On the Management of Prices and Policies for Heterogeneous Access Environments

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Abstract. The appearance of new services, as well as the unstoppable increase of the available radio access technologies, leads to a departure from the traditional strategies for the different actors involved in the wireless communications realm. It becomes necessary tackling the design of an architecture able to support the new challenges, being a key aspect breaking with some of the traditional solutions, which are unable to cope with the new requirements. One of the most important aspects is to address a holistic design, enforcing an open and flexible cooperation between the different entities, which is not usually possible with patches to the currently available alternatives. This is the framework of the Cognitive and Cooperative Communications and autonomous SErvices Management (C3SEM) project, which is founded on the cooperation and integration of the subjacent communication substratum with the service management architecture. In this paper, we describe one of its current open lines of research, in which we analyze different price management strategies, since it is sensible to believe that in the mid-term, operators would need to rethink their current strategies, which are mostly based on constant fees.

Keywords: Service management; Price policies; Heterogeneous access networks.

1 Introduction

It goes without saying that we are living a substantial change on the way mobile communications are understood. The appearance of devices able to use multiple technologies, new operators and business models, are some of the cornerstones of what is usually referred to as 4G. Although it is true that we have seen a relevant number of technological advances, there is still a wide range of challenges to tackle.

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In spite of the fact that those challenges could be individually addressed (as it has been done by numerous existing works), it has become clearer that it is necessary to tackle the analysis from a global perspective, favoring the interaction and cooperation between the different system elements. This is precisely the approximation which is being followed in the C3SEM project, which fosters two complementary lines of research, but with a great degree of cooperation/integration between them.

The first group of research lines focuses on the network itself, the communication substratum, proposing a set of functional entities, algorithms, mechanisms and protocols to enhance the behavior exhibited by current technologies. The three main lines which are being tackled are: access network heterogeneity, use of cognitive techniques, and the relevance of mesh topologies.

The second topic in which the C3SEM project focuses is the services. The greater possibilities which existing technology offers at the time of writing must be employed by the services and the end-users. In order to make this a reality, it becomes necessary improving the service management procedures.

As the first joint aspect between the two aforementioned groups, we describe, in this paper, some of the preliminary results obtained by a line of research which aims at optimizing price and policies management procedures to be used over wireless heterogeneous access environments. We assume that we have a set of network elements, cooperating between them (they could belong to the same operator or not) and offering access to the end-users. These choose the access which better suits their needs, based on a set of usage policies and the particular requirements from the services. The network must optimize its service management and price policies, so as to maximize its benefit, respecting the Service Level Agreement with the end-users.

In order to address the questions which have been presented before, this paper has been structured as follows: Section 2 summarizes the relevant state of the art of the various topics which are addressed herewith; Section 3 presents a typical application scenario and a high-level architecture which derives from it and which can be used so as to integrate the mechanisms which will be described afterwards; Section 4 describes a number of policy management procedures, and their application over wireless communication scenarios (in particular over UMTS networks). Section 5 presents a mechanism, based on a number of rules, which can be used so as to estimate the best price which an operator might offer, so as to maximize its benefit. Finally, Section 6 concludes the paper, advocating a set of lines of research, which are opened after the presented work.

2 Antecedents and State of the Art

During the second part of last decade, we could see a very relevant researching activity on architectures/mechanisms/algorithms aimed at ensuring an optimum access selection for highly heterogeneous network environments. The starting point can be put in 2003, when Gustafsson and Johnnson created the Always Best Connected (ABC) motto [1]. After this moment, we saw a large number of initiatives and proposals for architectures to reach this goal; some of the most relevant ones are:

the Multi-Radio Resource Management (MRRM) [2], which comes from the Ambient Networks European project, the Joint Radio Resource Management (JRRM) [3] and the Common Radio Resource Management (CRRM) [4], which were outcomes of the Everest and AROMA projects, respectively. Furthermore, we should also highlight the role taken by the most relevant standardization bodies, which have also identified the need to work over this type of scenarios; in this sense, the IEEE 802.21 working group has specified the Media Independent Handover Framework (MIHF) [5,6], which depicts the signaling required during access selection (and handover) mechanisms over heterogeneous network environments. Besides, within the 3GPP working group [7], mechanisms to favor the interconnection between cellular networks and more local accesses (WiFi) have been also specified.

Despite the aforementioned proposals, there are still a large number of aspects and challenges to cope with. Some of them are direct consequence of the advances which we have seen (like the cognitive use of the radio resources, spectrum, or the spring of multi-hop topologies, in which resource management has a larger number of difficulties [8]). On the other hand, it is also true that we still need to get in-depth knowledge about the possibilities which are opened with this type of functionalities, either from an analytical perspective [9] (so as to understand which are the bounds of their performance) or from a more realistic point of view (analyzing the limitations imposed by the required signaling protocols, cooperation agreements between involved entities, etc).

One of the aspects which have gained more relevance with this new network philosophy is that the end-user (on an automatic way) would have a greater degree of responsibility when taking the decision about the network to use. There are various parameters which can be used so as to take the “optimum” decision [9], amongst which we could mention: access elements load, radio link quality, connection with preferred operators, etc. Another fundamental parameter is, obviously, the price to pay for the connection. At the time of writing, operators offer plain fees, but the appearance of new competitors, with much more aggressive strategies, might bring about a change on this tendency. Besides, network operators, which might have less responsibility during the decision process, might use connection fees as an element to deter (make them more expensive) or to ease (make them cheaper) end user connections.

We thus face a problem with two clearly related aspects; on the one hand, we will analyze service management policies (including prices) of the operators, which would aim at maximizing their benefit; besides, we will analyze access selection strategies of the end-user using price as the fundamental deciding parameter.

3 Scenario and Reference Architecture

One of the objectives of the C3SEM project is to propose an integrated architecture of radio access network and management of services offered over the former. Among the features of this architecture it is worth mentioning its flexibility and management autonomy. With respect to the former, it means integrating a set of capabilities to harness the potential of a heterogeneous access environment, together with the use of cognitive techniques and cooperative forwarding techniques. As for the second, the goal is to develop self-managed services, using the context of the relevant domains. In the scope of this paper we refer to services that allow users to access content and other applications on the network.

To narrow the scope of the problem, we assume a scenario consisting of different information services offered by several suppliers on a competitive basis to the same group of users. These services require the concurrence of different components, some of them are spontaneously created and other are already deployed in the network, constituting the support of other applications (access services, transport, localization, security, etc.). In short, we have a set of services and service components, of which we highlight the network access, based on technologies such as Wi-Fi, WiMAX, UMTS, etc. These are offered by different suppliers, which might be conveniently federated among them.

Our scenario assumes that the final product is not tied to the access technology. Accordingly, one of the pivotal aspects of our architecture is to facilitate the access in a flexible manner. To do this we assume the existence of inter-domains information flows (i.e. between service providers, resource providers and service components in particular) to facilitate the access self-reconfiguration processes. Of course, a key aspect of this self-reconfiguration process will be the cognitive network techniques that make use of the above information as well as network provider local information so as to recommend a possible vertical handover between access technologies to a subset of the end users. The final aim is adapting the resources of the access network to specific service needs. The nature of the information used to determine the optimal access will be diverse but it is worthy to mention that among others we will make use of the offer and the demand, ultimately resulting in the price applied to the product or service.

Still in this scenario we must mention its dynamic nature, since it includes a demand that varies over time. Users access the service at random; new users subscribe to the service and others leave. In addition, resource providers can also augment or withdraw resources based on the perceived demand from service providers. Maintaining the quality of all services would be achieved by increasing the capacity of the resources allocated to the application (i.e. more servers and / or memory and processing capacity in a server, and / or increasing the capacity of the access network resources on a given geographic area). This is really complex if pretended to be done by means of best effort and / or manual techniques. The complexity of the process requires the implementation of autonomous management systems. Applications and services managed by means of autonomic principles are self-aware of this situation and adapt to it (self-reconfiguration). This self-reconfiguration will result in the allocation of "adequate resources" in the "appropriate nodes" and / or to "appropriate users" of the final service. The autonomous management systems will execute part of these processes in the local domain of the application provider, while another part will take place in remote domains.

In summary, on the one hand we seek transparency between domains to facilitate the essential flow of information but always respecting the local policies of each domain. On the other hand, we will foster the use of adaptive techniques and efficient optimization algorithms. As a consequence, it can be said that a closed architecture suitable for this demanding scenario is virtually unattainable. However, the existence of a generic framework architecture that synthesizes the design principles and serves to be instantiated in individual cases is essential.

The idea outlined above is expressed in the diagram of Figure 1. Customers and users benefit from services offered by different service providers. The latter have the concurrence of several network providers with various access technologies. Note that service providers and network providers are actually roles that can be adopted by the same or different administrative entities. In any case, we assume that the different access technologies of network providers are managed by independent management principles and the coordination of those is carried out by the service provider making use of them at any time. To this end, the service provider has appropriate mechanisms to coordinate the underlying access technologies. The set of all these coordination mechanisms owned by the service provider is called Orchestration Unit. The conception and design of this unit is one of the main tasks of this project.

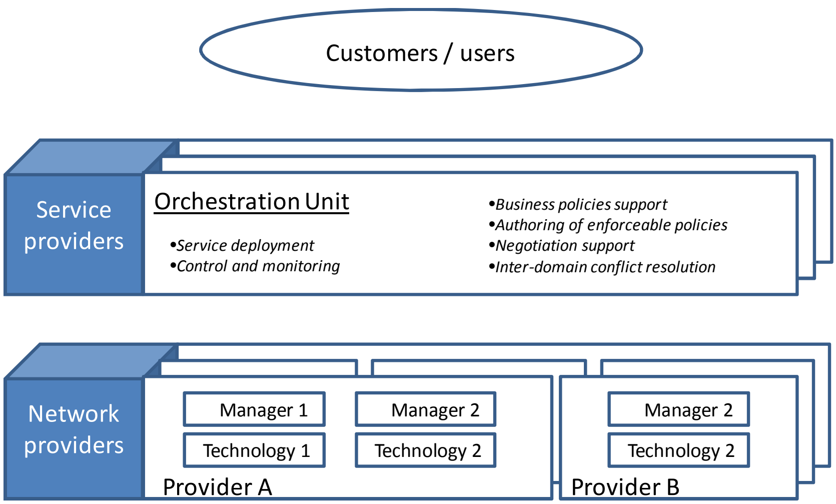

Fig. 1. C3SEM high level architecture

4 Policy Management for UMTS Networks

The Universal Mobile Telecommunications System is a suitable alternative to support high-speed services in mobile networks. Several standardization efforts have been made to develop the necessary elements for UMTS technology to provide information with guaranteed Quality of Service (QoS). These elements include [10]:

- Mapping of End-to-End services within the UMTS architecture, which include, the UE (User Equipment), the UTRAN (UMTS Terrestrial RAN – Radio Access Network), the core network and external IP networks.
- Traffic classes associated with QoS parameters.
- Negotiation of QoS functions.
- Multiplexing of flows to network resources.
- A service model that relates the underlying services, necessary to support the provisioning of End-to-End services.

A key aspect that enables UMTS technology to support the provisioning of multimedia services based on IP, and other services with guaranteed QoS, is its policy-based control architecture in its IP Multimedia Sub-system [11]. With a policy-based framework, network operators have a configuration mechanism that enables them to configure network devices dynamically, and also, to manage and control the multimedia services offered in a dynamic manner and in real-time.

In order to guarantee QoS in the service delivery it is needed to control access to the services and also to control the utilization of the resources that support such services. In the last decade several QoS-oriented aspects have been subject of research, including schemes for access control, user's transmission rate adjustments, congestion control, and management of classes of services supported by the UMTS technology. Although these technologies have partially demonstrated this technology's capability to provide high-speed services with QoS, their utilization in environments tailored to optimize the economic value of the network resources has been practically unexplored, even when the ultimate target of any network infrastructure is the maximization of revenue.

The C3SEM project is currently developing a service management methodology, similar to the one presented in [12], supported by UMTS technology taking into account business and QoS aspects (see Figure 2).

The methodology considers the definition of key business indicators, like economic losses due to rejection of services, losses due to service degradations, and service satisfaction. These business indicators are used to define the business strategies of the operator. In order to analyze the business strategies the methodology defines concrete metrics for the business indicators, so that these can be further analyzed and if it is the case, to be used for a re-definition of the management strategy.

In addition, the methodology contemplates the correlation and mapping of the business indicators with management objectives of the underlying services that support the End-to-End services: services of the terminal equipment (TE), UMTS Bearer Service, Access Radio Bearer Service, Backbone Network Bearer Service. These services are graphically depicted in Figure 2.

Finally, the methodology contemplates the derivation of management policies that control the services mentioned above. These policies will ultimately be enforced in the network elements that will support such services: P-CSCF (Proxy Call State Control Function), PCF (Policy Control Function), and the GGSN (Gateway GPRS Serving Node).

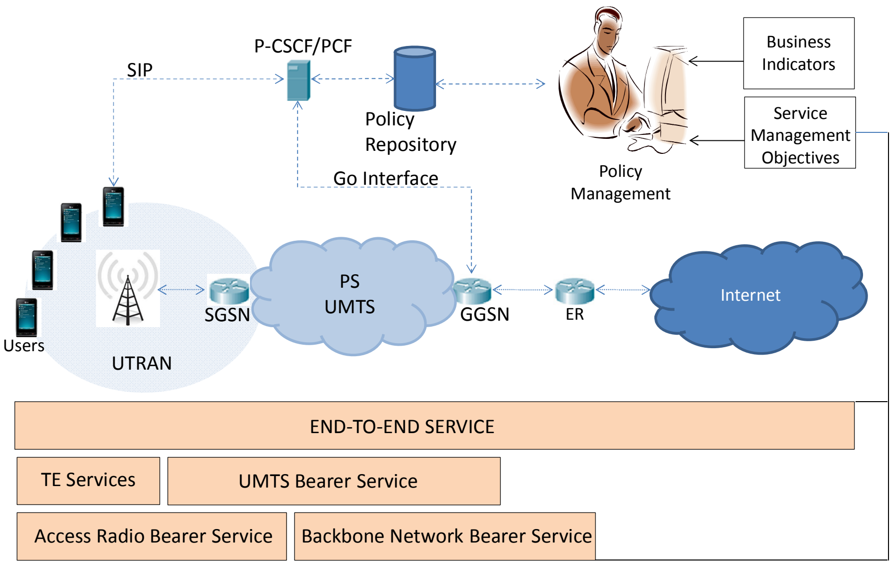

Fig. 2. Scenario for Optimization of configuration policies for UMTS Services

The ultimate target of the methodology under study is the definition of management policies that will control and implement the business strategies of the provider (providers). These policies will define for example, the monitoring parameters, granularity, and thresholds for technical parameters in the network and underlying services, and the policy-based proactive and corrective actions in line with the business strategies. The actions will be enforced with the aim of controlling for example, the rejection of new users of a specific profile trying to join in the network, or the adjustment of transmission rates for some specific users' profiles being served with a target radio channel, etc.

For the validation of this methodology the research project C3SEM is developing a test-bed platform based on OPNET [13], which will implement the management policies and the proposed mechanisms of this research. This test-bed platform will be used to extend this research towards the definition of business strategies intended to maximize the revenue under several patterns of users' behavior, mobility and utilization of network resources.

5 A Policy-Based Pricing Solution

In the context of the work described above, several operators compete for each user and different technologies sometimes compete and sometimes collaborate to provide a better service for mobile clients and pricing has a fundamental role. Using the right pricing strategy, an operator tries to obtain the highest possible revenue while the users try to get a service that fits their requirements at the minimum possible price. As stated in [17] "*From an economic point of view, pricing plays an important role in trading any resource or service. The most important objective of trading is to provide benefits to both the sellers and the buyers. Therefore, the price must be chosen so that* *the revenue of the sellers is maximized while the highest satisfaction is achieved by the buyers. There are two main factors influencing the price setting, namely, user demand and competition among service providers. Price and demand are functions of each other.*" Following these ideas, if demand is high the service provider can charge a high price, however, if demand is low, the price must be reduced to attract more mobile users. Moreover, competition between service providers also impacts on the price of the service. Typically, if the services are substitutable (even though different), users buy a service that provides the highest satisfaction at the lowest price.

As explained by Courcoubetis and Weber in [18] the kind of communication services mentioned in this work can be simply considered as means for transporting data with a given quality that is characterized by a certain error rate, delay and jitter. Obviously, the network access providers will want to profit from their investment charging a price for their services, but that is not the only reason for which pricing is important. The price of simple goods is often determined by a single parameter such as the number of copies, their weight or the length of a lease. However, communication services are specified by several parameters such as peak rate, average bandwidth or loss rate. In addition to that, multimedia service contracts are specified by additional parameters such as tolerance to bursts and adaptability to network changes. Since connectivity services can be specified in terms of so many variables, the number of different possible contracts is vast and complicates the design of a reasonable and coherent pricing strategy.

On the other hand, contracts are more than simple price agreements. For example, a contract may be an incentive for the user to produce traffic conforming to the agreed parameters. This, at time, will positively impact on the service quality and the price paid by the clients in general. All this motivates an effort to develop a pricing technique simple enough to be implemented by the operators, but, at the same time, sophisticated enough to successfully cope with other strategies working as a scalable feedback mechanism to control how the network is used. A provider can reduce the price of a service during off-peak hours to incentive the use of idle resources or charge an extra price to a user that exceeds the agreed traffic. Additionally, pricing may be seen as an alternative to TCP for congestion control. In a similar manner to TCP and its signaling, a higher price may induce users to reduce the packet transmission rate or to stop it completely. However, to be useful as a congestion-control mechanism, a pricing technique must be higly dynamic. It should be able to change the price of a particular service in real time and in a particular region of the network, for example in a particular access point that is suffering of congestion.

This project is working on a distributed, rule-based pricing system that implements exactly the same intuitive ideas implemented as policy-rules that control the price charged by each provider. Those rules are aimed to improve the quality of service and to increase the global income of a service provider in a world in which users are free to choose every time they connect.

A Overall System Architecture

Our system design has three types of actors that coexist on a geographical area: users, providers and a regulator (see Figure 3). Users are persons in possession of a wireless-capable device who are willing to establish a connection to the Internet with some quality of service requirements and at the minimum possible cost. As we envision it, users are not attached to a provider by a contract, instead, they pay for the provider's service on demand, by, for example, a credit card or pre-paid means, as it is common in current cellular 3G services. In our model, in front of equal or similar services, users will always choose the services of the least expensive provider. The providers have an access network conformed for a set of access devices that we will generically call Access Points (AP). A provider's objective is to sell access services to users while maximizing their revenue. The third entity, the regulator, is a neutral entity, probably played by a governmental agency in a real setup, with the objective of enforcing the pricing information sharing between the providers to allow pure market competition.

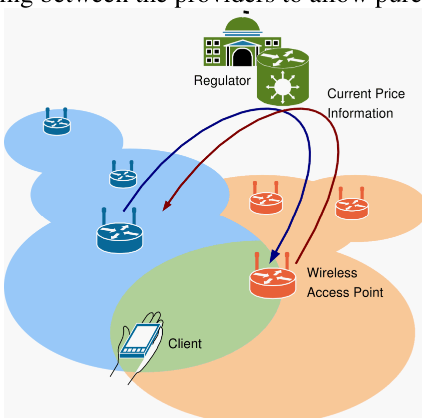

Fig. 3. A Scenario for Policy-based Pricing

In the particular scenario we are envisioning, each AP has its own price for a connectivity service of a given bandwidth and duration. Those prices may vary from one AP to another (even if they are operated by the same provider) and from time to time. In this manner, an AP in a popular part of the city may have a higher price than another in a neighborhood with few users or the same AP can diminish the service price during the low-usage parts of the day. The mobile user's terminal can connect to any of those APs and run an agent that is able to communicate with an AP and get information about the current price for a certain service the AP provides (later we will discuss about the technical solutions for this issue). Once it has the price from different APs, the agent connects to the AP with the lowest price, with or without human assistance. The established connection will last for the contracted time or until the connection is lost, for example, because the user moved out of the AP's coverage region.

B Governing policies

Policies are intended to allow each AP to decide what is the most advantageous price for its own connectivity service, having into account its context, user's demand, and potential competitors. These decisions are made by a Policy Decision Point [15] installed in the same AP, independently from the others and regardless of whether they belong to the same or competing providers, following a set of policy-rules modeling the economic criteria of demand and competition mentioned before.

The rules below are two of the 15 demand-based rules that can be seen in [14].

```
if few_users & users_steady then decrease_price_slow
if lots_users & users_increasing_fast then increase_price_fast
```

The rationale behind this set of rules is simple; the price of the service is increased, kept constant or decreased depending on the number of users served and its gradient of change. In this way, the price will be adapted to stimulate or inhibit service demand and its adaptation rate will track the evolution of such demand. In practice we accomplish it by classifying the number of users in three categories (few, mid and lots), the gradient of change in two (slow and fast) and also allowing two rates of price change (slow and fast).

On the other hand, there is a set of rules addressing the competition between providers. For example, the rules bellow are two of the 9 competition-based rules in [14].

```
if competitor_price_lower & competitor_price_decreasing_slow then decrease_price_slow
if competitor_price_higher & competitor_price_increasing_fast then increase_price_fast
```

Here the global objective is to accommodate the price to the evolution of the `competitors` to avoid users' migration. In particular we have classified the price of the competition in two categories (lower and higher) and considered two adaptation rates (slow and fast).

In this context, a competitor is an individual AP and two APs are competitors between them when their coverage regions overlap and they belong to different providers.

Paying attention to the rules, and having in mind that they are enforced independently at each AP, it is possible to see that demand-based rules induce some sort of competition between the APs of a single provider. Thus, if an AP has users in excess and a neighboring AP has idle resources, the former will increment its price and the later will decrement it causing a user migration from one AP to the other. If both APs are operated by the same provider, such a user migration caused by the price variations becomes a healthy load balancing mechanism.

Figures 4 and 5, taken from [14], depict this situation. Figure 4 shows a square geographic area covered by nine cells operated by an incumbent provider using a fixed rate pricing strategy (odd cells), and nine cells operated by a provider using our rule-base pricing strategy. It is an ideal situation in which both providers are competing under the same conditions. As can be seen in the figure, users are heterogeneously distributed causing the situation in which some cells are busier than others.

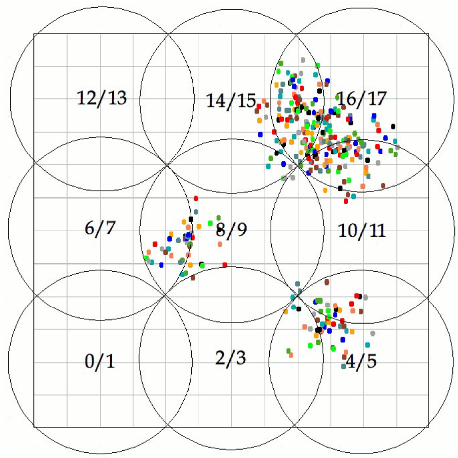

Fig. 4. Cells and Users

Figure 5 shows the resource utilization as percentage of the available BW following the simulations presented in [14]. In these experiments, the provider using our pricing strategy has a more balanced load distribution than the incumbent provider.

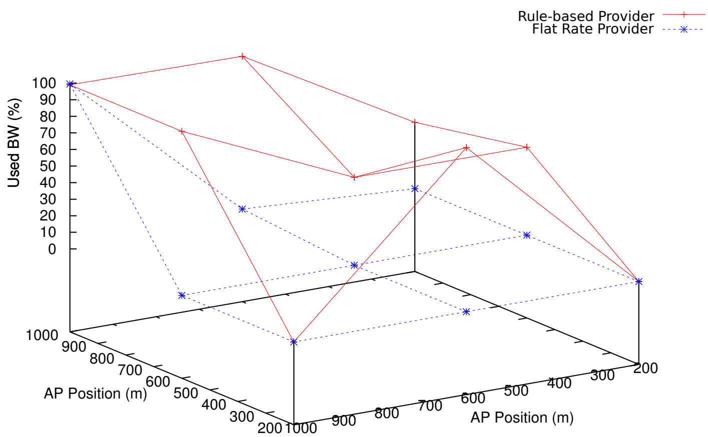

Fig. 5. Load Balancing with Rule-based Pricing

In [14] we also show how the rule-based pricing solution maximizes revenues too. These preliminary results allow us to think that a dynamic pricing strategy, on a more competitive market, may positively impact at the same time on the quality of the services provided and on the providers' revenue.

Furthermore, starting from the preliminary results presented in [14] and the tool introduced in [9] we can analyze which are the access selection strategies which can lead to optimum behavior in terms of operator benefits – for a certain price policy. On the other hand, we are also analyzing, by means of Game Theory techniques [16] which are the strategies which could offer an optimum performance and, as opposed to the work presented in [16] with more dynamic scenarios.

6 Conclusions

The C3SEM project addresses some of the challenges which have appeared upon the remarkable increase of the heterogeneity of access networks (not only technological, but also considering the operators behind them), proposing a novel architecture, which fosters a strong cooperation between the subjacent communication substratum and the service management architecture. Starting from the possibilities which are opened with the proposed solution, a large number of research lines can be explored.

Within such range of possibilities, this work has focused on the policies and strategies to assign prices, since operators might need to rethink current solutions (mostly based on plain fees) in the mid-term, due to the appearance of new services and business models. We have sketched a scenario based on the UMTS technology, in which the operator might benefit from a number of service management policies, based on business parameters and quality of service elements, with the goal of optimizing their benefits.

Furthermore, we have also proposed a novel scheme, based on self-learning mechanisms and a number of simple rules, to allow operators adapting their fees according to the dynamics of the particular scenario. The proposed architecture has been applied within a scenario with two operators and a regulator entity, showing a remarkable increase of the potential benefits.

After the work which has been presented in this paper, we open a wide range of research lines to be tackled. First, we will increase the number scenarios to analyze price assignment policies, using analytical tools to obtain optimum performances, which will be used to corroborate the results of the developed simulation platforms. In this sense, we propose applying both Linear Programming and Game Theory techniques, since they can provide a great added value to this line of research. Besides, the use of learning techniques will be exploited so as to better tune the rules used to modulate the price offered by the access elements, so as to better adjust the thresholds to activate them.

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