Ad Hoc Networks 13 (2014) 191–209

Contents lists available at ScienceDirect

Ad Hoc Networks

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

Analytical modeling of context-based multi-virtual wireless mesh networks

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ARTICLE INFO

Article history:
Available online 17 May 2011

Keywords:
Context-awareness
Wireless mesh networks
Virtual Networks
Modeling
User connectivity
Discovery mechanisms

ABSTRACT

The flexibility and self-∗ properties of wireless mesh networks (WMNs) and the programmable management of network resources brought by the innovative network virtualization techniques, are a twofold force to enable personalized access over wireless environments. Therefore, we design a context-aware multi-virtual architecture for WMNs to deal with the requirements of mesh clients and their applications (context can be defined as a set of requirements such as cost, security, mobility, applications' Quality-of-Service - QoS). In this approach, a WMN is split into several adaptable Virtual Networks (VNs), each one appropriate to specific levels of context. This approach requires the proper configuration of VNs' topologies and resources, and the definition of local and global (distributed) mechanisms to reconfigure VNs that best fit users' requirements. In this paper, we propose an analytical model to evaluate the impact of network virtualization and the complexity of the discovery and extension mechanisms defined for VN reconfiguration. Through a delay-based approach, we show the effectiveness of the architecture to deal with different communication requirements and with distinct scenarios for user connectivity establishment, even in the presence of user mobility or using a real WMN topology. The analytical model is compared against a simulation one, showing similar results.

1. Introduction

Wireless mesh networks (WMNs) [1] are easily adaptable, self-configuring and self-organizing networks, being a key technology to enable broadband access in wireless environments. WMNs provide access to mobile mesh clients that have, for instance, different trust, security, mobility, and cost preferences. Moreover, the services required by such clients have distinct Quality-of-Service (QoS) requirements. These preferences and requirements are denoted as context [2] of users and services. In order to deal with these context demands, WMNs have already shown high-potential since the topology of their infrastructure is flexible enough to promote the switching of routes and transport connections for different context-aware purposes. However, the integration of the plethora of context features in the management and control of WMNs is a topic not fully addressed in the literature.

The application of network virtualization techniques [3] to commodity network infrastructures brings attractive advantages. It is increasingly seen as a clear path for the simultaneous support of emerging paradigms and architectures. Through network virtualization, a physical infrastructure can be split into a number of different specific Virtual Networks (VNs). This concept can be used to personalize networks to users' context up to a high degree. Although network virtualization brings benefits for different types of networks, its suitability, when applied to WMNs, has not been extensively evaluated.

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doi:10.1016/j.adhoc.2011.05.004

The heterogeneous structure of WMNs, containing a large number of nodes handling different context requirements with several conflicting targets, can benefit from the separation of mesh clients in specific, programmable, and adaptable VNs. Moreover, the application of network virtualization to WMNs will certainly play an important role in the creation, maintenance, extension, and termination of communication flows in future wireless environments, increasing the users' Quality-of-Experience (QoE).

In this scope, we define an architecture that takes advantage of context-awareness and network virtualization, integrating these two concepts for WMNs to enable personalized communications for a group of users, according to their expectations and preferences. Each VN is configured to meet distinct levels of context requirements of users and their services, providing personalized, isolated, and non-interfering context-based communications in WMNs. In our approach, it is required to properly configure the assigned resources and topologies of the context-based VNs, and to define local and global control mechanisms to discover and extend VNs that best fit users' context.

We described the architecture and its key raised challenges first in [4]. Basic approaches for the evaluation of the architecture were presented in [5,6], and [7]. In [5], we performed a very simple probabilistic-based evaluation of the limits of the multi-VN approach in terms of the number of VNs, attached mesh clients, and virtual nodes per VN, in order to accomplish feasible delays for different data communication requirements. In [6], we analytically evaluated basic control mechanisms to discover and extend fitting context-aware VNs for users. More recently, we developed a simulation framework to evaluate the architecture, and the first results were presented in [7].

In this paper, we present the complete analytical model of the proposed context-based multi-VN architecture. Additionally, we evaluate and validate the model against the results of the implemented simulation framework. The model is used both in data and control planes. In the data plane, it allows the estimation of the end-to-end delay of a data packet within a specific context-based VN, even in the presence of multiple VNs and flows per VN. We aim to assess the suitability of network virtualization to personalize context-based communications in this type of environments. In the control plane, it provides the measurement of the impact (delays and overhead) of the proposed control mechanisms for VNs' association and reconfiguration in case of mobility or arrival of new users at the WMN: (*i*) the discovery of the VN that best fits users' context, and (*ii*) the extension of the best fitting VN to the nodes near the users. This work also describes the control functionalities of every architectural element and the required control signaling to associate users to fitting VNs. Finally, and as a proof of concept of the modeling work, we also perform simulations with a real WMN topology, using the node locations of the Funkfeuer Vienna WMN [8].

The obtained results show that the requirements of the data communications are indeed met, with a small impact of the proposed control mechanisms for VN reconfiguration both in terms of delays and overhead. As expected, mobility of users has a significant impact on the communications, and this impact depends on the required level of reconfigurations. Finally, the results obtained with the topology of a real WMN are similar to the ones of a specified WMN grid topology, still with a slight decrease on the delay of data communications. This shows that this approach is suitable for real running networks.

This paper is structured as follows. Section 2 summarizes the literature proposals that are related with this work. Then, Section 3 introduces the context-based multi-virtual architecture for WMNs, and the required control mechanisms to enable users' connectivity to the best fitting available VNs. Following, Section 4 presents the analytical model to evaluate the architecture and the proposed control mechanisms. Section 5 starts with the description of the simulation environment, and then presents the analytical results and their comparison against simulation results. Finally, Section 6 presents final conclusions and future work.

2. Related work

The envisioned architecture makes use of two fundamental concepts, that are context-awareness and virtualization to personalize WMNs. Context-awareness refers to the ability of the WMN to incorporate information about the user, user behavior, user preferences, and environmental conditions. The description, detection, and use of context are the prerequisites to propose context-based selection of appropriate network services and adaptations. To ease adaptation and flexible resource sharing, and more important, to be able to build and use on-demand networks with different networking mechanisms and protocols, network virtualization is applied to WMNs. Finally, since we investigate our approach based on analytical modeling for WMNs, this section also discusses related WMN modeling approaches.

2.1. Context-awareness

Context-awareness in networking takes advantage of information about terminals' or users' context such as the Quality-of-Service (QoS) of users' applications, mobility behavior, and cost, security and privacy preferences. The objective of using context information is to adapt routing or flow control, network selection, mobility management, or resource reservation in WMNs.

Several QoS-based routing protocols have been proposed for WMNs [9,10]. In [9], the levels of signal interference of the communication links are dynamically integrated in the routing metrics, whereas in [10], several context data (security, traffic priority, mobility, etc.) are used to describe and adapt the routing metrics. In [11], performance metrics, such as the path availability, bandwidth, and delay, as well as outages based on network monitoring and statistical evaluation, are used to assess the robustness and perform the selection of the best available path for a real-time communication. Furthermore, several works are in particular aware of mobility behavior of mesh clients [12]. In [13], a proactive and reactive routing algorithm is selected according to the intensity of mobility within the WMN. On the other hand, in [14], the current position of mesh clients is