ERCIM Scientific Report

Private Address Maps and Functional Composition

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1 Introduction

This document is the scientific report which covers my postdoctoral fellowship period from the 22nd August 2005 to the 21st May 2006. This 9-month fellowship was spent in the Autonomic Networking TechnologieS (ANTS) competence center at the Fraunhofer Institute FOKUS in Berlin, Germany.

I would like to take the opportunity to personally thank Mikhail Smirnov who has accepted to host me in the ANTS competence center during this ERCIM fellowship. I would also like to thank the members of ANTS for their kind welcome and technical collaboration. Finally, a special thank goes to Michael Kleis for all the fruitful discussions we had about the "brave new autonomic world".

2 Research summary

During this stay at Fraunhofer FOKUS, I concentrated my research efforts on two subjects. The first subject is related to *underlay networking*, i.e. an original networking framework that was initially proposed by Christian Tschudin at the University of Basel, Switzerland. During my stay in Berlin, I extended this framework with a concept known as "private address maps" (see section 2.1). This is the continuation of the work I carried out during the first half of my ERCIM fellowship at the University of Basel.

The second project is related to "autonomic networking", i.e. a novel research area in networking which has most of its roots at Fraunhofer FOKUS. In this recent research area I concentrated my efforts on "functional composition", a framework that is focused on the on-demand and dynamic formation of a chain of networking functions inside a network stack (or function pool). See section 2.2 for details.

2.1 Private address maps

The main goal of this work is to propose a radical solution to the address autoconfiguration problem of mobile ad hoc networks (MANETs). Our core assumption is that the current Internet-based networking model is not suitable to MANETs because such spontaneous networks are not topologically organised (with respect to addressing). That is, the Internet-like definition of an address does not fit to MANETs. Our counter current position is to remove addresses from the MANET networking model, leading to a networking model known as "routing by name" where a node identifier is directly mapped into a forwarding path without having to be first mapped into an address.

However today, existing applications and network systems largely operate in an *IP-by-default* mode and one cannot easily get rid of addresses. Hence, we propose that each network node maintains its own private address map of the network by locally choosing the addresses it wants to assign to its correspondents. This can be seen as an extreme use of network address translation (NAT) where the NAT functionality is activated in every node of a MANET. A key advantage of such an approach is that the nodes inside a MANET do not need to coordinate in order to allocate unique addresses. This radically solves a difficult problem in MANET networking. The concept of private address maps was implemented in Linux as part of the LUNARng protocol for MANETs.

2.2 Functional Composition

The design of the Internet is based on a thirty-years old layering approach which originaly aimed at factoring out functionality. However, critical networking concepts have slowly become *hard-wired* and the network layer has failed to scale in a functional way. That is, the place where the Internet has envisaged and endorsed functional scaling, that is the possibility to freely add arbitrary customized functionality, is the application layer. This is where remarkable breakthroughs have been achieved and variety was obtained (e.g. DNS, eMail, Web, VPN, VoIP and P2P). Clearly, the constraints imposed by the service decomposition of today's networks in somehow control-plane-hermetic layers restricts innovation and optimization to take place at the right place and at the right time.

In contrast, the new research field of "autonomic networking" is focused on systems that would inherently be dynamic and flexible. In a functional scaling perspective, the first trend is that current layered networking software needs to be *atomized* in a function pool (or soup), where smaller units (i.e. compartments or cells) can be recombined *on-demand* (i.e. upon requests). The second trend is that the networking functionalies that belonged to one layer beforehand will be used in the future at arbitrary places (in this new networking stack, or heap), requiring the introduction of autonomic organization principles. This concept, known as functional composition, is expected to exhibit the following properties:

- **Evolvability**: new network compartments can easily be added to the system, without the need to remove the previous instance(s) of the given functionality. That is, different versions of a compartment can co-exist, until older versions are totally superseeded by new instances.
- **Adaptability**: the interfacing scheme between modules should be flexible enough such that evolvability is not restricted by "API-like formalism". That is, compartments should dynamically learn what control-like data should be exchanged among them (there should be no static "function prototypes").
- **Variability**: for a given functionality (e.g. reliable transport), there can exist a rich palette of compartments specifically optimized for certain networking conditions or requirements (e.g. reliable transport for wireless links). This avoids the need of "one size fits all" compartments.
- **Self-healing properties** are already enforced by variability, i.e. when multiple compartments are available to fulfill a given task. In addition, distributed self-healing mechanisms should allow a node to *search* and *fetch* a given compartment among the public compartments advertised by its neighboring nodes.
- **Seamless collaboration**: a node should be able to use the public compartments provided by its neighboring nodes, without the need to run its own copy of the given compartment. This is the case for dedicated compartments that can only be run by special nodes (e.g. routing, file-sharing, access to specific hardware, etc).

During my stay at Frauhofer FOKUS, I have worked on a framework called OSCAR (On-demand Service Composition of Autonomic Resources), which was merely an attempt to understand the many issues introduced by functional composition. OSCAR was implemented in Linux.

3 Publications

- Christophe Jelger and Thomas Noel, "**Algorithms for Prefix Continuity in IPv6 Ad Hoc Networks**," to appear in *Ad Hoc & Sensor Wireless Networks* (journal), OCP Science, 2006.

  Abstract: Ad hoc networks are formed by the spontaneous collaboration of wireless nodes when no networking infrastructure is available. When communication to the Internet is desired, one or more nodes must act as gateways for the ad hoc network. In this case, global addressing of ad hoc nodes is required. This article presents and evaluates three algorithms which can be used by an ad hoc node to dynamically select a gateway and create an associated IPv6 global address. The core of our proposal is the concept of *prefix continuity*. By building and maintaining a forest of logical spanning trees, our proposal ensures that there exists, between a node A and its gateway G, a path of nodes such that each node on this path uses the same prefix P as the node A and its gateway G. This concept results in an organized ad hoc network, in the sense that sub-networks

(with respect to prefixes) are automatically created and dynamically maintained when multiple gateways are available. Moreover, the concept of prefix continuity ensures that each sub-network forms a connected graph of nodes which all use an identical prefix. In contrast to traditional wired networks, this feature is not trivial in ad hoc networks.

- Christophe Jelger and Christian Tschudin, "**Model Based Protocol Fusion for MANET-Internet Integration**," in *Proceedings of the 3rd Annual Conference on Wireless On demand Network Systems and Services (WONS'06)*, January 2006, Les Ménuires, France.

  Abstract: With the wide adoption of wireless communication technologies, the current networking design of the Internet architecture has shown some limitations. Restricted by inherent layering constraints, valuable networking information cannot flow freely inside the network stack and potential operational optimizations are impossible to achieve. To overcome these limitations, we extend the current trend of cross-layer approaches with a framework called *underlay protocol fusion*: the basic building blocks of Internet functionality are factorized out and merged in a function pool where information sharing and operational optimizations are performed.

  To illustrate our approach, we present LUNARng (LUNAR next generation). It is a fully distributed underlay protocol designed for the Internet integration of wireless ad hoc networks (MANETs) where fundamental services such as name resolution, address autoconfiguration, and IPv4/IPv6 routing are transparently available whether the MANET is connected or not to the Internet. Internet integration refers here to the ability to *insert/remove* a MANET *into/from* the logical organization of the Internet without any loss of functionality. Moreover by using *protocol models*, the underlay nature of LUNARng allows to optimally merge (with respect to the multihop nature of MANETs) network operations which are traditionally carried out at different layers of the protocol stack.

Submitted publication currently under review

- Christophe Jelger and Christian Tschudin, "**Private Address Maps (The Disappearing MANET Autoconf Problem)**," submitted in April 2006 to ACM Computer Communications Review (journal).

  Abstract: In this paper we propose a self-addressing framework for mobile ad hoc networks (MANETs) based on the degenerated use of network address translation (NAT) where each node builds its private "address map". In contrast to previous proposals, MANET nodes do not need to coordinate in order to generate unique (IP) addresses. This solves an important autoconfiguration problem for MANETs and fits well in cross-layering strategies for stub networks. We discuss the architectural impact of this approach in the bigger context of IP names, addresses and routability.

4 Conferences/workshops attended

- September 2005: 2nd IEEE COMSOC Conference on Sensor and Ad Hoc Communications and Networks (SECON'05), Santa Clara, CA, USA.
- January 2006: 3rd Annual Conference on Wireless On demand Network Systems and Services (WONS'06), Les Ménuires, France.