Computer Communications 32 (2009) 1871–1880

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Mobile IPv6 deployments: Graph-based analysis and practical guidelines

Guillaume Valadon [a,b,*], Clémence Magnien [a,b], Ryuji Wakikawa [c]

[a] UPMC Univ Paris 06, UMR 7606 LIP6, F-75005 Paris, France
[b] CNRS, UMR 7606 LIP6, F-75005 Paris, France
[c] TOYOTA InfoTechnology Center, USA, Inc., United States

ARTICLE INFO

Article history:
Received 6 March 2009
Received in revised form 8 July 2009
Accepted 9 July 2009
Available online 15 July 2009

Keywords:
Mobile IPv6
Mobility management
Graph
Centrality

ABSTRACT

The Mobile IPv6 protocol is a major solution to supply mobility services on the Internet. Many networking vendors have already implemented it in their operating systems and equipments. Moreover, it was recently selected to provide permanent IP addresses to end-users of WiMAX and 3GPP2. Mobile IPv6 relies on a specific router called the home agent that hides location changes of the mobile nodes from the rest of the Internet. To do so, the mobile nodes' traffic must flow through the home agent. This mandatory deviation produces longer paths and higher communication delays.

In order to solve these problems, we describe a new approach to address deployments of Mobile IPv6 based on graph theory and could be applied to any operator's network. In particular, we use notions of centrality in graphs to quantify increases of communication distances induced by dogleg routing and identify relevant home agents locations. We evaluate this approach using real-world network topologies and show that the obtained Mobile IPv6 performance could be close to direct paths ones. The proposed algorithm is generic and can be used to achieve efficient deployments of Mobile IPv6 as well as Home Agent Migration: a new Mobile IPv6 architecture using several distributed home agents.

1. Introduction

The Mobile IPv6 protocol allows a mobile node to communicate using the same IPv6 address while it moves, thanks to a specific mobility router – the home agent. However, its performance is threatened by the dogleg routing: the mandatory deviation of the mobile node's traffic to the home agent. Choosing an accurate location of the home agent is consequently a critical aspect of Mobile IPv6 deployments since it impacts communication delays and path lengths.

Here, we model operator's networks as graphs and formally describe the impact of the dogleg routing according to the home agent's locations using well-known graph metrics. In particular, we use notions of degree and centrality in graphs to identify relevant home agents locations, i.e. such that the dogleg routing causes only a small increase to communications distances. Based on these observations, we present a generic methodology to address Mobile IPv6 deployment issues, which could be applied to any operator network.

Our proposal is singular compared to other solutions, such as the Return Routability Procedure [10], since the optimization of paths is only achieved with a correct placement of home agents, is non-intrusive protocol-wise, and is not affected by strict packet filtering policies. Consequently, it can immediately be used to enhance Mobile IPv6 deployments, and remain compatible with the current Internet architecture.

The rest of this article is organized as follows: we first describe the Mobile IPv6 protocol as well as Home Agent Migration in Section 2. We discuss notions of degree and centrality in Section 3. Then in Section 4, we formally define the impact of Mobile IPv6 and Home Agent Migration on path lengths, and discuss a methodology for communications comparing home agent locations. In Section 5, we numerically evaluate this methodology using real-world network topologies. Finally, prior to the conclusion, we examine related work in Section 6.

2. Considered mobility protocols

2.1. Mobile IPv6

The Mobile IPv6 protocol provides a unique permanent identifier (an IPv6 address) to a mobile node (MN) independently of its network of attachment. The key component of Mobile IPv6 is the home agent (HA), which is located in the mobile node's home network. It is a dedicated IPv6 router that manages the home IPv6 prefix, as well as the binding between the permanent IPv6 address (the identifier) and the IPv6 address acquired in the visited network (the locator). In the Mobile IPv6 terminology, these addresses

* Corresponding author. Address: UPMC Univ Paris 06, UMR 7606 LIP6, F-75005 Paris, France. Tel.: +33 665729366.
E-mail address: guillaume@valadon.net (G. Valadon).

0140-3664/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.comcom.2009.07.008

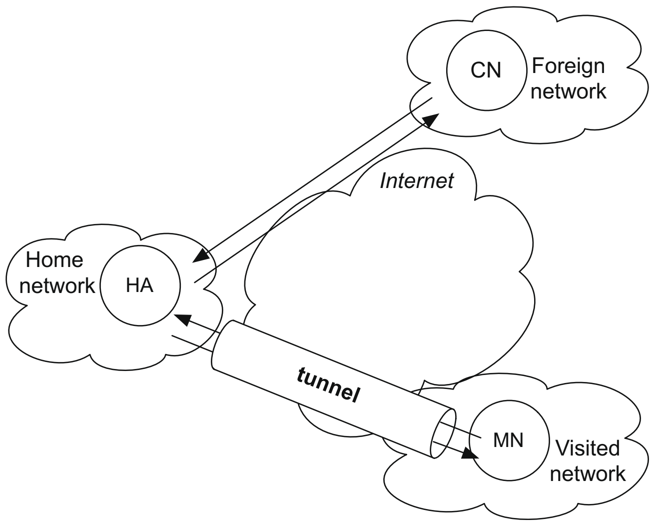

Fig. 1. Mobile IPv6: communication example.

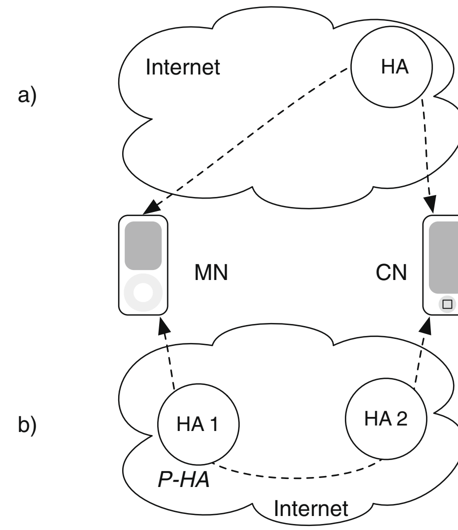

Fig. 2. Mobile IPv6 compared to Home Agent Migration.

are respectively referred as Home Address and Care-of Address. Packets sent to the Home Address, that belongs to the home prefix, by correspondent nodes[1] (CN) are routed to the home network and intercepted by the home agent which forwards them to the current location of the mobile node: its Care-of Address. Likewise, packets sent from the mobile node to its correspondent node must go through the home agent prior to being delivered. At any given time, the mobile node always communicates using its Home Address regardless of the network it is connected to. This deviation of packets to the home agent is called dogleg routing, and causes longer paths and higher communication delays between mobile nodes and their correspondents, see Fig. 1.

The effects of the dogleg routing strongly depend on the home agent's locations. Due to the addressing and routing architectures, the location of a home agent is topologically and physically restricted by its home prefix. It must be in the correct physical location so that it can receive packets destined to the home prefix. Therefore, the home agent has to be placed where this prefix is advertised on the Internet.

2.2. Home Agent Migration

We proposed a new mobility architecture, called Home Agent Migration [18], that uses the traditional Mobile IPv6 protocol with an additional mobility management plane. In this new plane, home agents are distributed all over the Internet and exchange information about mobile nodes that they can reach. This deployment is performed with the help of anycast routing [11] in which each home agent advertises the same home IPv6 prefix. Consequently, a mobile node will exchange traffic with its topologically closest home agent, reducing communication delays.

The aim of this new kind of home agent deployment is to provide an efficient route optimization scheme that (1) reduces communication latency, (2) is compatible with the current specification and implementation of Mobile IPv6's mobile nodes, and (3) is transparent for correspondent nodes.

Fig. 2 compares the network architectures of Mobile IPv6 (a) and the proposed system (b). Due to the distribution of home agents in the Internet topology, a mobile node will always use the nearest home agent as if the home agent had migrated close to the mobile node's location. This closest home agent is referred to as the primary home agent (P-HA in Fig. 2(b)). Similarly, packets sent by a second mobile node, here MN2, are routed to their closest home agent using generic IP routing mechanisms and are then forwarded to the primary home agent of MN1. With Mobile IPv6 (Fig. 2(a)), the mobile nodes communicates through a single home agent.

Due to anycast routing, the communications between mobile and correspondent nodes are not symmetric. In Fig. 3, we consider an architecture with two home agents HA1 and HA2 and two nodes, the mobile node MN, closer to HA1, and the correspondent node CN, closer to HA2. The notion of proximity is given by the regular routing of packets from the nodes to the home agents. From the MN to the CN (Fig. 3(a)), there is no straightforward way to know which home agent is closer to the CN: HA1 directly sends the packet to the CN as a regular router does. From the CN to the MN (Fig. 3(b)), packets sent from CN to MN1 are immediately intercepted by HA2 thanks to anycast routing then forwarded to MN1's primary home agent (HA1). Note that the communications between two mobile nodes are similar to communications from a correspondent node to a mobile.

3. Important graph vertices

In this article, we are looking for appropriate vertices for locating home agents. Note indeed that selecting the optimal

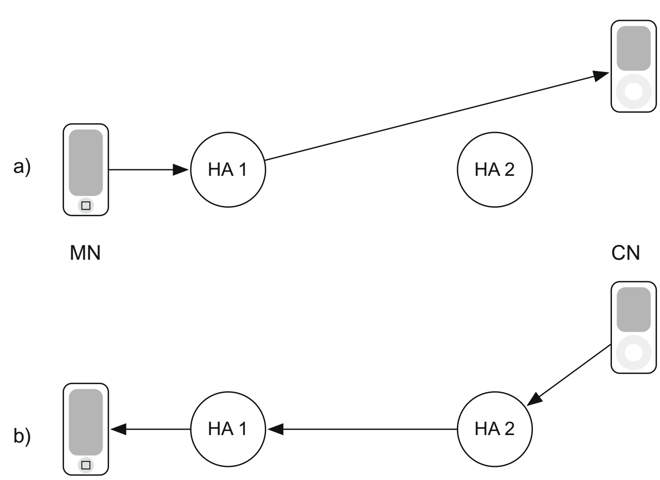

Fig. 3. Home Agent Migration: communication examples.

[1] From now on, we consider that correspondent nodes are always fixed nodes.