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A high performance link layer mobility management strategy for professional private broadband networks

Jasone Astorga *, Marina Aguado, Nerea Toledo, Marivi Higuero

University of the Basque Country UPV/EHU, Faculty of Engineering, Alameda de Urquijo s/n, 48013 Bilbao, Spain

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ABSTRACT

In this paper, we present an innovative approach to solving the mobility management problem in the context of professional private broadband networks in the vehicular scenario. These heterogeneous communication networks are commonly deployed and managed by mission-critical organisations with the aim of supporting their specific and highly demanding services. Taking advantage of the specific characteristics of these networks, we propose to solve the mobility problem at Layer 2. This way, the mobility management overhead is reduced compared to solutions that operate at Layer 3 or above and therefore, shorter handover delays and better end-to-end application performances are achieved. The core element of our proposal is an intelligent mobile switch that makes use of the services provided by the IEEE 802.21 protocol to enhance vertical or heterogeneous handover performance. To validate our approach, we have developed a prototype implementation of the designed mobile switch with IEEE 802.11 and IEEE 802.16 support. Using this mobile switch implementation, we have carried out a set of experiments over a real testbed and measured some key indicators to assess the mobility management process. The obtained results show that our handover strategy comfortably meets the requirements of the ITU-T Y.1541 recommendation for highly demanding applications and ITU-R report M.2134 for high-speed handover. To the best of our knowledge, our contribution is the first proposal that solves the mobility management problem at Layer 2 while addressing the multi-access technology context in the vehicular professional private network scenario.

1. Introduction

Currently, research and standardisation proposals for vehicular wireless networks do not converge towards a bottom-up standardised and fully defined communication architecture. Instead, the real picture is closer to an "amalgamation" of multiple wireless access technologies with their own technical specifications. In fact, known standardisation initiatives in this context, such as Communication Access for Land Mobiles from ISO (ISO CALM), the Intelligent Transport Systems initiative from the ETSI (ETSI ITS) and the Wireless Access in Vehicular Environment initiative from the IEEE (IEEE WAVE), do not propose a specific access technology under their global communication frameworks. All these technologies are expected to perform harmoniously and efficiently to meet the growing demand for ubiquitous and real-time communication services (Tafazolli, 2006).

To achieve high performance in these demanding services, interest in developing new techniques and procedures to allow heterogeneous networks to behave as a single network has increased. In the vehicular context, the main challenge is to efficiently address the sequence of intra- and inter-technology handover processes executed by the mobile nodes along their trajectories. This is commonly understood as the mobility management problem, which is not clearly solved in a heterogeneous and general-purpose network architecture. Al-Surmi et al. summarise the most important current open issues and challenges in IP-based wireless systems in Al-Surmi et al. (2012).

Instead of dealing with the mobility management problem in a general purpose communication network, in this study, we propose to address the mobility management problem in the specific context of professional private vehicular communication networks. Therefore, we tackle the issue with a context problem-solving approach. We understand that mobility requirements are common, but we have the benefit of the specific context of the professional private networks. We argue that under the professional private networks context, where a single organisation controls the entire IP-addressing scheme and the network elements of different link-layer technologies are configured under a common IP realm, the mobility management problem can be successfully and efficiently solved at Layer 2.

Professional private broadband networks are mission-critical communication networks used in a wide variety of sectors, including public safety, public transport, oil and gas, utilities, mining industry and others. In these types of deployments, no

* Corresponding author. Tel.: +34 946 017 395; fax: +34 946 014 259.
E-mail address: jasone.astorga@ehu.es (J. Astorga).

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commercial telecom operators are involved due to their mission-critical nature. The communication network is deployed and maintained by the specific company providing these mission-critical services. Professional private networks are generally demanded to provide high availability for a reduced number of users and often cover a large, extended area. Moreover, professional private networks, such as commercial networks, continue to face the demand for a multi-technology access scenario. They usually evolve from a set of multiple standalone networks into an integrated multi-technology access network.

To obtain end-to-end high performance communications over a heterogeneous access network, it is essential to achieve a high performance during the handover process. In this regard, several studies indicate that the handover performance is closely linked to timely initiation of the handover process (McNair and Zhu, 2004; Stevens-Navarro and Wong, 2006). To this end, two aspects are equally important: the handover policy (or the mechanism that rules the handover decision process) and the mechanism used to effectively communicate the decision to the different link-layer technologies.

Regarding this last aspect, in the last few years, the IEEE has been working on the development of a standard that defines a Media Independent Handover (MIH) framework: IEEE 802.21 (2009). This standard defines an abstract framework that improves horizontal and vertical handovers' performance by exchanging information between the different access technologies involved in the handover process and the higher-layer mobility management applications.

The major contribution of our paper is to present a novel mobility management strategy in the specific context of professional private broadband networks in the vehicular environment. The base of this strategy is to deal with the mobility management issue at Layer 2, instead of at Layer 3 or above. Taking the public transport sector as an example of the vehicular communication networks considered in this work, railway communication networks are one of the most demanding professional private networks. Consequently, aiming for a high performance mobility management solution for broadband professional private networks in the railway context, in this article, we propose a novel communication architecture based on our *IEEE 802.21 mobile switch concept*: a multi technology mobile switch with IEEE 802.21 support that enhances the handover performance by making use of MIH services and of an intelligent handover decision-making engine to initiate the handover process in a timely fashion.

To validate our approach, we present a real testbed implementation involving a vertical handover between two different access technologies: IEEE 802.11 and IEEE 802.16. We consider this validation methodology very valuable, since real world deployments of new approaches are scarce. The obtained results show that our solution comfortably meets the performance requirements of the highly demanding real-time IP services indicated in the ITU-T Y.1541 (2011) recommendation, as well as the handover interruption times defined in the ITU-R report M.2134 (2008) for inter-frequency handovers.

This paper is structured as follows. First, in Section 2, we introduce some background and preliminary concepts related to the motivation of our work. Section 3 describes the context and design assumptions of our proposal for the specific case study of a professional multi-technology broadband private network in the railway context, where a train migrates sequentially from an IEEE 802.16 access network to an IEEE 802.11 access network and vice-versa. Section 4 focuses on detailing our proposed vertical or intra-technology handover framework, describing our mobile switch and its major modules, procedures and interfaces. In Section 5, we describe our vertical handover process. Finally, Sections 6 and 7 provide the details of our testbed implementation, obtained results and main conclusions.

2. Background and preliminary concepts

In this section, we first study the existing approaches to address the mobility management issue, noting their obtained performance results. We then provide a brief description of the main IEEE 802.21 concepts because this protocol represents a key piece of our mobility management solution.

2.1. Mobility management initiatives

Minimising the handover impact between heterogeneous networks has long attracted significant interest in both the academy and industry. Consequently, many different initiatives have been proposed to solve the mobility management problem at different layers: the application layer (SIP: Session Initiation Protocol) (Huang et al., 2006), the transport layer (SCTP: Stream Control Transmission Protocol) (Pareit et al., 2008; Kim and Koh, 2008), the layer between the transport and network levels (HIP: Host Identity Protocol, SHIM6: Site Multihoming by IPv6 Intermediation) (Nikander et al., 2010; Nováczki et al., 2008; Ylitalo et al., 2008; Rahman et al., 2010), the network layer [Mobile IP (Kim and Koh, 2008; Lee et al., 2004; Hernandez and Helal, 2001; An et al., 2006), Fast MIP: Fast Mobile IP (Pérez-Costa et al., 2003; Boutabia and Afifi, 2008), Mobile-MPLS: Mobile-Multiprotocol Label Switching (Ren et al., 2001), HMIP: Hierarchical Mobile IP (Pérez-Costa et al., 2003; Mansourme et al., 2008; Castelluccia, 2000), Fast HMIP (Pérez-Costa et al., 2003; Hsieh et al., 2002)], combining different approaches (Leu, 2009), etc. A complete and detailed survey of different mobility management protocols is presented in Al-Surmi et al. (2012). This study provides a comprehensive classification of the studied mobility management protocols and initiatives according to different parameters, one of them being handover latency. Most current approaches involve heavy signalling processes to accomplish the handover, leading to high handover delays and therefore, high disconnection times and a high number of dropped packets during vertical handovers. This results in low performance communications.

In one example, Lee et al. (2004) measured the handover delay achieved by Mobile IPv6 both analytically and through a testbed implementation. The obtained results are very similar in both cases; they show that the average handover delay ranges from 1.9 s to 2.5 s. Similarly, Kim and Koh (2008) analysed the handover delay of Mobile IP and mobile SCTP (mSCTP) over IPv6 networks using both an analytical development and a testbed implementation. The measured values show that the mSCTP handover delay (an average of 0.4 s in the best-case scenario) is much lower than the Mobile IP handover delay (an average of 2.6 s in the best-case scenario). On the other hand, Hernandez and Helal (2001) analysed the performance of Mobile IP handover in a railway scenario, depending on the speed of the train. Their results show that due to the considerable overhead and high forwarding delay generated by the protocol, Mobile IP is not suitable for high-speed scenarios because the measured values for the handover delay do not satisfy the requirements specified by the ITU-T Y.1541 recommendation.

With the objective of providing a standard mechanism that allows improvement in the performance of handovers over heterogeneous networks, the IEEE 802.21 regulatory group began work in March 2004 and published its standard in January 2009. The main goal of this working group is to define independent mechanisms that allow the optimisation of handovers between the media types specified by the 3rd Generation Partnership