Rethinking IP Mobility Management

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Abstract

IP Mobility Management allowing for handover and location management to be handled by the network layer has been around for a couple of 20 years or so now. A number of protocols have been proposed including the GPRS Tunneling Protocol (GTP), Mobile IP, Proxy Mobile IP, and the Locator/Identifier Split Protocol (LISP) being the best known and most discussed in the research literature. This paper overviews existing solutions and suggests a new distributed and dynamic mobility management scheme and evaluates it against existing static approaches.

Keywords: IP Mobility Mangement, GTP, Mobile IP, Proxy Mobile IP, LISP, Distributed and dynamic mobility management.

1 Introduction

The Internet was originally designed for stationary hosts communicating in batch mode. One very important design goal was to keep the network entities as simplistic as possible and to have the end nodes more sophisticated. Gradually, this has changed over time with hosts being mobile and today performing much more real-time communication. Moreover, the network nodes today can change their states and are increasingly becoming capable of handling various flows individually.

With the advent of laptops and later smartphones and tablets the needs for mobility management increased. Supporting the two basic components of it hosts could be reached over time even if changing their IP addresses through the location management mechanism and ongoing communication flows would be moved seamlessly to a new connection using handover management.

The basic problem solved by IP mobility management is the separation of the IP addresses' dual meanings them being both a location indicator reflecting the hosts' current connection in relation to the topology of the Internet, but also an end point identifier. Typically this would leave to each host having two IP addresses where one is reflecting its current connection to the Internet while the other is acting as a stable endpoint identifier and could be used for seamless communication with other hosts not bothering them with IP address changes after moving to a new IP subnet.

The first IP mobility management protocol being designed was the GPRS Tunneling Protocol (GTP) [1]. Signaling is handled by GTP-C [2] where a node can activate, modify, or terminate a session on behalf on the end-user. GTP-U carries the end-user's traffic which can be in any of IPv4, IPv6, or PPP formats. GTP' carries charging data. GTPv0 runs on top of either UDP or TCP, while GTPv1 only runs on top of UDP. GTPv2 was designed for signaling between the Serving Gateway (SGW) and the Packet Data Gateway (PGW) in LTE networks. It should be noted that the mobile station does not need to be GTP aware itself. GTP is typically initiated in a network node after having received a PDP context activation request message from the mobile station.

Mobile IP was first proposed enabling mobility in IPv4 networks [3] and later also in IPv6 networks

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[4].

The basic operation of Mobile IPv4 introduces two types of specialized routers; home agents and foreign agents. Mobile nodes register with a foreign agent in the visited network, which in turn establishes a tunnel to the home agent located in the home network. The mobile node is assigned a home address (HoA) in the home network (which is stable over time) and a care of address (CoA) in the visited network (which changes each time the mobile node changes its attachment to the Internet). The home agent maintains a binding list containing associations of home addresses with care of addresses for each registered mobile node. Signaling is handled using registration request and registration reply messages.

Mobile IPv6 was, at least on paper, meant to be an integrated and mandatory part of the IPv6 protocol stack itself. The most important difference from Mobile IPv4 is that Mobile IPv6 does not use any foreign agents. The tunnel is instead established directly between the mobile node and the home agent. In Mobile IPv6, mobile nodes may also establish optimal routes to any correspondent node by sending binding update messages directly to them.

Proxy Mobile IPv6 [5] provides network based mobility management, which enables nodes to be mobile without having to handle mobility signaling in the end node. Actually, the entire TCP/IP protocol stack in the mobile node can remain unchanged. Proxy Mobile IPv6 uses two node types; the Local Mobility Anchor (LMA) and the Mobile Access Gateway (MAG). The LMA is a Mobile IPv6 home agent, while the MAG is a specialized access router. A shared tunnel is established between these nodes using GRE or IP-in-IP. Mobile nodes can be IPv4 clients, IPv6 clients or dual stack clients. The mobile node initiates any communication by sending a router solicitation to the MAG, which after a successful binding with the LMA, sends a router advertisement back to the mobile node. Proxy Mobile IPv6 is today adopted in WiMAX, 3GPP, and 3GPP2 architectures.

The IETF is also working on the Locator/Identifier Split Protocol (LISP) [6]. LISP requires no changes to the protocol stacks of the end hosts or to routers at the core of the Internet. LISP is designed to be an incrementally deployable protocol. The basic idea is to separate the IP addresses into two new numbering spaces; Endpoint Identifiers and Routing Locators. LISP allows for multihoming, mobility, and traffic engineering.

Overall, Mobile IP and the related IETF-led initiatives centered around IP mobility management have not been very much embraced by the telecommunications industry or, at least, deployed the way IETF defined it originally. Today, many applications survive IP address changes. Moreover, other layers than the network layer in the protocol stack often handle mobility. At the same time, mobile data traffic is booming and exceeds that of mobile telephony traffic nowadays. The presence of smartphones, tablets, USB dongles, and rich content applications all contribute to this very strong trend. Therefore, 3GPP have standardized Local IP Access and Selected IP Traffic Offload (LIPA-SIPTO) [7] in order to meet the increasing demands on capacity from end-users. The idea is to provide means of offloading cellular networks to WiFi and other radio access technology networks and also to allow some IP traffic not to be fully mobility managed, but rather routed from the access router to the local IP network available there.

In order to cope with this new mobile computing and communicating landscape, the IETF has created working groups standardizing APIs for multiple interfaces (mif) [8] and new solutions for distributed mobility management (dmm) [9]. The ultimate goal for the mif working group is to define an abstract API for hosts using multiple interfaces, while the dmm working group develops solutions not requiring a central mobility anchor, but rather allowing for distribution of mobility agents and also relaxing the requirement on stable IP addresses a bit. Another important factor favoring distributed mobility management solutions is that Content Distribution Networks (CDN) servers today are pushed towards the users enabling content to be cached in the proximity of the users. Our proposal is based on this fact and suggests having mobility anchors as near the user as possible. Moreover, we base our proposal on not all users being quite mobile at all times while connected to the network, but quite a big proportion being stationary or nomadic rather than mobile or highly mobile.

The remainder of this paper is structured the following way: Section 2 covers related work, while Section 3 presents our proposed solution. Section 4 describes the evaluation framework, while Section 5 presents our results. Finally, Section 6 concludes the paper and indicates future work.

2 Related Work

The research community has paid attention to IP mobility management since long time ago. Protocol and architecture proposals exist as well as performance evaluation studies. Handover latencies, tunneling overhead, and overhead related to signaling are common parameters of interest.

Yiping et al. [10] described a new architecture supporting Always Best Connected services covering an access discovery mechanism integrating service location protocols and location-based services. A personalized network selection scheme is proposed, as well as a Mobile IPv6-based seamless vertical handover scheme. The authors argue through analytical solutions both end-users and network operators would benefit from using their solution.

Perera et al. [11] proposed a mobility toolbox architecture for All-IP networks including support for Mobile IPv4, Mobile IPv6, NEMO, and HIP. This coexistence is effected by means of a mobility toolbox enabling mobility handling to be selected according to context. The design of the toolbox is described as a component of the Ambient Networks architecture. Feasibility and performance gains are demonstrated with a prototype implementation of network mobility.

Eastwood et al. [12] showed how IEEE 802.21 supports seamless mobility between IEEE 802.11VHT and IEEE 802.16m networks. The proposed mobility management scheme integrated these two access technologies along with IEEE 802.21 into one IMT Advanced (4G) compliant system.

Kong et al. [13] analyzed both qualitatively and quantitatively network-based approaches and host-based approaches to the mobility management problem. They stressed the key features of Proxy Mobile IPv6 and expected that it would be the mobility protocol of choice when realizing the next-generation All-IP mobile networks.

Pontes et al. [14] described integration issues between IEEE 802.11 and IEEE 802.16 networks in both infrastructure networks and ad hoc networks. They surveyed solutions from IETF, 3GPP/3GPP2 and IEEE and proposed using the IEEE 802.21 framework.

Song et al. [15] proposed a new architecture for integration of IEEE 802.16 and 3GPP networks. A new network element, the Data Forwarding Function, was introduced in order to eliminate data loss during vertical handover. By simulations, the authors showed that the proposed solution is effective in minimizing data loss during vertical handovers and pointed out that the solution is general and can be applied to other access networks as the handover solution is IP-based.

More lately, Bertin et al. [16] proposed a new mobility management scheme for flat IP network architectures. Furthermore, the same authors [17] evaluated their proposal through simulations and reported that benefits in terms of reduced handover latencies and global scalability would be achieved by moving towards their proposed solution.

Moreover, Chan et al. [18] argued for distributing the mobility management functionality being more compatible with upcoming flat IP network architectures. Limitations of existing solutions were reported to include non-optimal routes, not to be in line with evolved network architectures, not to scale well, waste resources to support mobile nodes not being mobile, complicate deployment due to too many variants and extensions of Mobile IP, introduce mobility signaling overhead with peer-to-peer communications, and to introduce a single point of failure or attack. The authors discussed applying the distributed mobility management model at the mobile core network level, at the access network level, or at the host level. Also, they discussed pros and cons with fully distributed approaches versus partially distributed approaches. They concluded that distributed mobility management has the potential to overcome many limitations of centralized mobility management, if carefully designed.

Finally, Condeixa et al. [19] analyzed mobility management assumptions and requirements in user-centric scenarios. The authors discussed challenges for obtaining a global mobility management solution considering user-centricity. They pointed out a few major concerns for a mobility management system including the integration of the user's identity in the binding mechanism, the coupling and decoupling of both control and data planes, the support of dynamic control points according to network conditions, user, and service requirements, and the decision on where to put the control points in the network.

Our own previous work in the area includes prototype development [20], comparison of network and host based mobility solutions [21], proposal of QoE optimized mobility solutions [22], and mobility management for highly mobile users [23]. Moreover, we proposed composite metrics [24], multimedia flow mobility [25], and globally optimized mobility handling schemes [26]. Last, but not least, we have previously proposed cross-layered designed mobility management solutions [27] and described common interworking techniques in heterogeneous wireless networks [28]. The model proposed in this paper is built on these previous results.

3 Proposed Model

The core of our proposed architecture is based on the latest suggestions from the IETF Distributed Mobility Management (Dmm) Working Group [9]. Each Point of Attachment (PoA), typically a base station or access point, is also an IP router. IP traffic may be locally broken out not having to be passed through a centrally located mobility anchor in the cellular core network or so. Figure 1 depicts the model.

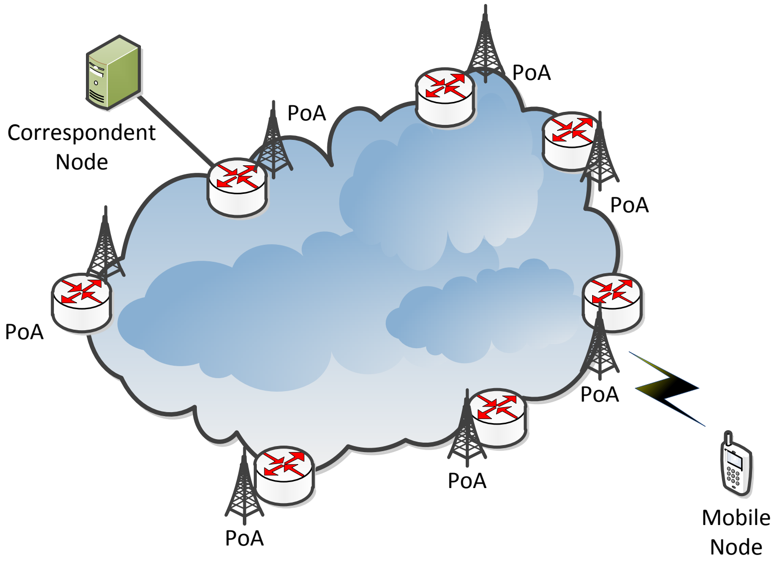

Figure 1: Proposed Architecture

When starting a new IP flow, mobile nodes can ask for

A) Full IP mobility mode (meaning the IP address may not change throughout the duration of the flow), or

B) Manual IP mobility mode (meaning the IP address may change but only after notifying the application using the flow), or

C) No IP mobility mode (meaning the IP address may change without prior notice).
when starting new flows.

As mentioned earlier, many applications today handle changes of IP addresses themselves and no need for IP mobility is needed. Those would ideally choose Type C flows. Other applications, e.g. Voice over IP applications, may benefit from being notified when the IP address has been changed, but can also cope with such a situation. Those would ideally choose Type B flows. The rest would choose Type A flows.

When a mobile node is handing off from one PoA to another, the following happens:

- Standard IP mobility signaling and connection migration (using e.g. Mobile IP) is performed for the A type of flows;
- Cross-layer communication is performed (using e.g. IEEE 802.21 [29] event services) telling upper layers the IP address is being changed. Then, a new IP address is configured for the B type of flows;
- A new IP address is configured for the C type of flows.

There will be different interfaces handling type A, type B, and type C flows present in the mobile node. There will be one interface handling all type B flows and another interface handling all type C flows.

Interfaces handling type A flows will exist on a dynamic basis and appear for each PoA where type A flows were initiated and still being active. When type A flows are started the present PoA will act as the mobility anchor for those flows. Once all flows associated with a particular interface have been terminated, that interface will cease to exist. Figure 2 shows a set of tunnels among different PoAs where traffic belonging to various A type of flows is directed. Such tunnels appear and disappear in a dynamic manner depending on the selection of mobility mode for each flow and the mobility pattern of the mobile node itself.

4 Evaluation Framework

The proposed architectural solution is evaluated by analyzing the reduction of mobility-related overhead to payload traffic after applying the proposed scheme compared to using a conventional IP mobility management scheme with a static mobility anchor used for all traffic regardless of type.

We use a bimodal packet size distribution model consisting of 44% packets of between 40 and 100 bytes length and 37% packets of between 1400 and 1500 bytes length [30] where also TCP traffic is reported to count for 92% of all IP traffic. Moreover, the distribution of TCP flows' durations presented in [31], where 75% of the flows have durations of 10 seconds or less is used.

Four mobility scenarios are covered: stationary, nomadic, mobile, and highly mobile. Stationary mobile nodes are not mobile at all and all flows remain through the same PoA. Nomadic mobile nodes stay at each PoA during 10 minutes. Mobile nodes stay at each PoA during 30 seconds, and highly mobile nodes stay at each PoA during 10 seconds.

5 Results

The numerical results in terms of bandwidth savings on the wireless link are presented in Table 1. Each mobility scenario is evaluated at five levels wrt. the fraction of TCP flows choosing the "Full mobility"

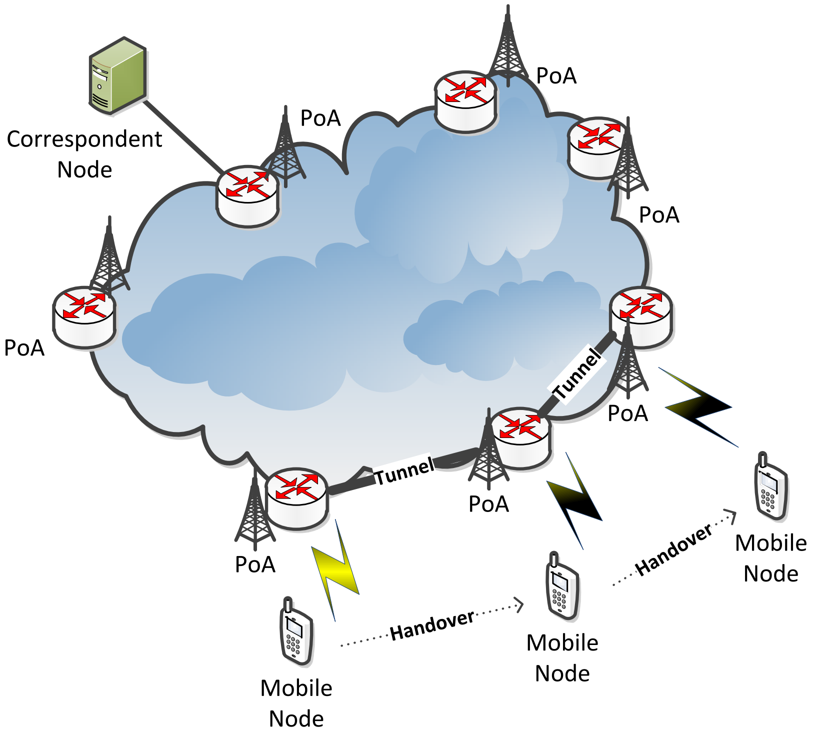

Figure 2: Handover Management for Type A Flows

Table 1: Bandwidth Saving on Wireless Link

Mobility Pattern	Fraction of TCP Flows Choosing Full Mobility Option				
	0%	25%	50%	75%	100%
Stationary	2.81%	2.81%	2.81%	2.81%	2.81%
Nomadic	2.81%	2.81%	2.81%	2.81%	2.81%
Mobile	2.81%	2.71%	2.60%	2.50%	2.39%
Highly mobile	2.81%	2.64%	2.46%	2.29%	2.11%

option: 0%, 25%, 50%, 75%, and 100%.

The values are computed so that the reduction in tunneling overhead for payload traffic is taken into account. The analysis is based on Mobile IPv4 using IP-in-IP tunneling.

6 Conclusions and Future Work

We proposed and analyzed a distributed and dynamic IP mobility scheme comparing it to a conventional IP mobility management scheme. Still only achieving 2.81% in terms of saved bandwidths we believe the proposed scheme will enable operators to build more efficient core networks and release the burden from centralized mobility anchors in today's core networks.

We intend to deepen the study and perform both simulations and experimental work in our campus WiFi network with peer-to-peer applications and locally deployed content delivery servers.

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