Autoconfiguration and Self-management of Personal Area Networks: a New Framework

Third Year Report

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Abstract

During the third year of this PhD we had a major objective: to continue the improvement of and to evaluate the solution designed during the previous years, called ASPAN. In that sense, we have proposed a new spanning tree algorithm regarding the interconnection of devices within a PAN and have developed a new simulator for its evaluation and comparison with state of the art spanning tree algorithms. In addition, a proof-of-concept prototype has been created in order to have a real implementation of the ASPAN solution. Using this prototype we were able to evaluate the features and flaws of our solution. Also, a first set of simulations using NS-2 has been performed in order to become more familiar with new features incorporated in the NS-2 simulator. However, intensive simulations regarding further evaluation of the solution will only be carried out next year.

This document reports the activities developed along the third year of this PhD, mentions the deviations from the work plan, and justifies them. Additionally, it mentions the relevant contributions expected for this PhD, and the work plan for the next year, that will mostly focus on the final evaluation of the proposed solution and the writing of the PhD thesis.

Contents

Acronyms

AODV Ad-hoc On-demand Distance Vector

ARP Address Resolution Protocol

ASPAN Autoconfiguration and Self-management of Personal Area Networks

BGL Boost Graph Library

DHCP Dynamic Host Configuration Protocol

DYMO Dynamic MANET On-demand

FEUP Faculdade de Engenharia da Universidade do Porto

IEEE Institute of Electrical and Electronics Engineers

IETF Internet Engineering Task Force

INESC Porto Instituto de Engenharia e Sistemas de Computadores do Porto

IP Internet Protocol

LAN Local Area Network

MANET Mobile Ad-hoc NETwork

NAT Network Address Translation

NGNs Next Generation Networks

NS-2 Network Simulator 2

OLSR Optimized Link State Routing

PAN Personal Area Network

PDA Personal Digital Assistant

PhD Doctor of Philosophy

PoA Point of Attachment

UPnP Universal Plug and Play

UWB Ultra Wide Band

VoIP Voice over IP

WLAN Wireless LAN

WPAN Wireless PAN

1 Introduction

This section defines the scope in which this PhD fits in and presents the structure of the report.

1.1 Thesis Scope

Next Generation Networks (NGNs) will be characterized by a movement towards ubiquitous connectivity. This includes an increasing number of wireless and wired technologies, multi-homed devices, and mobility of networks and end-users. In this communication scenario, user intervention must be minimized and technology must seamlessly adapt to different networking contexts and user needs. The increasing number of devices expected to be carried by a person, combined with the integration of electronic devices having computing and communications capabilities within clothes, human environments, or even in the human body, will trigger the emergence of new computing environments and bring up new communication models; some of these devices will form cooperative networks, such as Personal Area Networks (PANs).

Small incipient cooperative networks, such as Bluetooth PANs, can already be created. However, they require manual configurations and networking expertise. Also, Bluetooth does not provide mechanisms to adapt automatically to scenarios where, for instance, a PAN is changing its point of attachment (PoA) to the Internet dynamically; other solutions, e.g., IEEE 802.15.4 and WiMedia Ultra Wide Band (UWB), are proposed for creating PANs but they care only about creating PANs at the data link layer. The deployment of Mobile Ad-hoc Networks (also known as MANETs), where PANs are included, in a self-organized and spontaneous way has been a hot research topic during the last decade. However, the proposed solutions have been mostly based on routing protocols that work over IP. This has led to the definition of new protocols or the adaptation of legacy protocols regarding address autoconfiguration, for instance. On the other hand, protocols and solutions developed targeting local environments do not work directly over such networks, e.g., service announcement protocols, which also requires new or adapted solutions to be released.

It becomes consensual that IP will be the base protocol for NGNs; Internet will play a central role, supporting multimedia data and services, such as web browsing, e-mail, VoIP and video-conferencing, and will be the network to which most of the devices need to be connected. In addition, the convergence towards an all-Ethernet world, namely in the personal and local area domains will ease the deployment of new solutions, the transparent operation of legacy protocols designed to operate over Ethernet-like links, e.g., Dynamic Host Configuration Protocol (DHCP), Universal Plug and Play (UPnP), Address Resolution Protocol (ARP), and the easy integration

at the link layer of so far apparently heterogeneous technologies, such as Bluetooth, Wireless LAN (WLAN), and Ultra Wide Band(UWB). Therefore, the new communication paradigm, namely in the personal and local scopes, will most probably be based on an IP over Ethernet paradigm.

On the other hand, IP networks are becoming heterogeneous; different protocol suites operate simultaneously (IPv4, IPv6), and multiple addressing schemes (private IPv4, public IPv4, IPv6) and autoconfiguration mechanisms coexist. Also, with the advent of new communication paradigms where entire networks connect to the Internet while moving around, new autoconfiguration mechanisms, apart from those already defined in IP networks (e.g., DHCP), may be required. In this context, enabling the automatic and dynamic creation of PANs, and dealing with its dynamic and automatic connection to the global Internet poses new requirements to mobile communication systems, particularly in terms of autoconfiguration and self-management.

The aspects aforementioned characterize the scope of this PhD thesis. They identify a future communication world where users will carry entire networks (PANs) that will be formed by different devices interconnected by "heterogeneous" wired/wireless communication technologies. These networks will continuously be connected to the global Internet using the best point of attachment, will be based on an IP over Ethernet paradigm, and will run using different IP versions and multiple autoconfiguration mechanisms.

1.2 Structure of the Report

This report is organized in four sections. Section 2 provides an overview of the proposed solution and presents the relevant contributions expected for this PhD. Section 3 provides the work plan for the third year, the actual activities developed, and mentions and justifies the mismatches. Section 4 specifies the work plan for the next year and, finally, Section 5 draws the conclusions.

2 Overview of the Proposed Solution

In this PhD we provide a new framework, the Autoconfiguration and Self-management of Personal Area Networks (ASPAN), taking into account the scope defined in Section 1.1. The design and specification of the ASPAN solution takes as a fundamental principle the easy migration from legacy networks. Therefore, two basic requirements drive its design and specification: 1) whenever possible use legacy mechanisms; 2) introduce no modifications to the data plane. By following this approach we expect to deploy our solution easily using legacy devices.

The ASPAN framework follows a master-slave model where a central device controls all mechanisms regarding the PAN internal organization and its connection to the Internet. From the internal point of view, the framework considers bridging as the mechanism for interconnecting PAN devices; standard IEEE 802.1D bridges and the corresponding learning bridge algorithm together with a new spanning tree algorithm, called Campos's Algorithm, are considered. This basically explores the fact that at the personal and local domains an all-Ethernet world is becoming a reality. In order to deal with the heterogeneities within IP networks, ASPAN defines a mechanism for negotiating the proper IP version and autoconfiguration mechanism to be used within a PAN when different types of PAN devices (i.e., IPv4-only, IPv6-only, dual stack) come together to form the network. From the external connectivity point of view, ASPAN deals with the connection of the PAN to the Internet through the best access network according to user-defined policies; it also copes with the required configurations to enable that, for instance, selection of the proper IP version and autoconfiguration mechanism to be used within the PAN regarding the selected access network.

The following relevant contributions are expected to be provided by this PhD:

1. **PAN Bootstrapping and Management Mechanism**. This mechanism deals with the election of a master device, topology discovery, configuration of the PAN active topology, and the selection of the proper network layer to be used regarding the heterogeneities coming up from the two IP versions and multiple autoconfiguration frameworks coexisting in IP networks; additionally, it deals with the joining/leaving of PAN devices while the PAN is up and running. The configuration of intra-PAN connectivity is based on IEEE 802.1D bridges that allow the interconnection of PAN devices supporting different wired/wireless technologies, such as WLAN, Bluetooth, Ethernet, and WiMedia UWB. The major advantages of this mechanism are: 1) transparent support of legacy IP autoconfiguration mechanisms (e.g., DHCP) in multi-hop scenarios; 2) adaptation of the PAN topology according to the user context/preferences.

2. **Spanning Tree Algorithm (Campos's Algorithm)**. The Campos's algorithm deals with the computation of an approximate Minimum Routing Cost Tree (MRCT). By combining different approaches followed by state of the art algorithms, such as Prim's, Kruskal's, and Dijkstra's algorithms, it represents a new algorithm addressing the MRCT problem. It is only expected to be applied to small networks/graphs.

3. **Centralized mechanism for selecting the best PointOfAttachment towards the Internet based on user policies/network context**. Currently, the automatic and dynamic selection of the best PointOfAttachment towards the Internet is possible in stand-alone terminals, such as laptops, by means of internal policies of the operating system. Our mechanism extends this to the context of networks (e.g., PANs) and considers its selection based on user-defined policies. It includes the execution of the procedures needed to reconfigure a PAN when it changes its PoA, for instance, the reconfiguration of resources (configuration as IPv4 router or as a bridge) and services (NAT, DHCP) in each device. Our mechanism follows a centralized approach deemed more suitable for PANs from our standpoint.

3 Activities Performed During Third Year

This section describes the activities performed along the third year and identifies the deviations from the work planned and the reasons for that.

3.1 Activities Performed

The following set of activities was carried out along the third year:

1. Theoretical comparison between Minimum Spanning Tree (MST) and Shortest Path Spanning Trees (SPTs) algorithms.
2. Set of simulations using NS-2 in order to become familiar with multi-interface devices within the NS-2 framework.
    - Add-ons to the base NS-2 code regarding the deployment of IEEE 802.11 multi-interface devices over NS-2.
3. Performance comparison between single active spanning tree and multiple active spanning trees topologies by simulating some scenarios over NS-2.
4. Development of a new ranDOm graphs SimulatOr (DOSO) regarding the comparison of two well-known spanning tree algorithms, MST and SPT.
5. Further study of some spanning tree algorithms, namely Shortest Path Spanning Tree, Minimum Spanning Tree, and Minimum Routing Cost Tree.
6. Design of a new approximate MRCT algorithm, called Campos's algorithm, applied to small networks, such as Personal Area Networks.
7. Implementation and integration of a state of the art approximate MRCT algorithm (Add) and of the Campos's algorithm in the DOSO simulator.
8. Simulations using DOSO simulator in order to evaluate the Campos's algorithm against state of the art spanning tree algorithms.
9. Deployment of a proof-of-concept ASPAN prototype.
10. Writing of a paper concerning the publishment of the Campos's algorithm as a new approximate MRCT algorithm (ongoing work).

Taking into account that our goal at the beginning of the third year was to evaluate the ASPAN solution using simulations, and the NS-2 simulator in particular, we started by implementing some add-ons to the base NS-2

code regarding the simulation of multi-interface devices. Afterwards, we performed some simulations using a few specific scenarios in order to compare the performance of networks whose topology is defined by multiple spanning trees (typical network topology when routing is used) against networks whose active topology is defined by a single spanning tree (network topology when bridging is used), while considering the same number of nodes. The aim was to identify whether the difference in the routing cost was that significant, namely when the characteristics of the wired/wireless links differ a lot. This was performed after a theoretical comparison between the MST and SPT algorithms which lead us to conclude that when the links differ a lot there is a tendency to have similar routing costs regardless a single spanning tree (MST) or multiple shortest path trees (SPTs) are considered, as all SPTs tend to the MST.

Since the aforementioned analysis was very limited in terms of the number of different networks or graphs considered, we decided to develop a new random graphs simulator (DOSO) in order to perform a statistical and more complete comparative analysis of the two algorithms. DOSO has been implemented in C++ and uses the well known Boost Graph Library (BGL) which implements well known spanning tree algorithms, such as Dijkstra's and Kruskal's algorithms. After performing intensive simulations and studying further spanning tree algorithms we found the need to come up with a new spanning tree algorithm addressing the Minimum Routing Cost Tree (MRCT), which defines the best approximation to the solution with multiple spanning trees. The new algorithm intends to run faster than state of the art algorithms addressing the MRCT problem and provide approximate results better than the MST, in general. The new approximate MRCT algorithm, called Campos's algorithm, combines characteristics of different state of the art algorithms, such as Dijkstra's, Prim's and Add algorithms. In order to evaluate the Campos's algorithm we have implemented and integrated it in the DOSO simulator in order to perform a comprehensive comparison between our algorithm and state of the art spanning tree algorithms. The simulation results reveal that the Campos's algorithm is a good approximate MRCT namely regarding small networks. We are currently writing a paper so that the new proposed algorithm gets published as a new approximate MRCT algorithm.

Finally, we have deployed a proof-of-concept ASPAN prototype that has been implemented in the context of a final year project at Faculty of Engineering of the University of Porto (FEUP). The current prototype allowed us to conclude about some of the features and flaws of our solution and has allowed another kind of evaluation that complements the evaluation performed by using simulations.

3.2 Deviations from the Work Planned

The actual activities developed along the third year were not the same activities planned at the beginning of the year. The different direction followed along the year had mainly to do with the deep exploration of spanning trees and the need found along the work to compare the single spanning tree and multiple spanning tree approaches as well as the need to come up with a new spanning tree that approximates the MRCT problem faster. Furthermore, we found the need to have a proof-of-concept prototype so that we could complementary evaluate the ASPAN solution. Due to the focusing into the spanning tree issues we had to postpone the evaluation of the ASPAN solution using simulations to the next period before we start the writing of the PhD thesis. Nevertheless, it must be said that the kind of evaluation accomplished using the ASPAN prototype and the proposal of a new approximate MRCT represent valuable work in the context of this PhD thesis. In fact, on the one hand, we actually evaluated the ASPAN solution using a different mean – a proof-of-concept prototype – and, on the other hand, have come up with a new relevant contribution that enhances the contribution of this PhD as a whole. The work planned for the third year will be partly carried out during the next period, as we described in Section 4. The remaining part will be left for future work.

4 Work Plan for Fourth Year

This section presents the work plan for the next year. The work plan includes two major tasks that will be performed in parallel. On the one hand, we will start the writing of the PhD thesis. On the other hand, we will finish the evaluation of the ASPAN solution, namely regarding PAN internal issues. We will consider a set of simulations in order to evaluate the PAN Bootstrapping and Management mechanism including: the master election and topology discovery, configuration of active topology, and the joining/leaving of PAN devices. The solution will be evaluated concerning some parameters, such as: signalling overhead, user data throughput, and time to adapt to changes in PAN topology; a comparison with related solutions, namely ad-hoc routing protocols (AODV/DYMO, OLSR) will be performed. Further evaluations of the ASPAN solution will be performed based on the existing prototype.

5 Conclusion

This document reported the activities performed along the third year of this PhD, the deviations from the plan, and the reasons for that. In addition, it provided the scope in which this PhD fits in, described briefly our proposed solution, and pointed out the relevant contributions expected for this PhD. Finally, the work plan for the next year was described.

We may say that in general the objectives for the third year of the PhD were fulfilled. In spite of not following strictly the work plan defined at the begining, we came up with enhancements to the proposed solution and have identified a new relevant contribution that enhances the contribution of this PhD as a whole. Furthermore, new work that was not planned and that contributes to improve the quality of this PhD was performed, namely the development of a new simulator regarding the evaluation of a new proposed spanning tree algorithm (Campos's algorithm) and a proof-of-concept prototype. In the next period, we will continue the evaluation of the solution by means of simulations. The new findings and results are expected to be disseminated through publications. The remaining part of the final year will be devoted to the writing of the PhD thesis.

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