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A control framework for abstract multiparty transport

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ABSTRACT

The increasing demand for group-based multimedia communications, personalization and seamless mobility imposes the development of novel approaches to overcome the heterogeneity and dynamics of future network environments. The study developed in this article addresses a context-aware multiparty content delivery framework, capable of providing autonomic control of personalized group-based services to users by a hierarchical strategy with the concept of Abstract Multiparty Trees (AMTs). A thorough study of the proposed concept is presented, aiming to assess the scalability and flexibility of our framework and associated procedures. An analytical study quantifies the amount of reconfigurations and resources saved in the network whenever context changes, showing how the control framework scales when the network size increases. The evaluation through simulation analyses the performance of the proposed solution, meeting the results of the analytical study and showing a good performance regarding the reconfiguration of the AMTs in terms of time and control overhead. Finally, a proof-of-concept demonstrator is also detailed, in order to prove the feasibility of the AMT concept and the good performance of its main control operations.

1. Introduction

In recent years, we have witnessed a fast growing of multiparty multimedia services, given the proliferation of services such as IPTV, live video streaming or file distribution. Thus, multicast networking concept gained a new stimulus, as the most suitable solution to a rational use of available network resources while avoiding performance degradation. However, despite the efforts to endow multicast-based service provision with the scalability required by large networks and a vast number of users, new trends in content consumption (e.g. mobility or access heterogeneity) have been stimulating the research towards the development of novel architectures to address the challenges of future communication environments.

Concerns related to the Quality of Experience (QoE) of the services have never been so evident as now, with increasingly demanding users and applications. Thus, considering the heterogeneity that will prevail in the different elements of a communication environment, there is an opportunity to enhance user QoE by adapting and personalize service delivery according to the related information available. In this sense, multiparty content transport can be enriched through context-awareness. Capitalizing the information from the surrounding communication elements, groups can be dynamically created according to the context of their elements, and both network and services can be adapted to their particularities. This new level of awareness will enable a more personalized service provision, considering for instance the type of user, location, terminal capabilities, access technologies features or the service requirements.

This level of context-awareness implies an added network control complexity, considering that the network must properly adapt the service provision to any change related with one of these aspects. Thus, the development of scalable optimization schemes are required to support context-aware content delivery under heterogeneous and very dynamic conditions. From one, side, it is difficult to manage a network in a distributed way and to synchronize the information in the network nodes; from the other side, it is not possible to handle all network elements and its context in a centralized approach. In this article we present and analyze a hierarchical control framework that employs the concept of Abstract Multiparty Trees (AMTs) to control multiparty content distribution in an autonomous way, decentralizing the control and management functions.

We support that this strategy is the most suitable to take advantage of network heterogeneity and better adapt the service provision to context changes. The AMT principle consists in allowing end-to-end multicast content transport over network segments with different transport technologies (i.e., unicast and multicast),

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and also providing independence between source and listener trees (through different AMTs), and seamless resilience support. Central elements only need to control the edges of the AMTs, and all the adaptations and reconfigurations inside the AMTs are performed through these edge nodes, the overlay nodes, which implement proxy functionalities to mediate overlay connections. The end-to-end path is therefore the result of several independent multiparty trees. This approach increases the flexibility of the distribution trees, allowing to hide network dynamics and heterogeneity.

This article presents the proposed hierarchical control framework, detailing the algorithms and procedures that enable it, namely the selection algorithms designed to determine the control elements of each AMT, and the operations performed by the lower control level to enforce the decisions computed by the NUM in the physical network. Furthermore, a formal definition was adopted to provide a better insight of the AMT concept, which also enabled an analytical reasoning of how the AMT control scales with the network size, number of receivers, and how it reacts to network changes that require the rearrangement of the distribution trees. The outcomes of this analytical study showed the link savings and re-utilization that the AMT concept is able to reach when comparing to more traditional multiparty transport strategies. Moreover, the AMT performance is even more notorious for larger networks, which demonstrates its scalability.

An evaluation through simulation extends the study of the AMTs, comprehending a broader implementation of the algorithms and control schemes proposed. The simulation results highlight the AMT performance regarding the session establishment and reestablishment time (after a reconfiguration), and the impact of the amount of control overhead which has revealed insignificant.

A proof-of-concept demonstrator was also implemented to prove the feasibility of the AMTs, which evaluates its performance regarding the main control operations and events: creation, extension, removal and reconfiguration of the AMTs. The demonstrator proved to be very effective, properly reacting and adapting the AMTs in a very short time considering the amount of necessary operations.

The main contribution of this article is the comprehensive analysis of the AMT concept, aiming to prove its effectiveness as a control framework for multiparty content delivery. The outcomes of this study, not only prove the advantages of using the AMTs in terms of network resource savings and control flexibility, but also in terms of its feasibility and easy deployment in today's networks. Furthermore, the ability to deal and take advantage of the prevailing heterogeneity in communication networks is also an added value of our solution.

The remainder of the article is organized as follows. The related work is presented in Section 2. Section 3 overviews the multiparty transport framework proposed, and Section 4 formally introduces the AMTs concept. In the Section 5 it is performed an analytical study on the flexibility of the AMT principle. Section 6 presents the evaluation of the multiparty transport framework through simulation. A proof-of-concept testbed is also described in Section 7, as well as the results of its evaluation. Ultimately, Section 8 concludes the article.

2. Related work

2.1. Multicast incremental deployment

The multicast transport concept is, theoretically, the most suitable solution for content delivery to a large number of users (group-based services). However, despite its advantages, the multicast technology only in the recent years has seen a more significant commercial deployment, mainly due to the proliferation of multimedia streaming services. Its major drawback is related with the state maintenance required at each router [1], which impairs the scalability. With the proliferation of multicast services, the amount of forwarding state increases and requires more forwarding capacity from the routers. The use of multicast is clearly more attractive to network operators than for receivers, given the bandwidth savings. For receivers, the way they receive content is irrelevant as long as the service experience be satisfactory. On the contrary, multicast is very useful for content providers, so they may offer their services to a larger number of receivers in a very scalable way. In this sense, the research community has been trying to offer more flexible and incremental deployment options to ease the use of multicast concepts in legacy networks.

Application Layer Multicast (ALM) [2,3] is one of those strategies, which does not require an upgrade of the network infrastructure. This way, ALM is a more scalable solution since routers do not need to maintain per-group state. However, the content delivery trees created by ALM are non-optimal, which leads to longer latencies and possible packet duplication on the same link. Overlay Multicast [4] is another incremental solution, where multicast functionalities can also be supported by constructing a backbone overlay of intermediate proxies, which create multicast trees among themselves. End hosts may communicate with these proxies via unicast or multicast. In order to combine the best of both strategies (overlay and native multicast), another approach called Island Multicast [5] has been recently developed. The main idea is to achieve a solution that benefits from the incremental deployment of the overlay concept and also the delivery efficiency of IP multicast.

2.2. Multicast scalability

Regarding multicast scalability, there are thorough studies in the literature that provide a quantitative analysis of the network load reduction achieved by this technology. The groundwork under this topic was performed by Chuang and Sirbu [6], which calculates the number of links L in a multicast delivery tree that connects the source to m distinct network locations. The simulations performed for a wide panoply of networks (real and generated) show that the efficiency gains can be reasonably described by $L(m) \propto m^{0.8}$. Attempting to understand the universality of Chuang–Sirbu law, Phillips et al. [7] extends the previous study in order to determine the scaling law more precisely. Chalmers and Almeroth [8] validated the previous multicast scaling laws for real multicast sessions and group data. However, the study presented by Mieghem et al. [9] shows that, only for a small or moderate number of members, the Chuang–Sirbu law is a fair approximation.

2.3. Enabling richer communication environments

Besides the concerns about the scalability issues of the multicast concept, we have witnessed in the past few years a growing interest for context-aware network architectures that employ any kind of information to enrich the user experience of the services provided and make a better use of the resource available. In [10] it is proposed a virtual network operator supporting context-aware services such as location, device and identity management across multiple access networks, abstracting underlying technologies. It offers a service-rich experimental environment using overlay networks to increase QoE. Another context-aware architecture is proposed by [11], presenting a pervasive service platform to reach an ubiquitous communication and information access in very dynamic environments. A context broker is used to collect and store environment information, so that it can then be