SOFTWARE-DEFINED NETWORKING IN HETEROGENEOUS RADIO ACCESS NETWORKS

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Paper type
Research paper.

Abstract
Integrating different wireless access technologies to provide users with data service will definitely result in a heterogeneous radio access network. Moving from one wireless domain to another causes traffic being switched from one interface to another. This results in a reestablishment of TCP connection due to the change of the assigned IP address. Frequent handovers may force users to perform re-logins or application restarts, which undoubtedly jeopardize the quality of experience. This vertical handover problem will not be trivial as mobility is becoming a dominant factor in communications. This paper provides a possible solution architecture and research direction for vertical handover problem by leveraging the concept of software-defined networking together with existing proposals.

Keywords
Software-defined networking, handover, radio access network, data offloading, virtualization

1. Introduction
Radio-over-Fiber (RoF) technologies expedite the formation of heterogeneous radio access networks (HRANs), where different radio frequencies are transmitted over the same the fiber connection to the remote antenna to provide different wireless access, e.g. 4G (LTE), 3G (UMTS W-CDMA, UMTS TD-SCDMA, CDMA2000), and WLAN (Wi-Fi). Integrating different wireless access technology to provide users with data service, e.g. Wi-Fi and mobile networks operated by an entity to provide data service to its users, will definitely result in a HRAN. User Equipment (UE) is usually capable of managing one interface for Wi-Fi, and another for mobile communication (4G/3G). Moving from one wireless domain to another causes traffic being switched from one interface to another. This results in a reestablishment of Transmission Control Protocol (TCP) connection due to the change of the assigned IP address, and therefore application disturbance. It is expected that users will be as highly mobile (or even more) with their UE as they already are today. Frequent handovers may force users to perform re-logins or application restarts, which undoubtedly jeopardize the quality of experience.

This problem is defined as the vertical handover problem, where UE change their connections from one type of access technology to another type and cause connection reestablishment waiting time. As mobility is becoming more and more important, especially when wearable devices and vehicular connections become popular, the vertical handover problem will not be trivial.

This paper provides a possible solution architecture and research direction for vertical handover problem by leveraging the concept of software-defined networking (SDN) together with existing proposals.

2. Background
2.1 Radio-over-Fiber
Radio-over-Fiber (RoF) is a technology that allows radio signal to be modulated and transmitted over optical fibers in order to expand the reach of a Base Station Server (e.g. NodeB/eNodeB) or an Access Point (AP), to expand coverage with great flexibility. Current RoF technologies allow Remote Radio Heads (RHHs) to be deployed, where radio equipment is remote to the BSS. This equipment is used to extend the coverage and is generally connected to BSS via a fiber optic cable using Common Public Radio Interface (CPRI) protocols, or Open Base Station Architecture Initiative protocols (OBSAI).
In a RAN, various signals such as LTE, HSPA+, UMTS W-CDMA, and Wi-Fi, can be carried over the fiber at the same time to reach the RRH, providing different access technologies to the users. This architecture is considered as a flexible and cost-effective way of providing wireless access, especially to some areas that are difficult to cover.

2.2 OpenFlow and SDN
OpenFlow is a communication protocol that gives access to the forwarding plane of a router/switch over the network (McKeown, 2008). It is a component of the SDN concept. One philosophy of SDN is to decouple the system that makes decisions about where the traffic should be sent (control plane) from the system that forwards the traffic (data plane). OpenFlow is an option that enables the decoupling and is used by the controller (software) to interface the network devices. Since the position of OpenFlow in the large SDN picture is close to the hardware (ASIC/FPGA), it has drawn a lot of attentions from vendors as well as network operators.

By using protocol-controllable network equipment, operators can develop and use customized application programming interfaces (APIs) to send information to the controller. The controller will then translate the instructions into low-level protocols, such as OpenFlow, and modify the behavior of network devices, e.g. flow table, forwarding scheme, etc. In such a mechanism, various kinds of APIs or applications can be developed above the controller layer, implementing different functionalities of network management. Centered on the controller, APIs can be categorized into northbound, southbound, westbound, and eastbound APIs, shown in Figure 1. The northbound API enables applications to program the network and request services from it. The southbound API/protocol defines the control communications between the controller and the data plane devices, including both physical and virtual devices. OpenFlow is one of the southbound APIs/protocols that interface directly with devices. The westbound and eastbound APIs define the connections between controllers. However, northbound APIs and westbound/eastbound APIs are not yet standardized.

![Figure 1 SDN Controller and APIs.](image)

2.3 Proxy Mobile IPv6
Proxy Mobile IPv6 (PMIPv6), shown in Figure 2, is a protocol standardized by IETF in order to provide Network-Based Localized Mobility (Kempf, 2007) support in IP networks. It is a protocol for building a common and access technology independent of mobile core networks, cooperative with different access technologies e.g. 3GPP, 3GPP2, WiMAX and WLAN.

Terminal mobility in IP networks have been studied by IETF for a long time. IP-layer solutions have been developed by IETF for both IPv4 (Mobile IPv4 (Stalling, 2001; Perkins, 2002)) and IPv6 (Mobile IPv6 (Johnson, 2004)). This allows the movement of terminals (Mobile Nodes) and provides transparent service continuity. These solutions provide mobile Mobile Nodes with a permanent address (Home Address) and a temporary address (Care-of-Address). The Home Address (HoA) plays the role of identifier of the node in order to be used by upper-layer protocols (e.g. TCP) to identify the endpoints of a communication channel. The Care-of-Address (CoA) plays the role of locator of the node, which specifies how to reach the node by means of the routing system. However, the ability to move provided by the
aforementioned solutions while keeping session continuity is not sufficient. This is due to the fact that the IP handover latency is strongly affected by the time required to exchange signaling between the Mobile Node and the Home Agent. As a result, a local Home Agent closer to the Mobile Node is preferred so that the signaling message exchange can be faster.

However, Mobile IP and the localized mobility are host-based. This means that the Mobile Node must inform the network when the location is changed and must update the routing states in the Home Agent, or local Home Agent, or both. This results in complex security configurations to authenticate the message exchanges and modifications of the routing states. As a result, network-based mobility is more promising than the host-based.

Basic functional entities in the PMIPv6 are:

- Mobile Access Gateway (MAG): MAG performs the mobility-related signaling on behalf of the Mobile Nodes (MNs) attached. The MAG is usually the access router for the MN. It is responsible for tracking movements of the MN.
- Local Mobility Anchor (LMA): LMA is a home agent for the MN in a PMIPv6 domain. It maintains a collection of routes for each MN connected to the Localized Management Domain (LMD). Packets sent or received to or from the MN are routed through the tunnels between the LMA and the corresponding MAG. The LMA is a topological anchor point for the MN’s home network prefix(es).

![PMIPv6 overview](image)

Figure 2 PMIPv6 overview.

3. Leveraging SDN in HRAN

3GPP has proposed a set of protocols for terminal mobility management based on PMIPv6 (3GPP TS 29.275 v12.2.0, 2014). This enables a common mobility management platform for both wireless and cellular domains using PMIPv6. Since in PMIPv6, the Home Address of a MN is not changed during the change of attachment, it is possible to implement seamless vertical handover within one LMD. However, there currently lack solutions for cross-domain (from one LMD to another) vertical handover. Seamless handover among different operators will see its inevitable and unavoidable need in the future, especially for the NREN community where eduroam authentication mechanism makes the infrastructure transparent to users.

This paper proposes a possible architecture for cross-domain vertical handover using PMIPv6 with SDN assistance. The architecture is depicted in Figure 3. Under the assumption that LMA and MAG equipment is SDN-enabled, one SDN controller is located in each domain, connected to the LMA and MAGs. The SDN controller is responsible for creating the tunnels between the LMA and MAGs, and between LMAs in different domains.
Depicted in Figure 4, the proposed operation of SDN assisted vertical handover across different domains follows. When MN X detaches from MAG A in Domain A and enters Domain B, MAG A should deregister MN X from the Binding Cache of LMA A. As MAG B in Domain B detects an attachment event from MN X, MAG B proceeds to identify MN X, and checks if it is authorized to use the network-based mobility management service. If it is, MAG B performs mobility signaling on behalf of MN X. MAG B sends to LMA B a Proxy Binding Update (PBU) associating its own address with the identity of MN X. Note that since MN X does not belong the Domain B, its Home Domain should be included in the PBU as shown in Figure 4. Upon receiving the request from MAG B, LMA B adds its own address in another PBU and sends to LMA A. From the PBU sent from LMA B, LMA A discovers that MN X has entered another domain and immediately requests SDN Controller A in its domain to set up a tunnel from LMA A to MAG B. Since the tunnel is multidomain, SDN Controller A should requests SDN Controller B to jointly set up the tunnel in its domain. After the tunnel is established, SDN Controller A returns a OK message to LMA A. Upon receiving the confirmation from SDN Controller A, LMA A sends to LMA B a Proxy Binding Ack (PBA) including the prefix, which should not be changed. Then LMA B sends to MAG B a PBA including the prefix to confirm the previously received PBU from MAG B. A bidirectional tunnel (may have several segments) is established between LMA A and MAG B. MAG B sends to MN Router Advertisement messages including the prefix so the node can configure an address.

Downlink traffic sent to the MN is first received by the LMA in its home domain (LMA A) because of the unchanged Home Address of the MN. The home LMA should forward the traffic to the correspondent LMA (LMA B) through the tunnel created by the SDN controllers. After receiving the traffic from the home LMA, the correspondent LMA should forward the traffic through the tunnel bound for the MAG (MAG B) that the MN has attached to. Uplink traffic originated from the MN is sent to the correspondent LMA and is forwarded to the home LMA through the tunnel.

The architecture proposed has the following aspects to look into:

- **Multidomain tunneling is needed.** By keeping the Home Address of the MN as is, TCP connection is preserved. However, this requires that a tunnel is created between LMAs of different domains.
- **Communication between the SDN controllers is needed.** This is to ensure that the tunnel between the LMAs can be created since the tunnel is shared by two different domains. However, the communication demands a west-east bound communication of the SDN controllers, which is not standardized.
- **Longer traffic latency may be expected.** When MN moves to a foreign domain, traffic bound for the MN has to take a longer path to reach it instead of directly receiving by the foreign LMA.
Summary
Flow management in the heterogeneous radio access network is an utmost issue due to the need of seamless traffic handover. How to provide a seamless handover in a multidomain environment is challenging. The initial research carried out in this paper proposes to evaluate the use of SDN approach to assist the establishment of a network supporting seamless vertical handovers. The research will continue in the direction of exploring possibilities of using SDN approach in the radio access networks for cross-domain vertical handover.

Acknowledgements
The research leading to these results has received funding from the European Community’s Seventh Framework Program (FP7 2007–2013) under Grant Agreement No. 238875 (GÉANT).

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Biographies

Hao Yu (haoyu@fotonik.dtu.dk) received M.Sc. and Ph.D. degrees from Technical University of Denmark, Denmark, in 2007 and 2011, respectively. He is currently working as a Postdoc in Technical University of Denmark. His research interests include interdomain network management, software-defined networking, future Internet architecture, multicast for high-speed switches, traffic management in Carrier Ethernet, control plane for Next Generation Network (NGN), IPTV service and related applications in IMS and NGN.