Multi-Agent based Reinforcement Learning for Dynamic Resource Allocation in Next Generation Virtual Networks

Author: Rashid Mijumbi. Thesis Advisors: Joan Serrat and Juan-Luis Gorricho

Contact email: rashid@tsc.upc.edu, serrat@tsc.upc.edu, juanluis@entel.upc.edu

I. Introduction

The Internet is ossified. However, the demands of the users continue to increase such that resource and protocol stack specialization is a must for service providers. However, it would be economically unfeasible for each service provider to deploy physical resources for each service context.

Network Virtualization – which enables the building of multiple virtual networks over a shared physical network – has recently received attention from both academia and industry. One of the challenges to Virtualization is efficient resource allocation. Even in the offline case where all the requirements of the different Virtual Networks are known, this problem is NP hard, such that its optimization is computationally intractable. For this reason, most solutions to this problem have not only been based on heuristics, but have also made many simplifying assumptions such as availability of unbounded resources in the substrate network. In this paper, we propose to apply techniques from Artificial Intelligence to the resource allocation problem. Our objective is to propose a solution that is dynamic and online (including topology optimization); to allow for cooperation and negotiation between substrate and virtual networks; and to achieve a distributed and context aware resource management solution. In general, our ideal solution is an Autonomic Management of the Substrate Resources, implying that the networks are self-configuring, self-optimizing, self-healing and context aware.

II. Proposed Solution

To achieve the objectives of our work, our proposal is to apply Reinforcement Learning and Multi-Agent Systems to the resource allocation problem. Our idea is to represent each of the networks by an intelligent agent. Each agent that represents a virtual network is responsible for customizing its resources to the needs of its users while at the same time minimizing the costs incurred in using the substrate resources. Each of these agents has independent objectives. Similarly, each of the physical networks is represented by an intelligent agent whose main objective is to ensure that the overall resources are efficiently used. In the end, our proposal is for the different agents to not only learn from the decisions they make, but also to cooperate and negotiate with each other so as to achieve both local level as well as system level objectives.

In Fig. 1, we present a scenario of our proposed solution. While in this figure we represent two virtual networks sharing resources of a single network, our ultimate solution will be a general one with many virtual networks, and possibly many substrate networks.

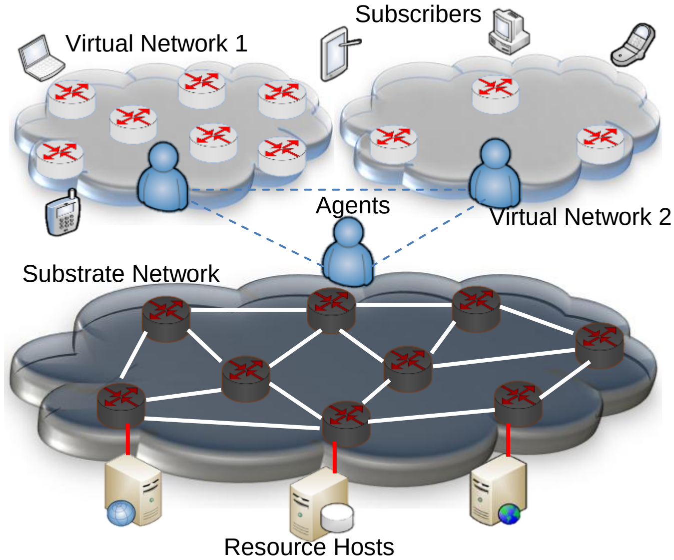

Fig. 1: Virtual Network Environment Proposed Framework

With this representation, some of the objectives of our work can be achieved as follows:

I) *Self-Configuration:* As users make requests for resources, the virtual network agents continuously evaluate their network topologies searching for possibilities of re-configuration. Whenever they find these possibilities, they can make requests for this to the substrate agents. Virtual network agents can also negotiate and cooperate amongst themselves so as to agree on the usage of substrate resources and achieve the best utility both on individual and system levels.

II) *Self-Optimization:* As the conditions of the substrate network change, substrate agents should exhibit proactive as well as reactive characteristics. For example, if a physical node and/or link is added to the network, or if their capacities are changed, the substrate agent should re-evaluate the network loadings to establish possibilities for re-allocation of resources. While this would ideally not require any action on the part of the agents, in our solution we require that these agents always look out for possibilities of optimizing their resource usage whenever there are changes to the substrate network.

III) *Self-Healing:* If for any reason a node and/or link becomes unavailable, the substrate agent – in collaboration with virtual network agents – should make decisions so as to cause the minimal possible disruptions in customer service. This situation is different from II) in a way that while self-optimization is mainly aimed at optimizing costs, and possible improvements in customer service levels, self-healing is much more urgent as in such cases there are possibilities of violating agreements with customers. Therefore, if the virtual network agents have to cooperate and/or negotiate in one of these two cases, an agent will adjust its objectives considering the possible conflict between utility optimisation and customer satisfaction.

IV) Context Awareness: The above three cases generally consider context awareness with respect to the network. However, we also require user context awareness. For example, with respect to a mobile virtual network, whenever users are connected to the network, they will send periodic updates about their location. Based on these locations, virtual agents will determine not only the exact location of the customer, but may also reason about the actual state of the user, for example; the agent can know if a user is walking, driving or stationary. Based on this user context information, the virtual network may take decisions about the resources being used by the user. For example, a user whose location is near a Wi-Fi hot spot **AND** this user is stationary **AND** this user is occupying a high bandwidth – say for a video on demand service – could be offloaded to the Wi-Fi and if there are necessary changes to the nodes for this specific customer, these changes can be effected by substrate agent.

III. Innovativeness and Contributions

The demands of users towards service providers continue to be conflicting in a way that they require better quality and highly customized services, but are only willing to pay less. It is inevitable that service providers have to specialize smaller quantities of resources so as to meet the diverse user needs. However, meeting users' price requirements and still remaining profitable means that service providers cannot feasibly deploy specialized physical resources for each user group or business context. For this reason, Network virtualization is very important as an enabling solution to this impasse. In fact, especially on the mobile front, as of May 2011 there were 645 virtual network operators worldwide, and 205 of these had become operation in one year [1].

Efficient Resource Allocation is one of the practical challenges to network virtualization. Most of the current approaches make some assumptions – such as unbounded resources – which cannot be achieved practically. While these could give solutions to specific instances of this problem, the possibility to make improvements is a major motivation of this work. Our work involves making the resource allocation task autonomic, which is a vital characteristic especially considering the complexity of current and future networks.

By the end of this work, we will have a dynamic resource allocation algorithm based on reinforcement learning. A solution based on Reinforcement Learning allows for incorporation into our proposal, economic costs to enable not only projects in the area of pricing for substrate network resources, but also practical development of resource pricing models between infrastructure providers and service providers.

Our proposed consideration of network and users' context will not only enhance decision making and hence improve resource utilization efficiency but would also help service providers in enhancing customers Quality of Experience.

We will also propose a Cooperation framework for the multi-agent system that represents the different networks. To this end, a Negotiation protocol based on network and user context will be proposed. This would allow for the coordinated and profitable use of resources whenever it is applicable.

IV. Acknowledgments

This work has been started within the project TEC2009-14598-C02-02 granted by the MEC Spanish Ministry and partially funded with FEDER funding. We also acknowledge the EVANS EU project funded under contract PIRSES-GA-2010-269323.

V. References

[1] The MVNO Directory 2011, Mobile virtual network operators and major resellers (5th Edition), Blycroft Ltd, May 2011.