ERCIM Scientific Report

Prefix Continuity and Underlay Routing in Wireless Ad hoc Networks

by
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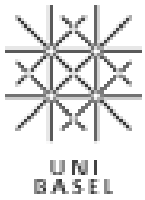

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1 Introduction

This document is the scientific report which covers my postdoctoral fellowship period from the 1st November 2005 to the 31st July 2006. This 9-month fellowship was spent at the University of Basel, Switzerland, in the Computer Networks Research Group headed by Pr. Christian Tschudin.

I would like to take the opportunity to warmly thank my collegues of the Computer Networks Research Group, Lidia Yamamoto, Christian Tschudin, and Evgeny Osipov, for their commitment, kindness, and enthusiasm. They have made my stay in Basel a fruitful and pleasant collaboration. More personally, I would like to thank Pr. Christian Tschudin who has accepted to host me in his research group during this ERCIM fellowship. Finally, I also give my best regards to all the members of the computer science department for their kind welcome.

2 Research summary

During this stay at the University of Basel, I concentrated my research efforts on two projects related to wireless ad hoc networking. The first subject is related to *prefix continuity*, i.e. an addressing concept that I started to develop with Thomas Noel during my PhD studies at the Louis Pasteur University in Strasbourg, France. The second project is related to LUNAR, i.e. an underlay routing protocol developed at the University of Basel.

2.1 Prefix continuity

The inherent nature of wireless ad hoc networks (MANETs) is that they do not rely on any existing infrastructure. In such networks, wireless nodes spontaneously collaborate to route packets among a multi-hop topology. Because nodes are free to move, the network faces unpredictable topological changes and thus routing becomes a challenging task. Moreover, in a spontaneous network which does not rely on any existing infrastructure, self-addressing of nodes is an essential functionality. In the mean time, it becomes clear that there is a growing interest in connecting MANETs to the Internet. In such hybrid ad hoc networks, one or more nodes act as gateways to the Internet: coherent addressing thus becomes essential, especially when multiple gateways and multiple network prefixes are available.

There has been a number of alternative proposals in order to support address autoconfiguration in traditional (i.e. autonomous) ad hoc networks. The main task of these schemes is to manage a pool of addresses, known as the *address space*. In short, the objectives of such protocols are to assign addresses to nodes, to handle network merging (e.g. the merging of two address spaces), and to react to address leaks (e.g. network partitioning). In contrast to autonomous networks, a hybrid ad hoc network has one or multiple connections to the Internet. The fact that such networks are connected to the Internet is a fundamental parameter and assumptions that hold for autonomous ad hoc networks do no longer apply. In particular, since a hybrid ad hoc network is *inserted* in the global routing system of the Internet, a logical *network-layer* organization of the network is desirable.

The concept of prefix continuity in a hybrid ad hoc network is the core element of our work. It ensures that there exists, between a node N and its gateway G, a path of nodes such that all nodes on this path use the same network prefix than G and N. Each subnetwork is thus a logical tree (with respect to the network layer) rooted at its gateway. When multiple gateways and multiple prefixes are available, a forest of (logical) trees is created and dynamically maintained as unpredictable topological changes occur. Figure 1 shows a hybrid ad hoc network with (a) and without (b) prefix continuity. There are 3 gateways, and each color corresponds to a given network prefix.

During my stay at the University of Basel, and in collaboration with Thomas Noel from the Louis Pasteur University (Strasbourg, France), I extended my original work (started during PhD) as follows:

- I proposed a new scheme to compute the 64-bits host part of an IPv6 address: the goal is to reduce the probability of an address collision when two nodes have the same MAC (EUI-48) address (see paper published in MedHocNet'05)
- I applied the concept of prefix continuity and IPv6 address autoconfiguration to

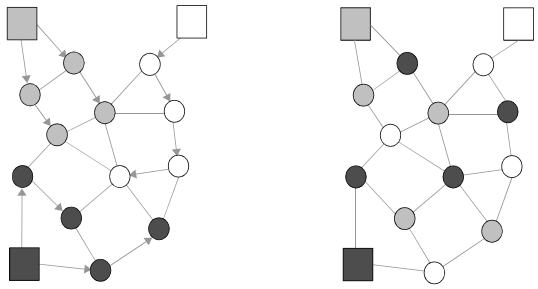

Figure 1: Ad hoc network with (a) and without (b) prefix continuity

LUNAR (see below)

- I applied the concept of prefix continuity to multicast routing (an article summarizing this work is currently being written)

2.2 LUNAR next generation (LUNARng)

The LUNAR (Lightweight Underlay Network Ad hoc Routing) protocol has originally been developed by Christian Tschudin at the University of Basel. This protocol positions itself between the IP and Ethernet layers, creating a subnet illusion in a MANET. The underlay nature of LUNAR leads to unique implementation benefits as LUNAR has full control on all the network traffic coming in and out of a node. In particular, the historical barriers between the somehow isolated protocols involved at the network layer (i.e. name resolution, link-layer address resolution, routing, address configuration) all disappear: LUNAR becomes a single entry point where all networking information flows.

During my stay at the University of Basel, and in close collaboration with Christian Tschudin, I extended the original LUNAR implementation with many new features. The new version, named LUNARng (LUNAR next generation), is a fully rewritten protocol which now supports the following features:

- IPv4 routing (as original version)
- IPv6 routing for link-local, MANET-local, and global addresses
- Name resolution (see paper published in ADHOC'05) for IPv4 and IPv6
- IPv6 address autoconfiguration - introduction of a new MANET-local prefix
- IPv6 address autoconfiguration for global scope addresses

- IPv6 Internet gatewaying (with prefix continuity - to be extended with multihoming features)
- Users directory (yellow-pages service): a feature which allows LUNAR users to proactively learn the presence of other users

3 Publications

- Christophe Jelger and Thomas Noel, "**Proactive Address Autoconfiguration and Prefix Continuity in IPv6 Hybrid Ad Hoc Networks**," to appear *in Proceedings of the 2nd IEEE COMSOC Conference on Sensor and Ad Hoc Communications and Networks (SECON'05)*, September 2005, Santa Clara, CA, USA.

  Abstract: In ad hoc networks (MANETs), wireless nodes spontaneously collaborate to route packets among a multi-hop and versatile topology. While such networks have originaly been considered as *autarkical* systems, it becomes clear that there is a growing interest in connecting them to the Internet. In such a *hybrid* ad hoc network, one or more nodes act as gateways to the *outside world*. This situation requires the use of a global addressing scheme in order to allow end-to-end communications between MANET nodes and correspondents in the Internet. In this paper, we present and evaluate an IPv6 address autoconfiguration protocol based on the original concept of *prefix continuity*. This feature ensures that there exists, between a node N and its gateway G, a path of nodes such that all nodes on this path use the same IPv6 prefix than N and G. As a result, all the nodes of a given sub-network form a logical tree rooted at the sub-network's gateway, and in which all nodes share an identical IPv6 prefix. In a multiple-gateways and multiple-prefixes environment, our protocol proactively and dynamically reacts to topological changes in order to maintain the prefix continuity of each sub-network.

- Christophe Jelger and Thomas Noel, "**Prefix Continuity and Global Address Autoconfiguration in IPv6 Ad Hoc Networks**," *in Proceedings of the 4th Mediterranean Ad Hoc Networking Workshop (MedHocNet'05)*, June 2005, Porquerolles, France.

  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, "**Underlay Fusion of DNS, ARP/ND, and Path Resolution in MANETs**," *in Proceedings of the 5th Scandinavian Workshop on Wireless Ad-hoc Networks (ADHOC'05)*, May 2005, Stockholm, Sweden.

Abstract: Name resolution is a key pillar of the fixed Internet: Without the existing distributed hierarchical infrastructure of name servers, neither eMail (MX records) nor web browsing (all links are expressed with logical names) would be possible anymore. A DNS substitute has to be provided for MANETs which permits, both in isolated network mode as well as in the mesh network case, to use logical names at the application level. In this paper we present a backward compatible distributed and decentralized name resolution scheme for MANETs: The particularity of our scheme is that name resolution, address resolution (IPv4) or neighbor discovery (IPv6) as well as routing path establishment are merged in a single operation. Using the underlay approach of LUNAR we integrate DNS logic at layer 2.5 such that classic Internet applications as well as operating systems settings and libraries do not have to be modified.

Submitted publications currently under review

- Christophe Jelger and Thomas Noel, "**Prefix Continuity and Global Address Autoconfiguration in IPv6 Ad Hoc Networks**," *Special issue of the Ad Hoc & Sensor Wireless Networks journal*, selected publications of the 4th Mediterranean Ad Hoc Networking Workshop (MedHocNet'05).

  Abstract: Identical to article accepted at MedHocNet'05, since this is a special issue of selected papers of this workshop.

- Christophe Jelger and Christian Tschudin, "**An Underlay Approach for Layer Fusion**," *IEEE Communications Magazine Special Issue on Cross Layer Protocol Engineering For Wireless Mobile Networks.*

  Abstract: With the wide adoption of wireless communication technologies, the current networking design of the Internet architecture has shown its limitations. Restricted by inherent layering constraints, valuable networking information cannot freely flow inside the network stack and potential operational optimizations are thus impossible to achieve. To overcome these limitations, we extend the current trend of cross-layer approaches with a framework that we call layer fusion: the basic building blocks of current Internet networking are factorized out and merged in a function pool where information sharing and operational optimizations are performed. To illustrate our approach, we present a backward-compatible distributed and decentralized name resolution scheme for wireless ad hoc networks. The particularity of our scheme is that name resolution, link-layer address resolution, as well as routing path establishment are merged in a single operation. Using an underlay approach, we integrate DNS logic at layer 2.5 such that classic Internet applications as well as operating systems settings and libraries do not have to be modified.

4 Conferences/workshops attended

- May 2005: 5th Scandinavian Workshop on Wireless Ad-hoc Networks (ADHOC'05), Stockholm, Sweden.
- June 2005: 4th Mediterranean Ad Hoc Networking Workshop (MedHocNet'05), Porquerolles, France.
- September 2005 (planed): 2nd IEEE COMSOC Conference on Sensor and Ad Hoc Communications and Networks (SECON'05), Santa Clara, CA, USA.