A Note on Federation Management: Autonomic Resource Allocation with Economic-enhanced Agents

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***Abstract*—In this paper, we propose an economic and management framework for autonomic resource allocation in federations. In the proposed approach resource allocation is based on a long-run cost-based pricing scheme. A significant consideration of the proposed approach is that resource sharing among federated domains exhibits substantial externalities or spillovers since decisions on resource levels made by a single domain affect all other network domains and their users. Then, we propose an integrated management framework based on economic-enhanced agents for implementing the proposed economic model.**

Keywords-Cost-based Netwotk pricing; Resource Management; Autonomic Networking; Federation Management; Network Externalities

I. INTRODUCTION

A. Background and Motivation

The dynamic, distributed, scalable and rapidly changing nature of networks has made the manual administration and management of the existing and next-generation networks relatively inefficient. Ideally, network management such as fault, configuration, security, performance and accounting management should be performed in an autonomic and self-managed manner in order to address the increasing complexity of today's networking systems.

The idea of autonomic networking and particularly the idea of self-optimization and self-configuration could be applied in network federations.

A network federation is a group of individual network domains having a common objective. If federation's overall objective was to allocate its network resources (e.g. bandwidth) in an efficient manner that maximizes its total welfare in terms of performance and cost, then two prerequisites would have to be met: (i) to maximize the sum of users' utilities from resource consumption; and (ii) to minimize federation's overall cost.

Thus, the only requirement for transforming a group of individual domains into a self-optimized (and self-configured) network federation could be the adoption of a common economic approach (and a common management framework).

From an economic perspective, the main idea behind federated network domains is cost minimization through resource sharing since network infrastructure tends to be very expensive. Resource sharing in network federation management faces two main challenges: (i) to automate resource allocation in order to efficiently manage large-scale federations; and (ii) to provide a uniform user interface or API over heterogeneous network infrastructures.

Although, several economic-based approaches have been proposed for addressing resource allocation problems in the field of networking, there is a lack of modeling when resource sharing comes into play. In particular, resource sharing among federated network domains implies substantial positive externalities or spillovers since decisions on resource levels made by a single network domain affect all other federated network domains and their users' performance. In that sense, resource allocation in network federations has been left unmodeled.

In this paper, we will investigate the role of resource sharing and the subsequent network externalities in federations' economic modeling. Moreover, the automation of the resource allocation process will be based on efficient long-run incremental cost (LRIC) approaches implemented by software agents.

Cost-based pricing is combined with a competitive framework, since the enforcement of competitive pricing schemes decentralizes the allocation process and leads federation to a stable self-optimized state that nobody has economic incentives to depart from.

Yet another issue is the enforcement of the proposed economic approach across different federated units using heterogeneous networking technologies. Therefore, we consider an integrated network management approach for implementing the proposed approach based on a policy-based framework with dynamic SLA provision.

B. Related Work

The employment of pricing schemes has been proposed by the research community as the preferred solution for the analysis of resource allocation problems in TCP/IP networks [1-3]. The hope is that the same idea could be employed in network federation management and that prices can be used as control signals to efficiently match users' requirements with the offered resources, thus leading to optimization of network federation efficiency.

Recently, long-run incremental costing (LRIC) methods have been proposed as the dominant methodology for estimating cost of network elements and services and setting efficient charges. LRIC has been primarily adopted to address the problem of inefficient pricing in the short-run, where large sunk costs lead to almost zero marginal charges. Moving to long-run, large costs (mainly capital costs) are considered variable and cost-based pricing is more efficient [4, 5].

A main issue in building LRIC schemes is what increments of output should be estimated. Studies reported in [6, 7] have implemented Total Service Long Run Incremental Cost (TSLRIC) and Total Element Long Run Incremental Cost (TELRIC), using services and network elements respectively as the main objects for applying LRIC. Long-run economic modelling and the role of externalities in the production of QoS-based network services have been investigated in a work reported in [8] for the analysis of traffic growth. However, long-run economic analysis and the role of externalities or spillovers in economic process has been initially explored in the economic literature, in works reported in [9, 10].

The key to aligning economic models with resource allocation is to define and implement a set of policies that enforce specific policy actions. Policies and Policy-Based Network Management (PBNM) have been the subject of great research over the last years. Policies are a set of rules to administer and manage access to network resources [11].

Autonomic networking has been proposed to be the preferred approach to address the problem of self-organization of complex networking systems. Although there are several works addressing the architectural issues of autonomic networking [12-14], there is a lack in research in addressing both economic and management issues related to self-optimizing and self-configuring aspects of networking environments.

Finally, the mathematical modeling of various economic problems has been extensively presented in the work of H. Varian, reported in [15].

C. Contribution and Paper Outline

The original contributions of this paper are in two areas: (1) the employment of a long run incremental cost (LRIC) approach with externalities for efficient allocation of resources in federations; and (2) the development of an integrated architecture that implements the proposed economic model based on economic-enhanced agents.

The remainder of the paper is organized as follows: in Sec. II we setup the cost-based model and find the marginal cost which in competition equals to equilibrium price. In Sec. III we propose the integrated agent-based and policy-based framework for resource management and finally we conclude the paper in Sec. IV.

II. THE ECONOMIC MODEL

We consider a network federation that consists of a set D of independent network domains and that each domain is managed by a resource operator which produces and sells the required resources for each network service. We assume that resources are offered in an unbundled manner and that there is no explicit agreement between individual domains other than to enforce long-run incremental cost (LRIC) pricing.

Suppose also that the only asset in our federation is something we call K. You may want to think of K as being network physical capital but it may also include other inputs as well such as human capital (e.g. knowledge or skills). Physical capital includes terminal equipment, local loop, switching/routing and long lines.

Now imagine that the production function of our federation takes the form:

$$Y = Af(K)$$

As it is mentioned, there is one aggregate input: K, which can be measured in terms of physical and human capital units needed to produce a certain amount of a resource. A, is the network management technology that is used to transform network capital into network resources and assumed to be constant. Y is the amount of the resource produced (e.g. bandwidth). Finally, a market exist on which individual federated domains sell resources to users or other domains. The quantities demanded and supplied determine the relative prices.

Due to high degree of infrastructure sharing in federated networks, network capital is shared between individual federated units. Let $\widetilde{K} = \sum_{i=1}^{m} K_i$ be the aggregate shared federation capital which is shared between all m federated units and let $\widetilde{\kappa} = \widetilde{K}/m$, be the average shared federation capital.

In competition and in large-scale federations, each resource provider is too small to influence aggregate (and thus average) variables. That is, in a competitive economy, federated units do not think they can affect the average (shared) federation capital and take it as given. This can be formulated through production externalities or spillovers: each individual unit's decision on network capital levels affects all other federated units output, but none of them takes this into account.

Therefore, the average federation capital can not be internalized by individual federated units in a decentralized competitive market. Thus, each federated unit considers $\tilde{\kappa}$ as given.

Thus, finally, the production function of each individual federated unit is a function of both its own network capital K and the average federation (shared) capital, $\tilde{\kappa}$.

The production function, therefore, of each individual domain i has the following form:

$$y_i(K) = AK_i^{\varphi}\tilde{\kappa}^{\psi} \tag{2.1}$$

where, A reflects the level of network resource management technology, which is assumed to be constant. $\tilde{\kappa}^{\psi}$ represents the input to the production function from average shared federation capital, and φ, ψ are the production elasticities of K_i, $\tilde{\kappa}$ respectively, where $\varphi + \psi = 1$, since we assume that the production function is Constant Returns of Scale (CRS) at resource provider's level. That is if we multiply K_i, $\tilde{\kappa}$ by $\lambda > 1$ we will get λ times as much output. Suppose also that $\varphi, \psi < 1$, since we assume that the production function is Decreasing Returns (DR) to physical capital and to average shared federation capital alone. That is, if, for instance, we double K_i then y_i is less than doubled.

A significant consideration of this model is that any increase in individual unit's network capital, increases all other units' output (under relation 2.1) since it increases average network capital. This increase is in excess of benefits reaped directly from each individual federated unit network capital increase. This effect can be formulated through network externalities or spillovers: each federated unit's decision on his individual network capital levels affects all other units' output.

In the long-run individual K_i is increased with respect to time whereas $\tilde{\kappa}$ is assumed to be fixed, since, as we mentioned, the individual federated units do not think they can affect the aggregate and thus the average (shared) federation capital and take it as given. The implication of such a consideration is that each federated unit, when minimizing its cost function, take derivatives with respect to K_i only; not with respect to $\tilde{\kappa}$, since $\tilde{\kappa}$ is assumed fixed.

We assume that time is divided into intervals of length $\overline{T}$ and total cost is defined over $\overline{T}$, in order to correctly match supply with demand decisions that we assume that are made over allocation periods $k\overline{T}, \quad k = 1,2,...$

Let wK be federated unit's long-run additional cost over the allocation period $\overline{T}$ due to network capital increase, where w is the cost per unit of K_i. Then, each federated unit solves the following problem:

$$\min C(w, K_i) = wK_i \tag{2.2}$$

such that

$$f(K_i) = y_i = AK_i^{\varphi}\tilde{\kappa}^{\psi} \tag{2.3}$$

Solving (2.3) for K_i, we have $K_i = (y_i A^{-1}\tilde{\kappa}^{-\psi})^{\frac{1}{\varphi}}$ and inserting in (2.2) we have:

$$C_i(w, y_i) = w(y_i A^{-1}\tilde{\kappa}^{-\psi})^{\frac{1}{\varphi}} \tag{2.4}$$

The marginal or long-run incremental cost is the following:

$$MC_i = \frac{w}{\varphi}\left(A^{-1}\tilde{\kappa}^{-\psi}\right)^{\frac{1}{\varphi}} y_i^{\frac{1-\varphi}{\varphi}} \tag{2.5}$$

In equilibrium, marginal revenue equals marginal cost and since in competition marginal revenue equals price, we have the supply function of each federated unit:

$$y_i(p, w) = \left[A\tilde{\kappa}^{\psi}\left(p\varphi w^{-1}\right)^{\varphi}\right]^{\frac{1}{1-\varphi}} \tag{2.6}$$

Then, the federation aggregate resource supply function and inverse supply function are derived:

$$Y(p, w) = m\left[A\tilde{\kappa}^{\psi}\left(p\varphi w^{-1}\right)^{\varphi}\right]^{\frac{1}{1-\varphi}} \tag{2.7}$$

$$p = w\varphi^{-1}\left(A\tilde{\kappa}^{-\psi}(Ym^{-1})^{1-\varphi}\right)^{\frac{1}{\varphi}} \tag{2.8}$$

where m is the number of federated units. We notice that the equilibrium price decreases as the average federation network capital, $\tilde{\kappa}$, increases, fact that should be attributed to higher degree of infrastructure sharing.

Moreover, we assume that there is a demand function which has resulted from a maximization process based on historical data of federated domains as well as users' preferences on resource consumption, income and resources' demand elasticities.

Alternatively, the demand function could have resulted from an optimization process that specifies the relation between end-to-end performance objectives (QoS-based guarantees) and network resources.

Regardless of which approach is used to determine federation's demand, we suppose that the federation demand function is linear, $D(p) = a - bp$ and thus the equilibrium price is the solution to:

$$a - bp = m\left[A\tilde{\kappa}^{\psi}\left(p\varphi w^{-1}\right)^{\varphi}\right]^{\frac{1}{1-\varphi}} \tag{2.9}$$

Also, it is worth mentioning, that this model finds the competitive, not the social optimum. The social optimum would be the case if there was an explicit agreement between federated units on a central authority which would take economic decisions on behalf of all individual federated units. That is the case of a 'social planner' who takes into account the production externalities in federation networking. The case of 'social planner' in federation management will be addressed in another paper.

III. MODEL SETUP

A. Management Architecture

Our approach to developing an architectural framework for implementing the proposed economic model, builds on Policy-Based Network Management (PBNM) framework.

The typical PBNM architecture consists of four structural elements as depicted in figure 1:

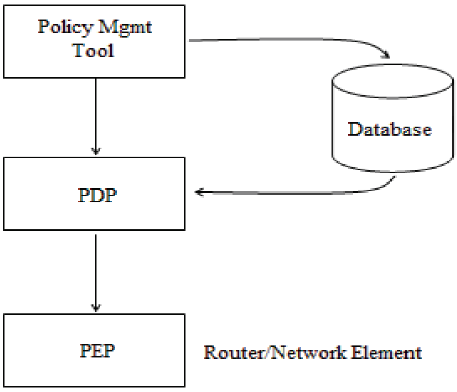

Figure 1. Policy-based management framework

- A policy management tool, which provides the user interface for creating, editing and verifying policies
- A policy repository for storing, searching and recovering policies
- A Policy Decision Point (PDP), for taking admission and configuration decisions, translating policies from Policy Information Base (PIB) to an understandable form from PEP.
- A Policy Enforcement Point (PEP), which applies policies to network elements.

Policy-based management defines a framework for applying economic and business rules, but it does not address the problem of configuring PEPs automatically, especially when PEPs use different communication protocols.

In order to provide a homogeneous interface over heterogeneous network components, research community has proposed proxy agents that function like gateways, performing the translation between heterogeneous protocols and thus providing a uniform interface or API to users or other applications.

Our management platform uses a request-response paradigm whereby clients send requests to servers, servers process the request, and replies are sent back to the clients. The types of requests that a client may send are determined by the server, and are defined in some definition language.

In the proposed management framework, a federation management system is a specific-client and the economic-enhanced agent is the specific-server. The communication between the user and the agent may be accomplished by using various mechanisms supported, although the preferred solution is the Extensible Mark-up Language (XML).

Data models can be defined as interfaces and management functions are accomplished using invocation of object operations. Hence, a uniform interface for interaction with heterogeneous management platforms can be provided to users. The interoperability with existing schemes is accomplished with proxy agents. A proxy agent, which is part of the economic-enhanced agent, performs the translation between policies and protocol operations. Using proxy schemes, the model can integrate different federated platforms under a uniform umbrella.

The economic-enhanced agents use XML for communicating with the user-console (i.e. manager). An XML-manager can be implemented as an object downloaded from an HTTP server. This permits the implementation of a graphical management interface that is downloaded from an HTTP server and viewed via a WWW browser. The XML-object acts as XML-client that negotiates the agreement with the user (e.g. SLA) and then communicates with the economic-enhanced agent using XML.

As depicted in figure 2, our enhanced policy-based approach includes four main structural elements:

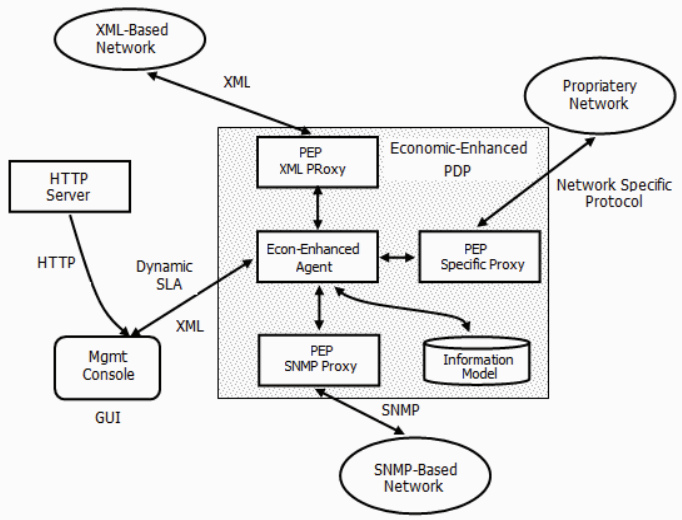

Figure 2. Economic-Enhanced Agent

- **The Graphical User Interface (GUI):** A GUI object is an object received by the user console using HTTP. Then, it establishes a connection with an economic-enhanced agent by using XML/SOAP. The user entity creates and edits dynamic (i.e. on demand) SLAs or SLSs.
- **The Economic-Enhanced PDP:** Economic-enhanced PDP implements the economic model and the communication with PEPs. In particular, the economic-enhanced PDP: (i) offers services to user management consoles through its API; (ii) manages PEP-Proxies and thus manages (i.e. configures) PEPs, since PEP-Proxies act like gateways to PEPs; (iii) implements the proposed economic model; and (iv) manages the corresponding data model resided in Repositories and thus maps the output of the proposed model to specific policies in order to be implemented by the proxies. Each economic-enhanced PDP manages a unique federated domain.
- **The Information Model**: We assume that there is a corresponding information model that reflects the proposed economic approach. Some elements of the information model are presented in the following section but the detailed definition of the information model is not addressed in this paper.
- **PEP-Proxies**: Policy Enforcement Point Proxies are objects residing in PDPs, interfacing real PEPs (e.g. routers). A PEP-proxy manages the communication between PDPs and PEPs by mapping the Information Model expressed in XML to specific PEP protocols (SNMP, proprietary protocols, etc). XML-based protocols for network element configuration are already in use (e.g. Cisco NETCONF).

The economic-enhanced agents between federated domains can also cooperate with each other using the XML protocol in order to manage the whole network. This cooperation is based on specific network managed object interfaces that one agent can provide to others. This allows the construction of a distributed network management architecture where economic-enhanced agents can provide management services to other agents and act as manager to agents of other management platforms. That way SLA-chains could be provided for managing inter-domain SLAs.

A Root Agent (RA) which is an economic-based agent resided in a hierarchically upper level is also needed, The Root Agent is aware of the number of individual federated units, aggregates the individual domains' supply functions as well as the demand functions and finds the competitive price. This price is the competitive price of the federation market which is, then, published and distributed to domain agents.

B. Elements of the Information Model

The data model represents the proposed economic model by adopting special interfaces with specific economic attributes and services that are described in the proposed approach. Based on those services, users can create, update and delete SLAs. More precisely, two forms of SLAs are considered: (i) Local SLAs (i.e. intra-domain SLAs); and (ii) SLA-chain (i.e. inter-domain SLAs), which correspond to two types of connections: (i) connections managed by a single network operator; and (ii) inter-connections that involve two or more federated units.

We also consider the following basic interfaces:

- User and Domain interfaces that represent the user entity and the federated domain.
- Production, Resource, NetworkCapital, AverageCapital, Demand, Supply and Cost interfaces as well as an Equilibrium interface that represent the economic characteristics of the approach.
- SLA and SLAChain interfaces represent intra-domain and inter-domain SLAs respectively.

IV. CONCLUSION

This paper consists of two separate models: an economic approach and a network management model that are combined to form a joint economic and architectural framework for applying economic policies that lead network federations to self-optimizing and self-configuring resource allocation.

Based on the proposed long-run cost-based economic approach and a competitive framework users act as price-takers and buy resources on demand over specific allocation periods. A unique characteristic of the economic approach is that takes into account that resource sharing exhibits substantial positive externalities since decisions on resource levels made by a single federated domain affect all other independent network domains and their users.

Our architectural approach builds on agent-based and policy-based network management principles. We propose special economic-enhanced agents that implement the economic approach while at the same time configure the appropriate network elements of the federated units by using specific proxy-agents. Finally, elements of a proposed information model are presented. The main entities included in the information model represent the characteristics of the economic model.

We also believe that there are issues that need further investigation. First, the case of a 'social planner' who takes into account the production externalities in federation networking should be investigated and compared to competitive solution. Second, the detailed definition of the information model in XML should be explored.

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