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D3M: Multicast listener mobility support mechanisms over distributed mobility anchoring architectures

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ABSTRACT

The explosion in mobile data traffic is a driver for future network operator technologies, given its large potential to affect both network performance and generated revenue. The concept of distributed mobility management (DMM) has emerged in order to overcome efficiency-wise limitations in centralized mobility approaches, proposing not only the distribution of anchoring functions but also dynamic mobility activation sensitive to the applications needs. Nevertheless, there is not an acceptable solution for IP multicast in DMM environments, as the first proposals based on MLD Proxy are prone to tunnel replication problem or service disruption.

We propose the application of PIM-SM in mobility entities as an alternative solution for multicast support in DMM, and introduce an architecture enabling mobile multicast listeners support over distributed anchoring frameworks in a network-efficient way. The architecture aims at providing operators with flexible options to provide multicast mobility, supporting three modes: the first one introduces basic IP multicast support in DMM; the second improves subscription time through extensions to the mobility protocol, obliterating the dependence on MLD protocol; and the third enables fast listener mobility by avoiding potentially slow multicast tree convergence latency in larger infrastructures, by benefiting from mobility tunnels. The different modes were evaluated by mathematical analysis regarding disruption time and packet loss during handoff against several parameters, total and tunneling packet delivery cost, and regarding packet and signaling overhead.

1. Introduction

The explosion in mobile data consumption, prompted by the dissemination of smart devices like smartphones or tablets, drove mobile operators to the research of data offloading techniques affecting all layers of the communication architecture, such as Local IP Access (LIPA)/Selected IP Traffic Offloading (SIPTO) (Samdanis et al., 2012) or IP flow mobility (IFOM) (de la Oliva et al., 2011). These efforts are dedicated to saving radio resources on the managed access, with the offloading impacts ranging from the wireless access to the edge routers. As current mobile networks are evolving toward all-IP architecture for integrating heterogeneous wireless accesses and providing seamless connectivity between them, the increase in traffic demand seriously impacts the scalability and reliable operation of mobile networks, which is based on a centrally deployed architecture for IP mobility management support, applying protocols such as Mobile IP (MIP) and Proxy Mobile IPv6 (PMIPv6). In such a deployed network, the mobility anchor point—Home Agent (HA) in MIP or Local Mobility Anchor (LMA) in PMIPv6—assumes key responsibility in the management of binding updates and packet forwarding of all data packets of associated Mobile Nodes (MNs), thus leading to single point of failure, suboptimal routing, and consequent packet routing delay (Chan et al., 2011; Al-Surmi and Ali, 2012). With these concerns, the Internet Engineering Task Force (IETF) created distributed mobility management (DMM) WG,[1] and both the mobile industry and network operator communities have shifted their attention to the design of distributed mobile architectures and associated future mobility protocols. The core feature of distributed mobile architectures is the distributed deployment of mobility anchors close to the edges, enabling multiple IP flows to be distributed through several anchors and thus providing an efficient IP mobility solution to deal with the increasing mobile traffic. The impact of such approach has been identified by analytical studies (Jeon et al., 2013; Ahmad et al., 2012), and some variants following the core principle have also been proposed and evaluated (Ahmad et al., 2012). With the main portion of all traffic being video, and with the expectation that it remains the

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[1] IETF DMM WG, http://datatracker.ietf.org/wg/dmm/charter.

dominant traffic in future wireless/mobile networks (Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018, 2014), the interest and need for IP multicast support are rejuvenated, and have motivated research of its support under distributed mobility architectures.

There are two possible standard mechanisms used for providing IP multicast support over mobile networks. The first option is to apply an Internet Group Membership (IGMP)/Multicast Listener Discovery (MLD) Forwarding Proxy (Fenner et al., 2006a) (in short IGMP/MLD Proxy); the other option is to apply a complete multicast routing protocol. Both PMIPv6 and early research aimed to design mobility solutions fitting the concept of distributed mobility management use the former approach. Namely, Figueiredo et al. (2012) present a solution applying IGMP/MLD Proxy in all mobility management entities, which can be differently adapted taking into account two design considerations: solution proactivity and the distribution degree of the control plane. This protocol design may lead to duplicate traffic, where a serving DMM router receives multiple copies of the same multicast stream, one for each IGMP/MLD Proxy instance running on the router. Aiming to solve this issue by tackling the lack of coordination between the IGMP/MLD Proxy instances and the serving router, a channel-manageable IP multicast architecture framework has been presented in Jeon et al. (2012). It solves the duplicate traffic issue by introducing a channel control server managing a multicast channel for a given serving router. However, due to its focus in assuring IP multicast mobility service efficiency, service disruption while coordinating multiple IGMP/MLD Proxy instances may be a consequence. Besides, managing all the serving routers does not scale. An additional option is to extend MLD Proxy functionality with the support for multiple upstream interfaces (Nguyen and Bonnet, 2013a).

On the other hand, Protocol Independent Multicast Sparse Mode (PIM-SM) (Fenner et al., 2006b) has proven production experience, and is a widely accepted multicast routing protocol used to build multicast networks. Contrarily to MLD Proxies, it enables a multicast router to seamlessly manage multiple upstream interfaces, not requiring any modification or extensions. Namely, Reverse Path Forwarding (RPF) is used to decide from which interface the multicast packet should be received among all the available routing interfaces. As such, we consider it is an option which should be exploited over a distributed mobility architecture.

Furthermore, the aforementioned solutions all lack one important feature: adaptability to the service needs. Given the current diversity of Internet streaming (VoD and user generated videos) or broadcasting-based (online gaming and live TV) video applications being actively used by users over mobile networks, very distinct requirements characterize them, in such aspects like handover latency, jitter or packet loss. Thus, following a ‘single mobility fits all’ approach is not an efficient option. Similarly, the ‘ad-hoc’ availability of multiple appropriate multicast mobility schemes is a necessary strategy, as efficiency and flexibility are—more than ever—key for network operators. With this in mind, in this paper we propose a distributed mobility management and Multicast-enabled architecture (D3M), a flexible architecture providing multicast mobility protocol solutions for DMM environments. The proposed D3M architecture is based on PMIPv6 (Gundavelli et al., 2008), and as such the MN is not involved in the mobility signaling process. It leverages on the PIM-SM routing protocol, and enables different realizations depending on two design criteria: the multicast subscription discovery and the multicast packet resumption origin. The former defines how the target mobility access router (MAR) can be informed regarding multicast subscription information of attached or incoming MNs, and is associated with the time required by the target MAR to acquire the MN's subscriptions and initiate the multicast subscription. The latter regards the multicast subscription origin—i.e., where to resume multicast packet forwarding of previous session(s) from—and thus is related to the time spent before receiving multicast packets through the target MAR after the handoff event. Generally, faster multicast re-subscription and seamless packet forwarding schemes are preferred for better Quality of Service (QoS), but raise trade-offs between mobility performance and complexity, and the amount of incurred processing and signaling costs. Besides, not all multicast applications demand the highest QoS at all session time, thus their mobility requirements can be different. Each mode presents a trade-off between the preservation of user QoE[2] (Quality of Experience) during handoff and the introduced complexity or amount of incurred processing and signaling costs. Additionally, operators can opt to enable one or a subset of the available modes, adapting the solution to the users and/or service performance requirements. Nevertheless, all schemes prevent the occurrence of tunnel replication cost, one of the main problems when integrating IP multicast support in mobility management protocols.

With this motivation and design principles in mind, three D3M modes are specified: Native IP multicast (NIM), Native IP Multicast with Subscription Transfer (NIM-ST), and Anchor-Based Multicast (ABM). They are distinguished not only by the approach used concerning the two design criteria, but also by the extent to which they are integrated with the considered DMM protocol; in other words, on how much the solution depends on DMM characteristics. NIM utilizes only native IP multicast infrastructure, not being dependent upon any benefits of the given DMM architecture. NIM-ST mode also relies on native IP multicast but additionally employs a new multicast subscription transfer for fast subscription acquisition of incoming MNs. Finally, ABM mode provides multicast packet anchoring using the mobility tunnel established between the previous MAR and the new one, as well as multicast subscription transfer.

The main contributions resulting from this work are the following:

- To the best of our knowledge, this is the first framework applying the deployment of multicast routing functions in DMM routers;
- The proposed framework enables three distinct operation modes. Each mode can be either independently used or strategically combined by taking different user and/or service requirements into account.
- The three proposed modes were evaluated in terms of service handover latency, packet delivery cost—including tunneling impact—and packet loss against different variables such as the user density. Besides, packet and signaling overhead were analyzed.

The structure of this paper is as follows. Section 2 provides preliminary knowledge for the understanding of IP multicasting operation based on PIM-SM and distributed mobility management. In Section 3, we propose the D3M architecture and its three operating modes. Section 4 analyzes the performance of the three modes, while Section 5 provides the numerical results obtained from the given analysis. In Section 6, we discuss additional qualitative performance factors. This paper is concluded in Section 8.

2. Preliminaries: basic technologies

2.1. IP multicasting operation

PIM-SM is used to establish and maintain multicast routes using RPF mechanisms, which ensure loop-free multicast packet forwarding. The decision where to forward a multicast packet is based on a source address and not on a destination address, unlike unicast routing. It is enabled by using a Multicast Routing

[2] Throughout this document we refer to QoE as the user's quality perception of the service, while QoS will be used for referring network-side performance metrics.