Applying SDN/OpenFlow in Virtualized LTE to Support Distributed Mobility Management (DMM)

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Abstract: Distributed Mobility Management (*DMM*) is a mobility management solution, where the mobility anchors are distributed instead of being centralized. The use of DMM can be applied in cloud-based (*virtualized*) Long Term Evolution (*LTE*) mobile network environments to (1) provide session continuity to users across personal, local, and wide area networks without interruption and (2) support traffic redirection when a virtualized LTE entity like a virtualized Packet Data Network Gateway (*P-GW*) running on an virtualization platform is migrated to another virtualization platform and the on-going sessions supported by this P-GW need to be maintained. In this paper we argue that the enabling technology that can efficiently be used for supporting DMM in virtualized LTE systems is the Software Defined Networking (*SDN*)/OpenFlow technology.

1 INTRODUCTION

Long Term Evolution (*LTE*) is the fourth generation (*4G*) technology which is standardized by the 3rd Generation Partnership Project (*3GPP*), see *e.g.*, (3GPP Release 10, 2013). It is capable of providing high data rates as well as support of high speed mobility. In the LTE system two main network parts can be identified which are called Evolved UMTS Terrestrial Radio Access Network (*e-UTRAN*) and the Evolved Packet Core (*EPC*). The e-UTRAN consist of base stations that are denoted as Evolved Node-Bs (*eNodeBs*). Each of these eNodeBs are controlling different cells which provide radio coverage and connectivity between the User Equipment (*UE*) and the EPC. The EPC is composed of several network elements. The main important ones are the Serving Gateway (*S-GW*), the Packet Data Network Gateway (*P-GW*) and the Mobility Management Entity (*MME*). The P-GW, that is the main mobility EPC anchor point, connects the EPC to other external networks. A mobility anchor point is mainly in charge of mobility related user data forwarding. Moreover, the P-GW also performs various functions such as IP address/IP prefix allocation or policy control and charging. The S-GW supports the transport of the user data between the UE and the external networks. The MME is the control node that processes the mobility management signaling, (*i.e.,* handover) between the UE and the EPC.

Mobility management provides the mechanisms for maintaining active and seamless session continuity to users across personal, local, and wide area networks without interruption. Most of the current IP mobility solutions standardized by both IETF (*Internet Engineering Task Force*) and 3GPP rely on a centralized mobility anchor entity which is in charge of both mobility-related control plane and user data forwarding. The presence of this centralized network node makes mobility management prone to several problems and limitations such as: (1) suboptimal routing, (2) low scalability, (3) signaling overhead, (4) more complex network deployment, (5) security and reliability issues due to the existence of a potential single point of failure, and (6) a lack of granularity on the mobility management service, see *e.g.* (Bertin et al, 2009), (Chan et al, 2011). Currently, operators and research communities are investigating alternative mobility solutions that are more distributed in nature, by using distributed mobility anchors, denoted as Distributed Mobility Management (*DMM*). The use of DMM allows a cheaper and more efficient network deployment capable to meet their customer requirements. As shown in Figure 1, DMM implements a flatter system in which the mobility anchors are placed

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closer to the user, distributing the control and data infrastructures among the entities located at the edge (*access*) of the network. DMM may be partially or fully distributed, where in the former the distribution scheme is applied only to the data plane while in the latter to both the data and control planes. It is important to notice that in the fully distributed approach data and control planes needs to be decoupled although they are both handled by the distributed anchor points.

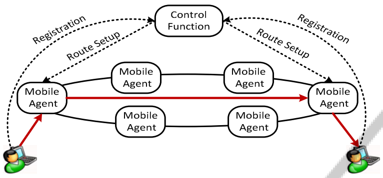


Figure 1: Generic DMM approach scheme.

The Mobile Cloud Networking (*MCN*) project 0(EU FP7 MCN, 2013), as one of the EU FP7 projects, integrates the use of cloud computing concepts in LTE mobile networks in order to increase LTE's performance. This is accomplished by building a shared distributed LTE mobile network that can optimize the utilization of virtualized computing, storage and network resources and minimize communication delays. In particular, the integration of cloud computing concepts in a LTE system, can be realized by: (1) extending the cloud computing concept beyond the typical (*macro*) data centers towards new smaller (*micro*) data centers that are distributed within the e-UTRAN and the EPC, and (2) deploying and running cloud-based (*virtualized*) e-UTRAN, denoted as RAN as a Service (*RANaaS*), and EPC, denoted as EPC as a Service (*EPCaaS*). This trend is also in line with the emerging ETSI activities in Network Functions Virtualization (NFV). The use of DMM can be applied in such environments not only to enhance the LTE mobility management performance and provide session continuity to users across personal, local, and wide area networks without interruption, but also to support traffic redirection when a virtualized LTE entity, like the P-GW running on an virtualization platform (*i.e.,* originating data centre) is migrated to another virtualization platform (*i.e.,* destination data centre) and ongoing sessions supported by this P-GW need to be maintained. In (Chan, 2013), the main IETF requirements for DMM solutions in IPv6 networks deployments are defined as follows:

- **Distributed Deployment:** IP address mobility and routing solutions provided by DMM must enable distributed processing for mobility management so that traffic does not need to traverse centrally deployed mobility anchors and thereby avoid non-optimal routes.
- **Transparency:** DMM solutions must provide transparent mobility support above the IP layer when needed**.**
- **IPv6 Deployment:** DMM solutions should target IPv6 as the primary deployment environment and should not be tailored specifically to support IPv4, in particular in situations where private IPv4 addresses and/or NATs (*Network Address Translations*) are used.
- **Co-existence:** The DMM solution must be able to co-exist with existing network deployments and end hosts. For instance, depending on the environment in which DMM is deployed, DMM solutions may need to be compatible with other deployed mobility protocols or may need to interoperate with a network or mobile hosts/ routers that do not support DMM protocols.
- **Security Considerations:** A DMM solution must not introduce new security risks or amplify existing security risks against which the existing security mechanisms/protocols cannot offer sufficient protection**.**
- **Flexible Multicast Distribution:** DMM should consider multicasting. So the solutions can be developed that, not only to provide IP mobility support when it is needed, but also to avoid network inefficiency issues in multicast traffic delivery (*e.g.,* duplicate multicast subscriptions towards the downstream tunnel entities).

In the context of this paper also the following additional requirements are defined:

- **Dynamicity:** The dynamic use of mobility support by allowing the split of data flows along different paths that may travel through either the mobility anchor or non-anchor nodes, even though no specific route optimization support is available at the correspondent node. This requirement will tackle the lack of fine granularity of the centralized mobility management approaches.
- **Separating Control and Data Planes:** Keeping the control plane centralized while distributing the data plane is a possible solution to minimize the signaling overhead between the mobility anchors due to the lack of knowledge that a distributed anchor point has of its peers and their connected UEs.
- **Network-based:** Not burdening the UE with extra signaling and keeping the user unaware of the on-going handoff procedure within the same

domain are fundamental aspects that need to be provided by the DMM solutions deployed in LTE networks.

Several DMM solutions have been proposed in the IETF and 3GPP contexts. However, it is not yet clear whether these DMM solutions can be applied in virtualized LTE network systems. In this paper we argue that the best candidate enabling technology that can efficiently be used for supporting DMM in virtualized LTE systems is the SDN/OpenFlow technology. In particular, this paper answers the following research question:

"Can SDN/OpenFlow be used efficiently for DMM support in virtualized LTE systems?"

This paper is organized as follows. Section 2 is providing a brief overview of the SDN/OpenFlow technology and explains how it could be exploited to support DMM in virtualized LTE systems. In Section 3 a brief introduction of other possible candidate technologies is provided. Moreover Section 3 analyses and compares these technologies with the SDN/OpenFlow approach. Section 4 shows in an example how the SDN/OpenFlow concept can be applied in the virtualized LTE system. Furthermore, Sections 3 and 4 are answering the research question listed above. Finally, Section 5 concludes and provides recommendations for future work.

2 SDN/OpenFlow

SDN (ONF, 2103) is an architecture that decouples forwarding functions and network control, which become directly programmable. This enables the underlying infrastructure to be abstracted for applications and network services. In particular, SDN capable switches and routers can be configured and programmed using a centralized management entity, denoted as SDN controller. Several SDN based protocols are being developed, such as the IETF FORCES (*Forwarding and Control Element Separation*) and OpenFlow. OpenFlow (OpenFlow, 2013) is the most commonly used SDN based protocol which carries signalling message between SDN controllers and the underlying network infrastructure, bringing network applications to life. With OpenFlow, the forwarding plane of a SDN/OpenFlow capable switch or router can be accessed over the network and reconfigured according to the needs of applications and network services. The vast majority of Ethernet switches and routers used nowadays contain flow-tables to implement firewall, NAT, QoS (*Quality of Service*) and other functionalities. A flow-table of SDN/OpenFlow capable switches or routers can be remotely programmed partitioning the network's traffic into separated flows. Features offered by OpenFlow protocol can be used to deploy a DMM solution offering IP address continuity and traffic redirection in the operator's transport network. This can be achieved by treating each traffic path from the Internet PoPs (*point of presence*) to the mobility anchor points (*e.g.,* P-GWs) as a separated flow. In this way traffic redirection can be supported without involving any IP address translation or modification, when for example a virtualized LTE entity, like the P-GW, running on an virtualization platform (i*.e.,* originating data centre) is migrated to another virtualization platform (*i.e.,* destination data centre) and ongoing sessions supported by this P-GW need to be maintained. Alternatively SDN/OpenFlow switches contain a list of actions that can be applied on every transiting packet that belongs to a specific flow. Example of these actions are: *Drop, Push-Tag, Pop-Tag, Group* and *Set-Field*. The optional *Set-Field* action is the most interesting for the purpose of this proposal providing to SDN/OpenFlow switches the possibility to modify headers of packets and frames, used by *e.g.,* Ethernet, VLAN, and IP. Both flow tables and action lists are added, modified or removed by the SDN/OpenFlow Controller which has a dedicated secure connection with each SDN/OpenFlow switches and routers. The procedures and messages used to support and perform such modifications are specified in the OpenFlow specification document 0.

3 MOTIVATION: WHY SDN/ OpenFlow SHOULD BE USED FOR DMM SUPPORT IN VIRTUALIZED LTE SYSTEMS

This section introduces other possible candidate DMM enabling technologies and analyses and compares them with the SDN/OpenFlow approach in order to verify whether they can be applied for DMM support in a virtualised LTE system.

3.1 IETF Based DMM Enabling Technologies

The IETF DMM working group charter addresses two complementary aspects of mobility management procedures: the distribution of mobility anchors towards a more flat network and the dynamic activation/deactivation of mobility protocol support as an enabler to distributed mobility management (Chan, 2013). The following DMM solutions are specified within the context of IETF.

3.1.1 Double NAT (D-NAT)

Double NAT DMM solution proposed in (Liebsch, 2012) adopts the concept of an identifier-locator split to solve the routing in the transport network above the mobility anchors. Forwarding downlink packets to the mobile nodes's current mobility anchor can be achieved using tunnels as already done in both Mobile IP and Proxy Mobile IP (*PMIP*) solutions. To avoid encapsulation overhead introduced by tunnelling the use of NAT is proposed at both ends of the operator's transport network. Two new entities, performing address translation from identifier address to locator address and vice-versa, need to be introduced in the network. These entities are referred to as Ingress NAT router and Egress NAT router. Using NAT functionality is required only in the case of downlink traffic, where the Ingress NAT router performs translation of the identifier address into the locator address and it forwards the packets down into the operator's transport network. The Egress NAT router, on the other hand, translates the locator address back to the identifier address in order to forward the packet to the mobile node. The Egress NAT routers will therefore always be placed closer to the southern edge of the operator's transport network than the Ingress NAT routers.

3.1.2 Distributed Mobility Anchoring (DMA)

P. Seite (Seite et al, 2103) proposed a distributed mobility traffic management with dynamic user's traffic anchoring in the networks' access routers (*ARs*). It relies on a flat architecture where a new entity named Mobility capable Access Router (*MAR*) is introduced to provide mobility management functions. The MAR has both mobility anchoring and location update functional capabilities and can acts as a Home-MAR (*H-MAR*) or as a Visited-MAR (*V-MAR*) for a given mobile node. A H-MAR is responsible for the allocation of Home Network Prefix (*HNP*), used in this solution instead of HoA, to mobile node. On the one hand, when a mobile node moves away from the home network, the H-MAR is responsible for tracking the mobile node's location and forwarding packets to the V-MAR where the mobile node is currently attached to. On the other hand a V-MAR manages the mobility-related signalling for a mobile node that is attached to its access link. The architecture of this solution relies on a centralized database storing ongoing mobility sessions for the MNs.

3.1.3 Inter-domain DMM

J.C. Zuniga *et al.* in (Bernardos and Zuniga, 2103) proposed a method which aims to ensure session continuity in an inter-domain roaming scenario. It is based on the partial distributed single operator scenario that uses an entity called Distributed Gateway (*D-GW*) placed at the edge of the network. The D-GW supports two roles: Anchoring D-GW and Serving D-GW. The control plane relies on a central entity called Central Mobility Database (*CMD*). The inter-domain solution uses a centralized Local Mobility Anchor (*LMA*), usually located in the home domain, as top-level anchor to guarantee session continuity when crossing operator borders. It is assumed that the necessary roaming agreement are in place in order to support setting up tunnels between the LMA located at the home domain of the mobile node (*MN*) and the visited D-GWs, which in a 3GPP EPC scenario may correspond to the eNodeBs or Home eNodeBs (*HeNBs*) used for femtocells.

3.2 3GPP Based Solutions IETF Based DMM Enabling Technologies

Currently, in the 3GPP EPC architecture, the mobility management solutions mostly rely on a centralized mobility anchor entity, *i.e.*, P-GW, which is in charge of the control of the network entities involved in the mobility management and the user data forwarding. There are however, two solutions specified by 3GPP that are already introducing the concept of DMM into the 3GPP EPC architecture, *i.e.,* LIPA and SIPTO.

3.2.1 Local IP Access (LIPA) / Selected IP Traffic Offload (SIPTO)

LIPA and SIPTO 0 have been introduced by 3GPP in LTE Release 10. They enable data traffic offload at appropriate points in the Radio Access Network (*RAN*) in a highly cost-efficient manner leading to an increased system scalability and enhance the operators flexibility to cope with the growing mobile data traffic demanded. LIPA allows a UE, connected in a residential or corporate deployment via a HeNB, to directly connect to other devices and services in the local network, relieving this portion of data traffic from the mobile operator's core network. LIPA breakout takes always place at the newly introduced Local GW entity located in the local/home or enterprise femtocell network. SIPTO, on the other hand, offloads selective IP traffic to the Internet at the local gateway (*L-GW*), similar to LIPA, or above HeNB such as the HeNB gateway located in home and enterprise networks. When the UE is connected to a macro-cellular network, SIPTO offload takes place at or above the RAN. By breaking out selected traffic closer to the edge of the network, operators may avoid overloading their scarce resources, *i.e.* P-GWs and S-GWs, as well as avoid inefficient routing in the mobile backhaul network.

3.3 Analysis and Comparison

In order to provide DMM support in virtualised LTE systems, the selected DMM enabling technology needs to support the DMM requirements listed is Section 1. Table 1 analyses and compares SDN/OpenFlow technology with the other candidate DMM enabling technologies that were briefly described in the previous subsections, by using the DMM requirements listed in Section 1.

Table 1: Comparison (Y:Yes, N:No, P: Partial, N.c:Not considered, N.s:Not specified, C:Considered, O.l:Only local, without support for IP address continuity).

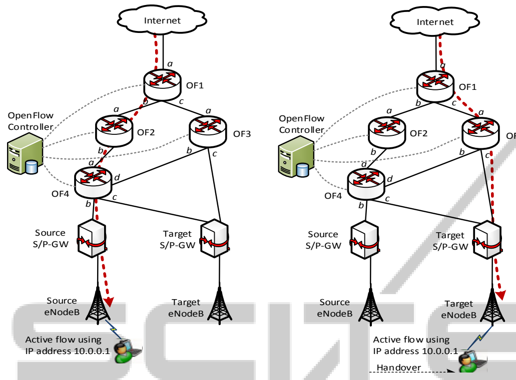
Requirements	SDN/ OpenFlow	D-NAT	DMA	Inter-domain DMM	LIPA/ SIPTO
Distributed deployment	Y	Y	Y	P	O.l
Transparency	Y	Y	Y	Y	O.l
IPv6 deployment	Y	Y	Y	Y	Y
Co-existence	N	N	P	Y	P
Security considerations	N.c	N.c	N.c	N.c	C
Flexible multicast distribution	Y	Y	N.s	N.s	N.s
Dynamicity	Y	N	Y	N	N
Separating control and data planes	Y	Y	Y	Y	Y
Network-based	Y	Y	Y	Y	Y

Based on the analysis and comparison given in Table 1, it can be deduced that the SDN/OpenFlow based DMM technology can satisfy most of the DMM requirements introduced in Section 1. The *Co-existence* requirement is not satisfied due to the fact that SDN/OpenFlow requires the introduction of new entities and features, *i.e.,* SDN/OpenFlow Controller and switches, in the operator's transport network. However, due to the ongoing activities in the SDN area, see (ONF, 2103), it can be assumed that operators will probably introduce and deploy SDN/OpenFlow Controllers and switches in their operator's transport networks. Therefore, it can be deduced that the SDN/OpenFlow technology is a promising candidate that can efficiently be used for DMM support in virtualized LTE systems.

4 EXAMPLE OF INTEGRATING SDN/OpenFlow IN VIRTUALIZED LTE SYSTEMS

In this section, an example is provided on how the SDN/OpenFlow enabling technology could be applied in virtualized LTE systems to support DMM. In a virtualized LTE system, the S/P-GWs are running on Virtual Machines (*VMs*) that are hosted on one or more micro data centres. The DMM framework described in (Liebsch et al, 2013) can be used for this purpose. In particular, 0(Liebsch et al, 2013) defines 4 new functional entities: *FE_I*: Ingress for DMM indirection (*redirection*), *FE_E*: Egress for DMM indirection, *FE_IEC*: Control to establish states for DMM indirection and *FE_MCTX*: Function to transfer/establish context for IP address continuity. In Figure 2, it is considered that: OF1 supports *FE_I* and OF4 and OF3 support *FE_E*. The *FE_IEC* and *FE_MCTX* are supported by the SDN/OpenFlow Controller (*OC*), in cooperation with MME. DMM can be used to provide (1) session continuity to users (*UEs*) that are moving from one mobility anchor, *e.g.,* S/P-GW to another mobility anchor, and (2) traffic redirection when a virtualized LTE entity, like the P-GW running on an virtualization platform is migrated to another virtualization platform and ongoing sessions supported by this P-GW need to be maintained. In this example, DMM is used to provide session continuity to users that are moving from one virtualized S/P-GW to another virtualized S/P-GW. In such an architecture, SDN/OpenFlow switches and SDN/OpenFlow Controllers may be implemented in VMs and the functions can be remotely configured and upgraded using soft-EPC components based on the end-users requirements. With OpenFlow the forwarding plane of a

SDN/OpenFlow switch or router can be accessed over the network and modified according to the service requirements. As shown in Figure 2, a simple OpenFlow network is used as transport network above the EPC. All the routers are OpenFlow capable and their flow tables are managed by the same OC.



(a) before handover *(b) after handover*

Figure 2: OpenFlow approach to support DMM in a virtualized LTE system.

In this example, when a UE changes his EPC mobility anchor point, flow tables of all SDN/OpenFlow switches will be updated by OC to re-route the downlink traffic (*i.e.,* arriving from Internet), from the original S/P-GW, see Figure 2(a), to the new S/P-GW, see Figure 2(b). Due to the fact that no modifications will be performed on the data packets, traffic redirection can be performed only if all routers and switches in the operator's transport network are OpenFlow capable. For uplink traffic (*i.e.,* sent towards Internet), a static forwarding path will be setup when a flow is created. If a path to the specific destination hosts already exists, for instance in case of widely visited end-hosts, no changes will be needed to the setup paths. This static path will be used throughout the whole life of a flow in the operator's transport network.

5 CONCLUSIONS AND FUTURE WORK

In this paper several DMM enable technologies have been analysed and compared. In particular, this paper argued and verified that the SDN/OpenFlow technology is a promising candidate that can efficiently be used for the support of DMM in virtualized LTE systems. In order to further validate this statement, the use of the SDN/OpenFlow technology for the support of DMM in the virtualized LTE system will be prototyped and evaluated within the context of the EU FP7 project 0(EU FP7 MCN, 2013).

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