Context-Aware Connectivity and Mobility in Wireless Mesh Networks

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Abstract. Wireless Mesh Networks (WMNs) have shown a high-potential to fulfill the requirements of the Next Generation Networks (NGNs). Although mobility management is crucial to develop large-scale WMNs, the heterogeneity of today's Internet will imply a context-aware architecture in the future to optimize the users' experience. Network virtualization, as a mean to share and isolate resources, can be used as an element to construct different types of virtual networks (overlays), each one optimized for a specific set of contexts: security, mobility, Quality of Service (QoS), cost, preferences. In this paper, we present a context-aware multi-overlay architecture that enables a user to connect to the WMN that best fits its requirements and approaches. We concentrate on how to build such an architecture: how a user can move maintaining its requirements through the re-configuration of overlays, and how context can be mapped, organized and distributed in the network nodes. We also discuss the entities and the complexity of this architecture

Keywords: Network Virtualization, Wireless Mesh Networks, Multi-overlay architecture, Context-awareness, Mobility, Multi-homing, Intelligent decisions.

1 Introduction

Wireless Mesh Networks (WMNs) have emerged as a key technology for Next Generation Networks (NGNs). Traditional wired infrastructure for wireless access networks is not feasible or too expensive for many application scenarios in the near future. Replacing wired infrastructure with wireless links promotes an ease up time-to-deployment, allowing ubiquitous broadband access in a cost-effective manner.

Another emergent topic of the future Internet is the network virtualization, which brings a number of advantages, such as physical/logic separation and independence, hardware multiplexing, resource isolation and security, reliability and redundancy, and flexibility on the topology and protocols supported.

Currently, users and networks have very heterogeneous context requirements. Moreover, context information can optimize mobility performance by avoiding unnecessary handovers and long latencies, while aware of users' activity, preferences, and other context information. Integration with WMNs may offer a flexible physical infrastructure where different multi-hop paths may support several types of context.

In [1] it is presented a new approach to enable highly adaptive WMNs through the support of multiple overlays for context-based WMNs. In this approach, we model

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context and virtualize the WMNs by introducing multiple overlays to represent the context characteristics. Hereby, we also consider multi-homing supported by different providers and different WMNs. In this approach, a user will connect to the WMN that best fits its requirements. In this paper we show how to build such an architecture: how a user can move maintaining its requirements through the re-configuration of overlays and how this architecture can be used to optimize mobility; how context can be mapped, organized and distributed, and how the nodes of specific overlays can be discovered in an efficient way. This paper is organized as follows. Section 2 addresses the current state of virtualization and context-aware solutions over WMNs. Section 3 depicts the proposed architecture for context-based WMNs through virtualization, attempting at the management of overlays, mobility optimization and integration of context, whereas, section 4 presents the possible entities for this whole architecture as well as its envisioned complexity in real environments. Finally, section 5 concludes the paper and presents topics for further work.

2 Related Work on Context-Awareness and Overlays in WMNs

The literature contains some proposals to introduce context in WMNs. However, they are mainly focused on QoS-aware routing mechanisms [2]. In contrast, our general approach for heterogeneous networks has the potential to improve routing protocols by modeling and using different types of context, dividing a WMN into multi-overlays networks in order to provide networks that best match the different users' requirements and to optimize multi-homing. Based on the expected performance, the overlay can be setup and mapped to the physical network [3], [4]. Recent works used machine learning techniques for this purpose in WMNs [5], [6].

There are a huge number of approaches for mobility management in WMNs, aiming to support a seamless handover for the user (see as e.g. [7], [8]). Since mobility is a key requirement in any type of proposal, optimization of mobility through this multi-overlay architecture is also an objective. For a user, when it moves, it changes its physical connection; however, due to virtualization and overlay's reconfiguration, it may remain logically connected to the same logical node.

Similar to operating system virtualization, network virtualization has the potential to support multiple (logical) networks simultaneously [9]. Logical overlay networks proposing "network slicing" are, as e.g., addressed in [10] that accommodate several experiments simultaneously in space, time and frequency division manner. In [11], the authors describe an approach of a joint optimization streaming rate allocation of flows and power consumption of links for forwarding data flows in multicast overlays over WMNs. In [12], a Wireless Ring over a regular WMN is proposed in order to carry high-bandwidth data. In [13], it is proposed MeshChord, which uses location-dependent addressing schemes in order to reduce traffic for maintaining a Chord overlay over WMNs. Although these approaches use multi-overlays, they do not consider context and the corresponding open research issues: (i) how to identify and rate context characteristics and automatically map them to a network structure; (ii) how to create an appropriate number of multi-overlays; (iii) how to select the best fitting overlay; and (iv) how to adapt and maintain the multi-overlays.

3 Multi-Overlay Environment

This section presents the context-aware multi-overlay approach envisioned for highly dynamic WMNs supporting optimized users' experience in mobile and multi-homing environments. Since wireless mesh routers are meant to build well-structured networking organizations which need to fulfill several connecting targets, we introduce context-awareness along parallel virtual networks (or overlay networks). These overlays can be used to optimize the network along one or more context parameters, and to connect users that share the same or similar context. We consider different types of context: user, network, price and predicted context.

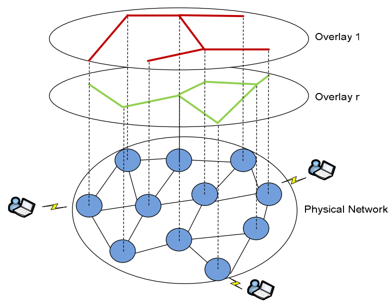

Fig. 1. Multi-Overlay Architecture for Context-based WMNs

In this approach we also consider multi-homing, supported by different providers and different WMNs, with the possibility of different users to be associated with different overlays. A first sketch of our multi-overlay architecture is shown in Fig. 1. This multi-overlay environment requires an effective solution for its management and control. We need mechanisms to select the overlays, as well as information/signaling to create/reconfigure them and to distribute the nodes through them. The creation and reconfiguration may be activated through users' mobility.

The integration of context with respect to the different entities (e.g., user, device, application, network, Internet Service Provider - ISP) in WMNs introduces several open issues and challenges that need to be addressed: overlay's characterization according to its context, and distribution of the context in the network; virtualization in wireless environments in order to decrease interference; intelligent algorithms to choose the best overlay for a user, according to the context of all entities involved, as well as, to decide between overlays' creation or reconfiguration to optimize users' experience; mapping of the overlays in the physical network, and, resources' scheduling and polling; allocation of different overlays for different user's applications, interfaces or connections (multi-homing); scalability of the solution.

The next sub-sections present the mechanisms to support the management of overlays, mobility and context-embedding.

3.1 Management of Overlays

The overlay's management has three different and important phases: (i) selection, (ii) creation and (iii) reconfiguration:

(i) *Selection of Overlays*. When a user arrives at the network consisting of a multitude of overlays, the best one should be selected for user's connectivity. In section 3.3 we present two different distributed solutions for the mapping and integration of context in the network elements, and mechanisms to efficiently find the closest node belonging to a specific overlay.
(ii) *Creation of Overlays*. If a user requires an overlay which is not already available in the network (all overlays currently available exhibit characteristics not fitting to the user's requirement ranges), the best matching overlay may be chosen or a new overlay needs to be created.
(iii) *Reconfiguration of Overlays*. Based on context, preferences, and resulting mobility management, overlays may need to be reconfigured proactively.

3.2 Mobility Optimization through Overlays

In the proposed approach, the movement of a user may require the reconfiguration of the network, through creation and reconfiguration of overlays, to enable the user to be connected to the same overlay while moving. However, the concept of overlays can also improve mobility management, since the reconfiguration of the overlay may provide the user with the same logical router. For the user, when it moves, it remains logically connected to the same mesh router (belonging to the same overlay). Therefore, with this approach, mobility just requires a change of physical connection to a different physical node (link-layer handover), being IP-independent.

Fig. 2 depicts the main processes required to optimize mobility of a user (between an old and a new mesh router) through this context-aware multi-overlay architecture. Mobility of users can be modeled or predicted and this aspect will be introduced as a context parameter. Besides network-centric mobility management, user triggering is also possible and will require similar processes. The old router needs then to attempt at the user's context, find the predicted new mesh router for the user, and send the user's context to the mesh router. The next step is the reconfiguration of overlays:

(i) First, it is verified if the old and new routers both belong to the user's overlay. If it is true, there is no need to reconfigure the current overlay and the algorithm is stopped. After paths/routing updates, the user switches to the new router.
(ii) If the new router does not contain the user's overlay, but it can be extended to the new router, the overlay is reconfigured. After overlay and paths/routing updates, the user switches its physical link to the new router.
(iii) If the new router does not contain the user's overlay, and it cannot be extended to the new router, an available and suitable overlay for the user needs to be found, in the new router or even in its physical or virtual neighbors. In this case, one virtual link is added and, after overlay and paths/routing updates, the user switches to the suitable overlay.
(iv) If the new router does not contain the user's overlay, and there is no suitable overlay in its neighborhood, a distributed decision needs to be in place.

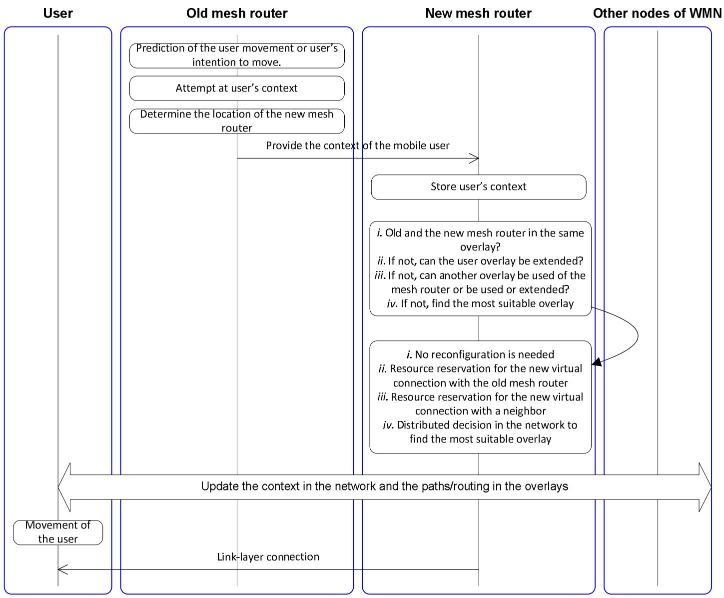

Fig. 2. Mobility Optimization through Multi-Overlay Environment

A user movement requires the update of the context in the network and of the paths/routing in the overlays. This update can be performed using the advantages of DHTs, finding an intermediate solution between the standard routing protocols for WMNs and the information that DHTs provides. As an example, the network can be divided in clusters (domains) with a DHT-based Peer-to-Peer (P2P) control overlay, where each cluster is represented by a key. These clusters have to be organized in the overlay based on their physically proximity (using "shortcuts" between them) in order to decrease the number of physical hops per overlay hop. The routing inside each cluster can be a standard WMN routing protocol.

We expect that this reconfiguration process is finished before the user's movement; when the new mesh router detects the user in its neighborhood, it is promoted an instantaneous link-layer connection.

3.3 Integrating Context through Distributed Hash Tables

The most traditional approach to store context data and resolve search requests is to use a centralized search engine. Although this approach can provide fast responses to a context query in a small network, it has limitations such as scalability, processing bottlenecks and single points of failure. P2P approaches, on the other hand, have been proposed to overcome these obstacles. They typically implement DHTs and use hashed keys to direct a lookup request to the specific nodes by leveraging on a structured overlay network. We then use DHTs' approach to organize our multi-overlay context-based environment. For this purpose, we require the knowledge of the current overlays in the network and their main features. We propose two independent solutions to integrate context through DHTs.

First solution. The overlays are organized based on their context features; users also contain their context parameters. The user's context will be matched against the overlays' properties in order to find the best overlay for a user.

The overlay's features of a cluster (domain) can be distributed in a P2P control overlay, where each peer is a router of the physical network which stores a key that represents the properties of the overlays it contains. Through this P2P overlay, an efficient lookup procedure may be supported in order to find the best overlay for a user, attempting not only at the matching of the user's and overlays' context, but also at the location of a point of attachment for a particular overlay. To support this approach, it is required to devise a mechanism to efficiently create a key, based on all types of context to describe each. One drawback of this approach can be the potentially slow lookup procedure for a large number of overlays.

Second solution. The DHT can be organized in a ring, based on context's features that characterize the overlays (see Fig. 3).

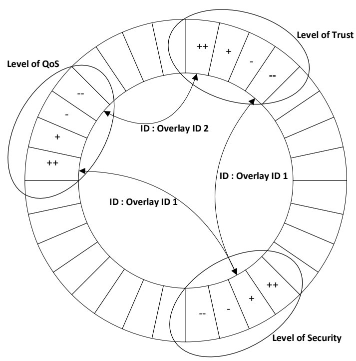

Fig. 3. Context Organization through DHTs – Second Solution

The context parameters are divided in levels/IDs (for e.g., context can be described with the following levels: QoS – 0; redundancy – 1; trust – 2; reliability – 3; etc.). Each level/ID of context can have four different sub-levels/sub-IDs (++, +, - ,--). Then, the different levels of contexts can be connected based on the ID of each data overlay, in order to represent the data overlays' features. As represented in Fig. 3, data overlay 1 is characterized by a "++" sub-level of QoS (0), a "+" sub-level of security (4) and a "--" sub-level of trust (2). In order to organize its context in our DHT, we should use "shortcuts" between these sub-levels, based on the ID of the data overlay 1.

Through this process, it is possible to efficiently and directly find several possible overlays that can be allocated to a user. However, this solution has two main drawbacks: all this information has to be presented in all nodes of a P2P control overlay of a specific domain; if the number of data overlays is large, since they can be characterized by different types of context, the number of "shortcuts" based on the ID of the same data overlay (multi-level DHTs) is also large. This may also slowdown the process of finding the best suitable overlay for a user. The bootstrapping of DHTs and the shortcuts' maintenance will need to be evaluated.

Moreover, both solutions will need to be evaluated in terms of overhead and cost. Notice that the lack of resources of wireless environments and the number of protocols at different layers in this approach may introduce challenges on the support of DHTs in this type of environments. These challenges will be evaluated and different solutions need to be investigated

Scalability of the approaches can be achieved by using two levels of P2P control-overlays: a higher level P2P overlay, where each peer represents a domain, and the lower level with the control peers of each domain (the two solutions, presented before, focus on the context-embedding inside a domain). In the higher level, each peer can be characterized by the context characteristics of the best overlay of the domain for a specific context requirement. However, there are several issues that still need to be investigated, such as the location of a peer of a domain and the size of a domain.

4 Architectural Discussion

The creation/reconfiguration of a particular overlay requires the existence of an efficient resource manager. It is also required an entity that acquires and stores the context of all entities involved. Both these entities, ***Resource Manager*** and ***Context Acquisition/Repository***, should be distributed in the network through DHTs in a P2P control overlay. The context information should reside in an abstraction layer (overlay) between the physical and the virtual environment, organized by one of the solutions presented in section 3.3. A framework for managing the user's mobility – ***Mobility Manager*** – should reside in all mesh routers, in order to predict the movement of its attached users, and trigger the reconfiguration process of the overlays. Finally, it is also required a framework that integrates the context of all entities and network resources, and promotes an intelligent overlay's management – ***Overlays Manager***. Here, the cost of each decision – create or reconfigure an overlay – should be evaluated: the matching of overlays' features and users' requirements should be performed to select, create or reconfigure an overlay; the overlay manager has to select the correct overlay's instance in each router, and coordinate all entities.

Breaking a WMN into a number of virtual overlays can introduce different types of costs. We will have management costs to create and manage the virtual networks, as well as, usual costs of loss of aggregation in virtual environments. However, the flexibility envisioned in these high-dynamic WMNs provides the optimization of user experience, enabling its connection through already established overlays with the required characteristics. The use of DHTs and network virtualization in wireless environments can introduce overhead, performance delays and signaling cost; these aspects require a carefully evaluation, and need to be compared with central approaches and other distributed mechanisms. The real number of overlays supported by a WMN, as well as, the QoS/QoE offered to a user, need also to be evaluated.

5 Conclusion

In this paper we proposed a novel architecture consisting of multiple overlays in order to integrate context in WMNs to optimize the user experience and promote multi-homing, attempting at the advantages of network virtualization. We introduced the key challenges that need to be addressed in order to integrate context in a multi-overlay context based virtual environment, as well as solutions to optimize user's mobility, and to organize the context and the virtual networks in this architecture.

In the future, we plan to evaluate the presented solutions and to compare them against other approaches, regarding overhead and signaling costs. Moreover, we plan to measure the real benefits of this architecture and its implementation cost. Finally, the mobility of the virtual mesh routers, multi-homing and multi-path support, efficient resource management and multi-domain environments are other topics that need further research.

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