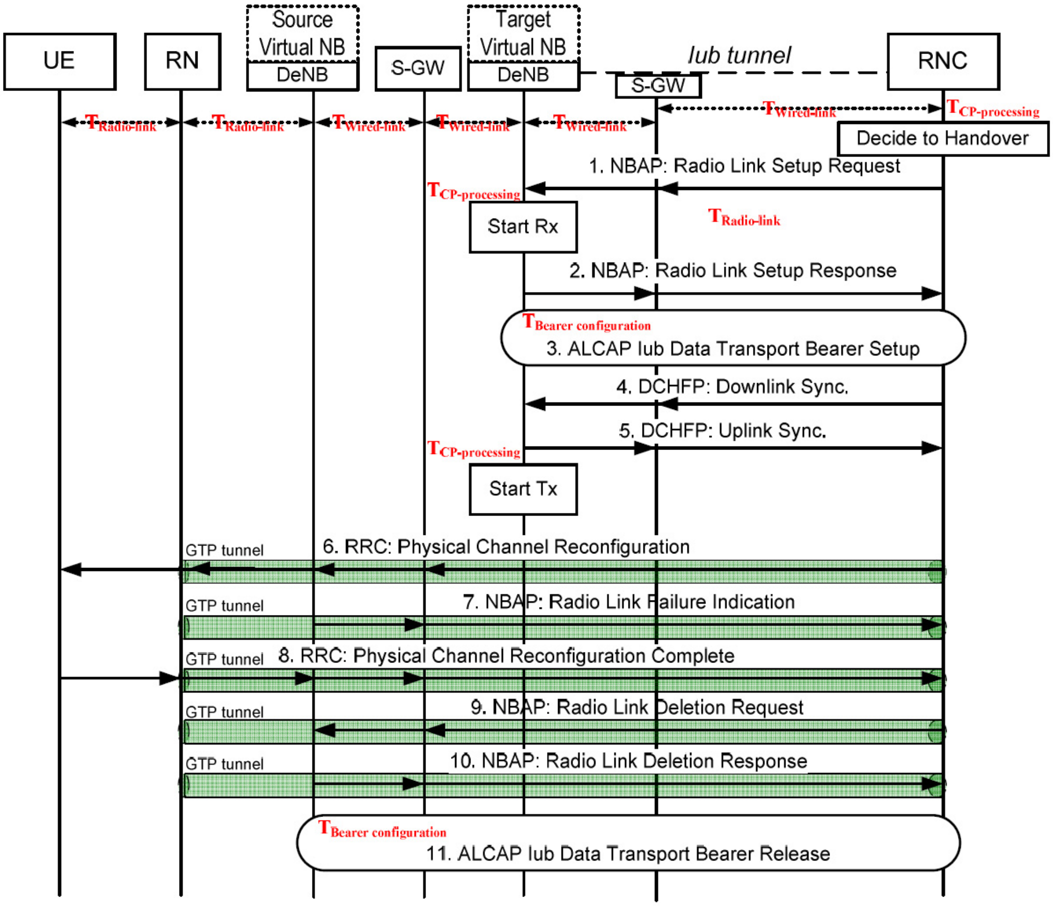

Figure 10. Inter-NB handover procedure in Arch_A

Table 3. Quantitative comparisons

Metric	HO latency (ms)		Number of HO signal	
	Arch_A	Arch_B	Arch_A	Arch_B
Intra-NB handover	51	9	8	2
Inter-NB handover	179	107	22	16

with RN is able to provide services for both UMTS UEs and LTE UEs by virtualization supporting. Thus, analysis results have shown that our proposed structures can allow the UEs' transition between core networks of UMTS and LTE-Advanced with virtualization technique. It is an achievable and novel Multi-RAT Virtualization architecture for future 4G wireless network. A future direction of research is to extend the virtualization to RN due to the fact that RN also has eNB functionality and can serve many multiple version end users. It will enlarge the end users flexibly and provide mobility virtualization feature because both RN's access link and backhaul link are radio interfaces.

Acknowledgment. This work was supported in part by the National Science Council (NSC), Taiwan, under the grant no. NSC 102-2221-E-164-007. The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

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