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A hybrid DMM solution and trade-off analysis for future wireless networks

J. Carmona-Murillo [a,*], V. Friderikos [b], J.L. González-Sánchez [c]

[a] Department of Computing and Telematics Engineering, University of Extremadura, Spain
[b] Centre for Telecommunications Research, King's College London, UK
[c] Research, Technological Innovation and Supercomputing Center of Extremadura(CénitS), Spain

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ABSTRACT

Mobile Internet data traffic has experienced an exponential growth over the last few years due to the rise of demanding multimedia content applications and the increasing number of smart mobile devices. Seamless mobility support at the network level is envisioned as a key architectural requirement to deal with the ever increasing demand for data and content, cell densification and to efficiently utilize a plethora of heterogeneous wireless access networks (HetNets). Current and emerging efforts on that frontier aim to evolve mobility management protocols towards a more distributed operation to tackle shortcomings that stem from fully centralized oriented approaches. However, as will be detailed hereafter, there are instances where distributed mobility management result in lower performance, which might affect real time and several over the top (OTT) applications (as well as incur increased levels of signaling overhead in the network). To this end, in this paper we provide a meticulous analysis of the different trade-offs between centralized and Distributed Mobility Management (DMM) and based on the analysis we propose a Hybrid DMM solution that overcomes, in terms of mobility costs, both centralized and distributed mobility management protocols. Furthermore, we also conduct a comprehensive analytic and numerical comparison of the different mobility solutions. Our results indicate the significant benefits in terms of packet delivery cost and signaling overhead that Hybrid DMM solutions might bring. Finally, we conclude by discussing some open ended issues in mobility management in emerging and future wireless networks.

1. Introduction

Over the last few years, IP-based mobility management in the Internet has been one of the most active research fields in communications. Mobility management protocols are responsible for maintaining the ongoing communications while the user roams among distinct networks (changing points of attachment) and also to provide reachability for mobile users in such heterogeneous environment in terms of access. The existing IP mobility support protocols developed by the IETF (Internet Engineering Task Force) are all based on centralized mobility anchors that manage the traffic and signaling of the Mobile Nodes (MNs). The two most representative centralized mobility management protocols are Mobile IPv6 (MIPv6) [1] and Proxy Mobile IPv6 (PMIPv6) [2]. MIPv6 introduces a home agent (HA) as a mobility anchor, while PMIPv6 tries to manage mobility locally (i.e., at the foreign network) by introducing a centralized agent called local mobility anchor (LMA). This node is responsible for both mobility signaling and user data forwarding. However, centralized mobility management protocols need to be redesigned in order to cope with the recent trends in mobile Internet and the current increasing mobile data traffic demand. This demand is expected to continue rising with an almost exponential trend even for the foreseeable future [3].

Moreover, as mobile data traffic increases, the growth in signaling load is expected to increase almost 50% faster than the growth in data traffic over the next few years .[1] The generated amount of control information is increasing dramatically for Evolved Packet Core (EPC), and is expected to grow even more with the deployment of Long Term Evolution Advanced (LTE-A), as the access network is connected directly to base stations, managing all signaling

* Corresponding author.
E-mail addresses: jcarmur@unex.es (J. Carmona-Murillo), vasilis.friderikos@kcl.ac.uk (V. Friderikos), joseluis.gonzalez@cenits.es (J.L. González-Sánchez).

[1] Signaling is growing 50% faster than data traffic, 2012 http://nsn.com/index.php?q=system/files/document/signaling_whitepaper_online_version_final.pdf.

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traffic. Looking further into the future, 5G networks that will entail inevitably cell densification (i.e., smaller cells) to increase overall network capacity will result in an even increased signaling cost for managing mobility. One of the keys to signaling traffic explosive growth is the increasing number of Internet-connected mobile machine-to-machine devices and applications with high mobility demands that result in heavy control data. These requirements in both data and growing signaling traffic demand has become a critical consideration for network operators when dimensioning and planning mobile networks to meet a satisfactory user experience. In this increasingly heterogeneous and complex environment, efficient mobility management can be deemed as a key functionality related to the overall network performance, due to its implication in control and data planes.

In order to address these limitations which inherently occur in Centralized Mobility Management (CMM) protocols, Distributed Mobility Management (DMM) solutions are being developed to efficiently handle the current mobile traffic explosion. In DMM, the core idea is that the mobility anchors are distributed within the network, topologically closer to the users, with the aim to provide an almost optimal routing support and an efficient use of network resources to improve the scalability required for next generation mobile networks [4].

However, and as already alluded to above, despite the fact that a number of mobility management approaches are on-design phase towards a more distributed operation aiming to mitigate the problems related to centralized operation, there are instances where DMM incurs higher costs and the performance of the network might be compromised. In fact in some of these cases, CMM seems to solve more efficiently the mobility problem and therefore should be preferred. Particularly those in which cell resident time is short and/or the number of remaining active sessions in previous networks is high. These situations happen, for example, when an MN moves frequently and it begins new sessions in different visited networks. In these cases, the performance of DMM approaches fall down due to the number of tunnels that need to be managed by the distributed nodes. In addition, centralized-based management might be preferable in high velocity (vehicular) group-mobility situations such as for example trains, busses and/or even cars.

As stated in [5], future mobile network architectures might potentially exhibit a hybrid behavior in which the mobility management of some traffic will be kept centralized, while mobility support for other applications can be distributed. Network virtualization and software defined networking techniques that would allow flexible and programmable networks based at the control and data user plane will allow to efficiently utilize hybrid mobility schemes as the ones proposed hereafter.

In this paper, a Hybrid DMM mobility management scheme is proposed, that adapts to the specific topological characteristics of the infrastructure network of mobile operators, in which the data and signaling traffic are forwarded following a centralized or distributed scheme depending on, hereafter detailed, decision criteria for protocol selection. The key benefit of the proposed hybrid solution is that it manages to reduce significantly both signaling and routing cost. To the best of our knowledge, this is the first effort to exhibit a hybrid centralized-distributed solution for future mobile network architectures.

The rest of the paper is organized as follows. In Section 2, we briefly present closely related work in the area of mobility management. Section 3 details the background and the motivations, highlighting the evolution of the IP mobility management and introducing the benefits of hybrid solutions; and details of such hybrid scheme are described in Section 4. Section 5 defines the network model and system parameters. Section 6 introduces the decision criteria algorithms in which are based the hybrid solutions. The cost analysis are presented in Section 7. Section 8 shows the numerical evaluation. Finally, concluding remarks from this work are given in Section 9.

2. Background

During the last few years, mobility management at the IP level attracted significant attention from both industry and academia, and it has been an active field in communications research. This has been mainly driven by the increased heterogeneity of wireless access which calls for solutions at the IP level in order to support session continuation when mobile users change their point of attachment. Relevant standards development organizations such as IETF and 3GPP (Third Generation Partnership Project) are making ongoing efforts to address the new needs in mobile IP networks; these works have recently resulted in some proposals to create an evolved architecture of the current mobile networks [6,7]. Current packet-based mobile architectures, such as 3GPP EPS (Evolved Packet System) and WiMAX make use of IP as the enabling technology for both voice and data communications. Therefore, IP mobility management protocols will inevitably play a key role to address continuity and session persistence throughout user movement among different networks. At the same time mobility control at the IP layer has been considered a network management tool for provisioning load balancing and/or data offloading in heterogeneous wireless networks [8].

The main IP mobility management proposals are based on MIPv6 and PMIPv6. Fig. 1 shows an overview of both protocols [9].

In order to enable the mobility service in MIPv6, the Mobile Node (MN) is assigned with a permanent home address (HoA) in its Home Network (HN), and establishes a connection with the communication peer, the Correspondent Node (CN). Thus, when the MN stays in its home domain, it is able to receive packets destined to its permanent address. These packets are forwarded through conventional IP routing mechanisms. A Home Agent (HA) serves as the anchor node in the HN that tracks the network connection point (location) of a user as the user moves. Periodically, or whenever the user changes their point of attachment to the network, the user registers with the HA through Binding Update (BU) messages, informing of its current location. In this foreign network, the MN acquires a new address called Care-of Address (CoA). When the MN is away from its home network, packets sent to the permanent address of the MN are intercepted, encapsulated in a tunnel and forwarded to the MN's current CoA. In MIPv6, the HA is the centralized part of the system since it is on the critical path of both signaling and data for mobile users.

Mobility in Mobile IPv6-based solutions requires the host to send mobility management signaling messages to the home agent, which is potentially located -topologically- far from the visiting network. In addition to performance issues for supporting seamless session continuity this means that the protocol requires stack modification of the mobile node in order to support the mobility improvements. In addition, the requirement for the modification of mobile nodes may cause them to become increasingly complex.

Network-based protocols on the other hand, are mainly derived from PMIPv6. PMIPv6 is based on MIPv6 in the sense that it extends MIPv6 signaling and reuses many concepts such as for example the HA functionality. The new principal functional entities of PMIPv6 are the mobile access gateway (MAG) and local mobility anchor (LMA). The MAG typically runs on the AR. Its main role is to detect MN's movements and initiate mobility-related signaling with the MN'LMA on behalf of the MN. In addition, the MAG establishes a tunnel with the LMA to enable the MN to use an address from its home network prefix and emulates the MN's home network on the access network for each MN. On the other hand, the LMA is similar to the HA in MIPv6. Its main role is to maintain